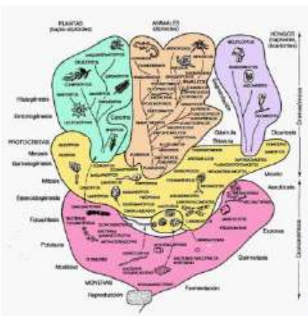
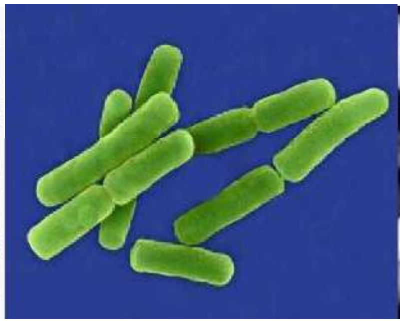
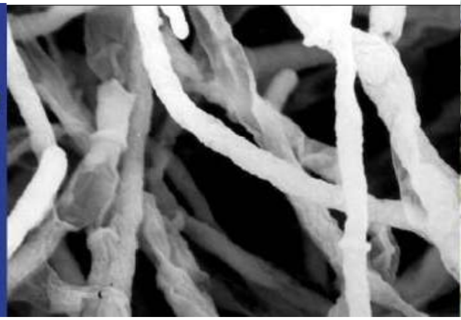
Lecture 1
Introduction to Plant and Fungal Biology

- Plants and fungi in the Tree of Life
- The role of plants and fungi in the biosphere
- The importance of plants and fungi for humans
- A brief introduction to the history of Botany


Characteristics of Life

Living beings present a wide variety of **morphologies**. Despite this great diversity, living beings share some **common characteristics** that distinguish them from non-living forms.

Characteristics of Life

- Metabolism
  - The ability to absorb inert matter from the surrounding environment and organise it according to a specific vital arrangement (**anabolism**).
  - The ability to break down matter in an organised way and return it to the surrounding environment as inert matter (**catabolism**).
- Productivity
  - Manifested in growth and reproduction.
    - **Growth**: increase in the volume of an organism.
    - **Reproduction**: generation of offspring similar to the progenitor.
- Excitability
  - The ability of a living being **to react** to a change in its external or internal environment that is explained not by the energy provided but by the use of its **own energy reserves**.

Characteristics of Life

Living beings share a fundamental characteristic: they are **made up of basic units called cells**, which can be formed only by the division of pre-existing cells.

bacteria

Figure 1-1d Essential Cell Biology 3/e (© Garland Science 2

paramecium

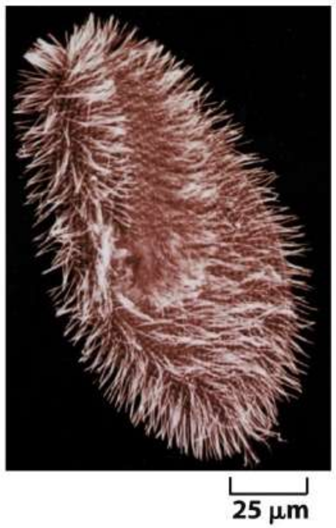


Figure 1-1b Essential Cell Biology 3/e (© Garland Science 2010)

cross-section of the shoot of a young plant

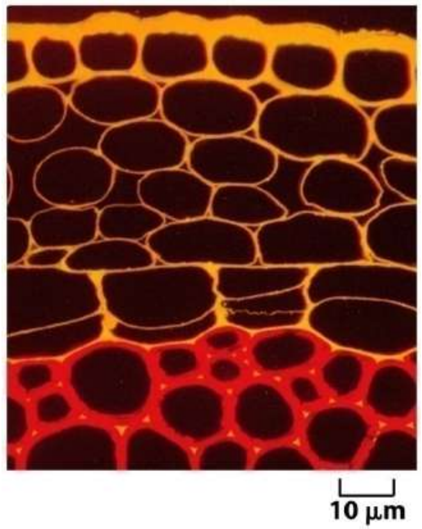


Figure 1-1c Essential Cell Biology 3/e (© Garland Science 2010)

cerebellar neuron

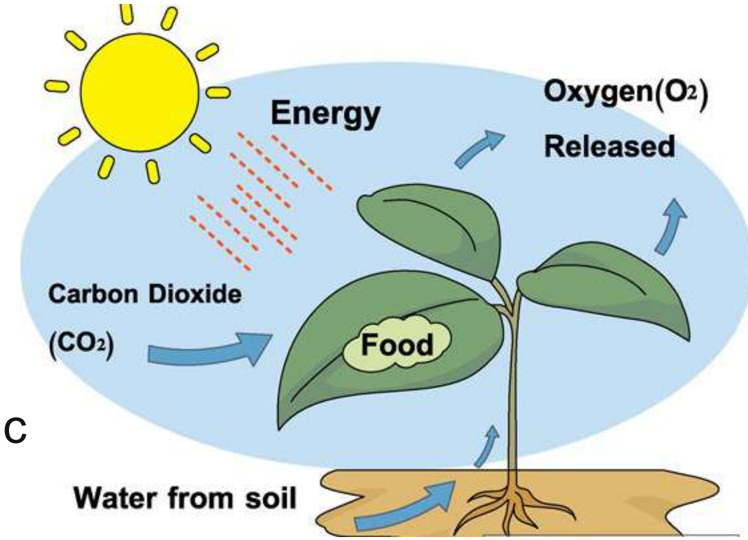
Figure 1-1a Essential Cell Biology 3/e (© Garland Science 2010)

Living beings may therefore consist of one cell (**unicellular organisms**) or several cells (**multicellular organisms**) that appear in a wide range of shapes, sizes, functions and requirements.

Sources of energy

- **Heterotrophic organisms (for carbon)**
  - **(CO_2 from organic sources)**
  - These are consuming and/or decomposing and/or recycling organisms: e.g. many prokaryotes, protists, fungi, animals, etc.

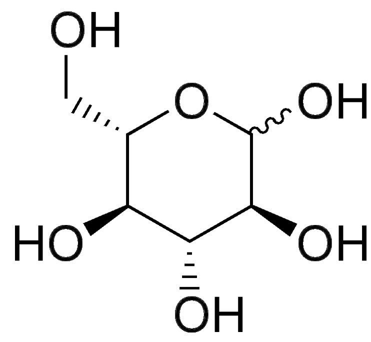
- **Chemoheterotrophs**: organisms that obtain energy from the decomposition of energy-rich organic molecules.
- These organisms do not generate energy autonomously but obtain it from organisms that have previously generated it (e.g., they obtain energy from food).
- **Photoheterotrophs**: organisms that obtain energy from light (some prokaryotes).



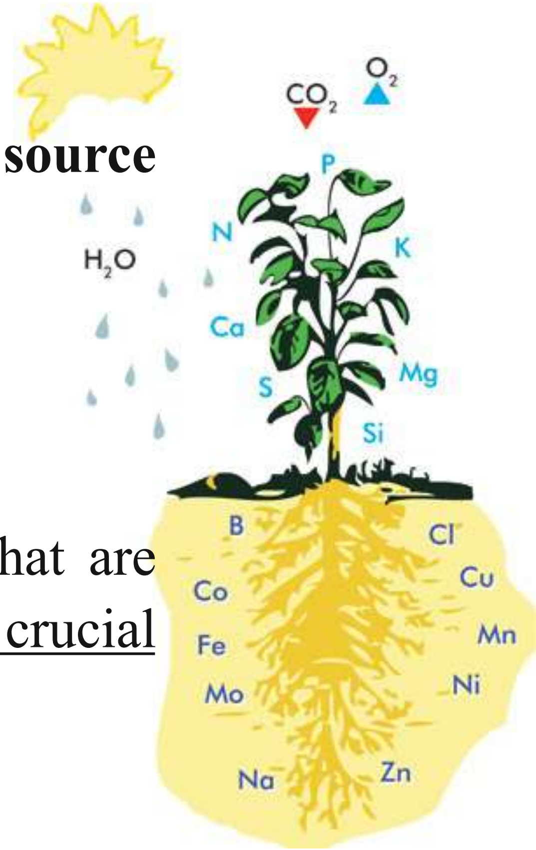
- **Autotrophic organisms (for carbon)**
  - **(direct CO2 intake)**
  - These are primary producers in ecosystems.

- **Photoautotrophic**: these obtain energy from light.
- **Chemoautotrophic**: these use energy from inorganic compounds.

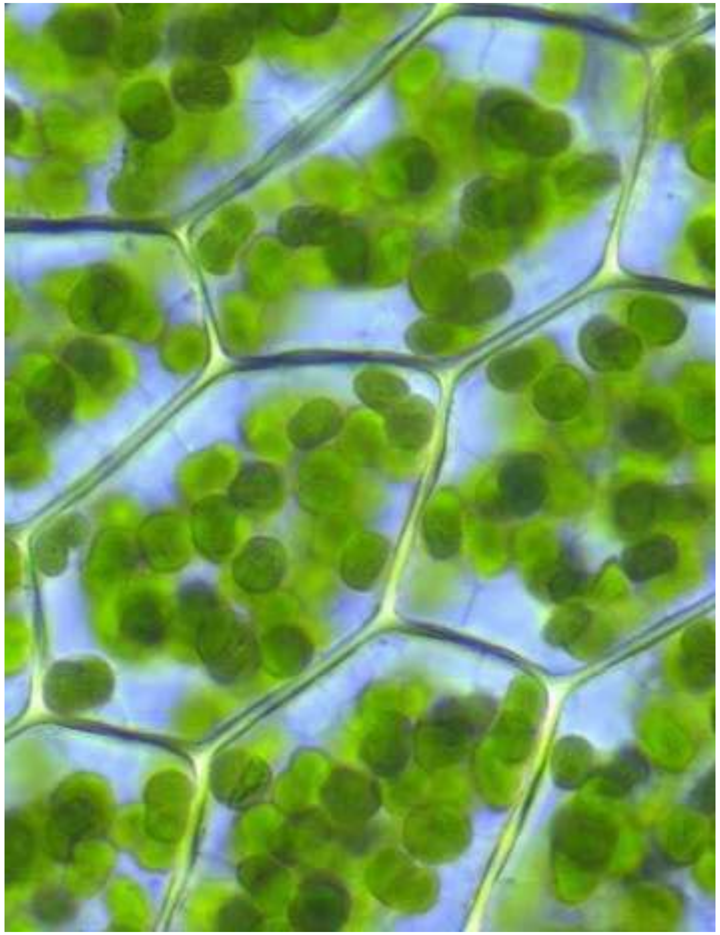
Photoautotrophic organisms



- These organisms obtain **energy** from **sunlight**.
- **Photosynthetic pigments**: e.g. chlorophylls, phycobilins and others.
- Synthesis of organic compounds with a high energetic value: **glucose** ($C_6H_{12}O_6$).
- **CO_2** is the **source of carbon** (tropospheric air), and **H_2O** is the **source of hydrogen** (soil water).
- H_2O is also the **source of oxygen**.
- **Soil minerals** (N, S, P, Fe, K, Ca, Mg) dissolved in water that are absorbed and used <u>to produce chlorophyll and conduct other crucial plant processes</u>.

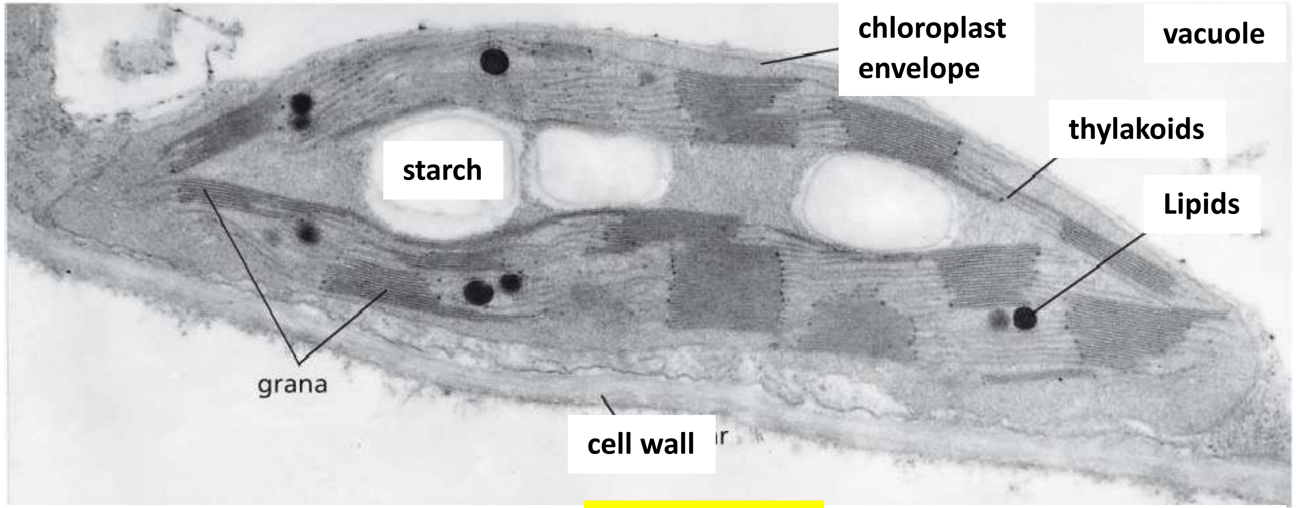


Energy production in plants



Mesophyll cells

$$6CO_2 + 6H_20 \rightarrow C_6H_{12}O_6 + 6O_2$$



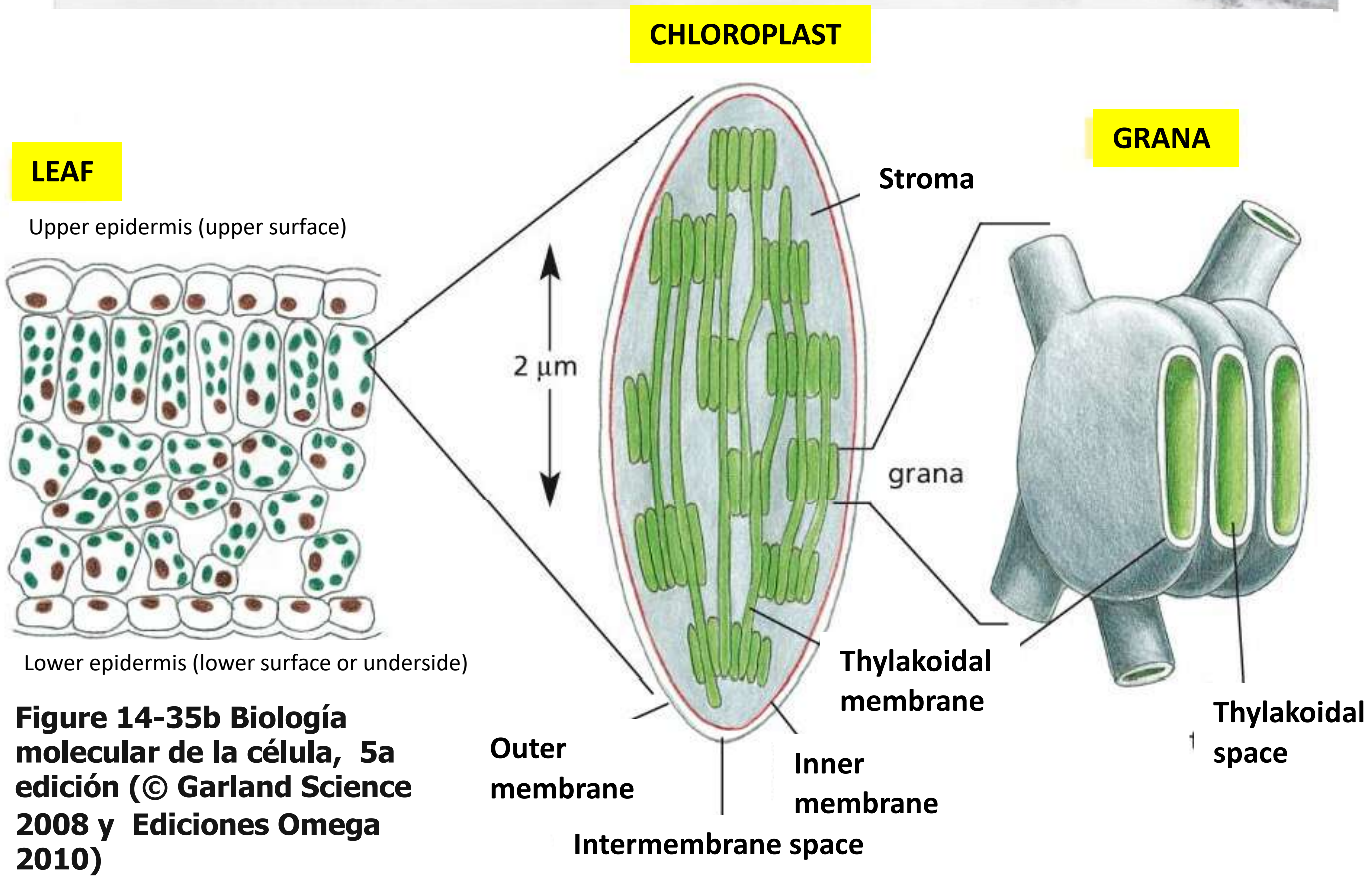
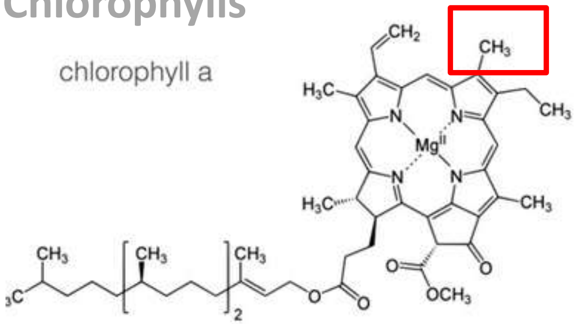


Figure 14-35b Biología molecular de la célula, 5a edición (© Garland Science 2008 y Ediciones Omega 2010)

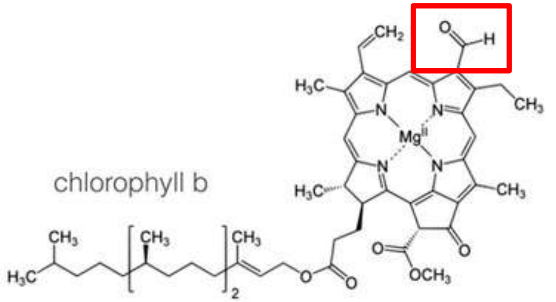
The absorption spectra of chlorophylls and other pigments

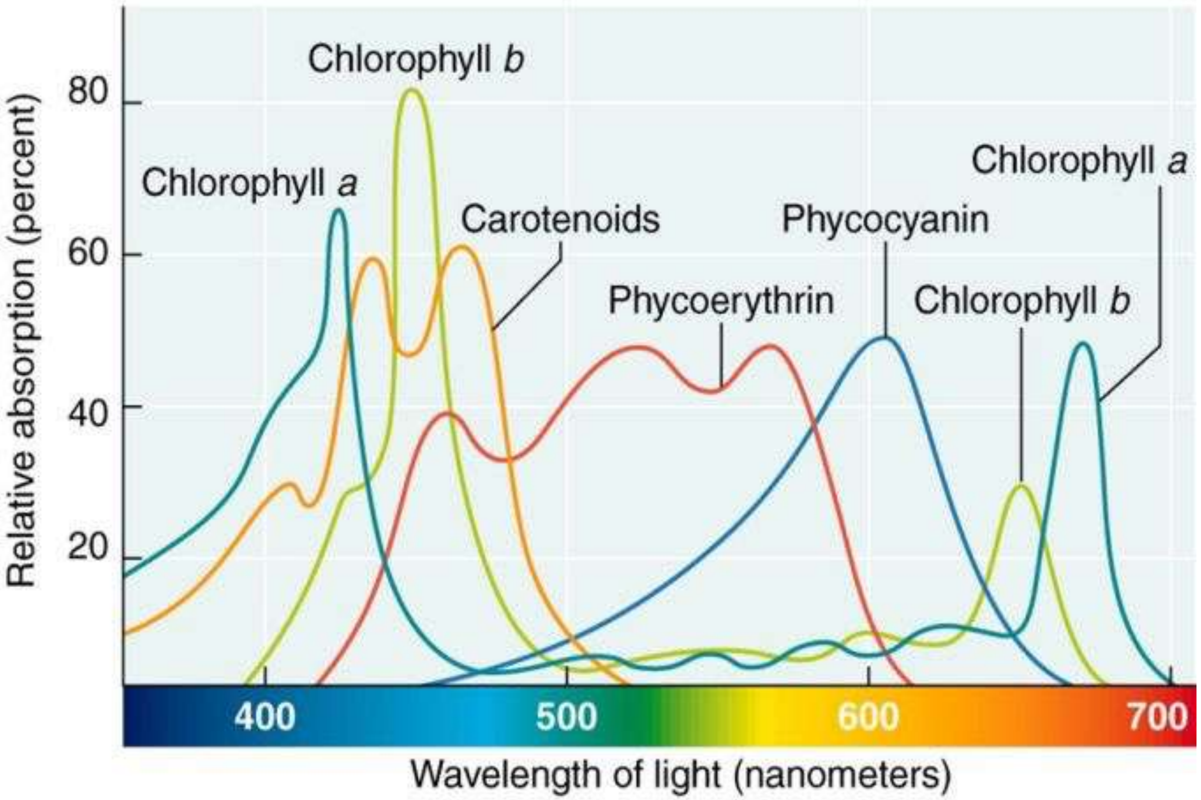
Chlorophylls

chlorophyll a



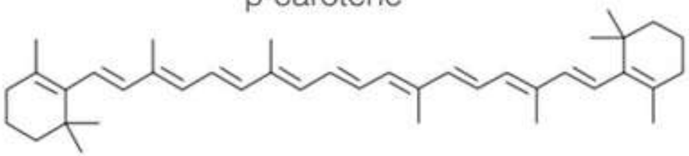
chlorophyll b



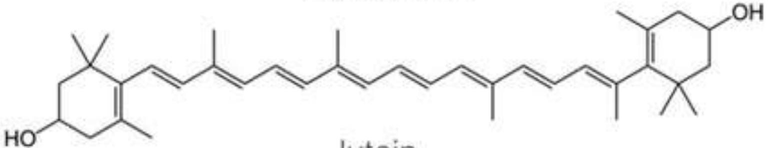


Carotenoids

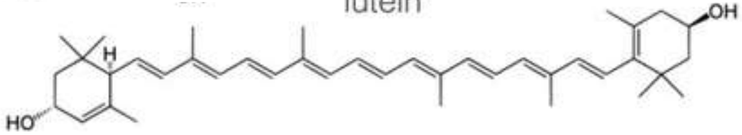
β-carotene



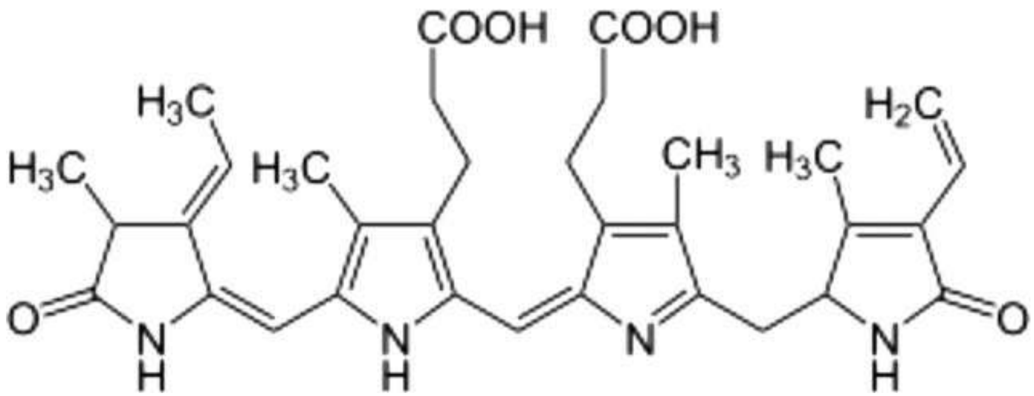
zeaxanthin



lutein



Phycoerythrin

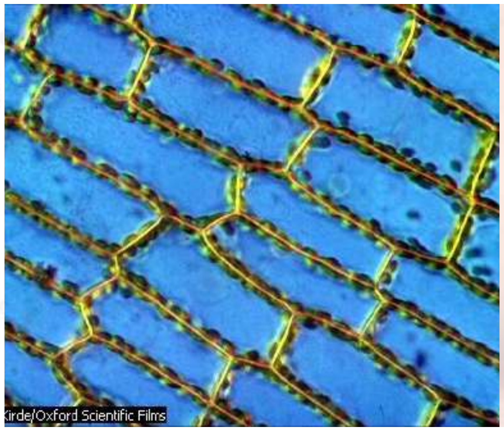


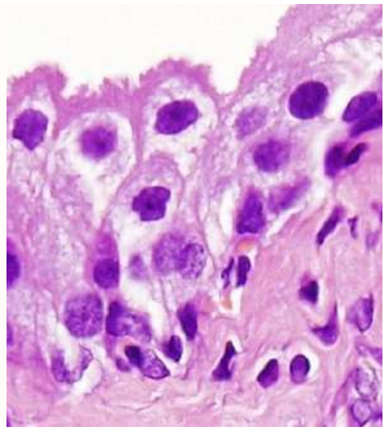
Plants and fungi in the Tree of Life

There are over 10 million different organisms on **Earth** today. This diversity is the result of 3.8 billion years of **EVOLUTION**.

Until the **19th century**, living beings were intuitively separated into **two categories (kingdoms)**: **animals** and **plants**. These categories were very distinct from each other because of their:

- overall morphology
- motility
- presence or absence of a cell wall
- energy sources

Plants and fungi in the Tree of Life

In the **20th century**, thanks to advances in our knowledge of cellular organisation, the main difference between living organisms – **prokaryotes and eukaryotes** – was established.

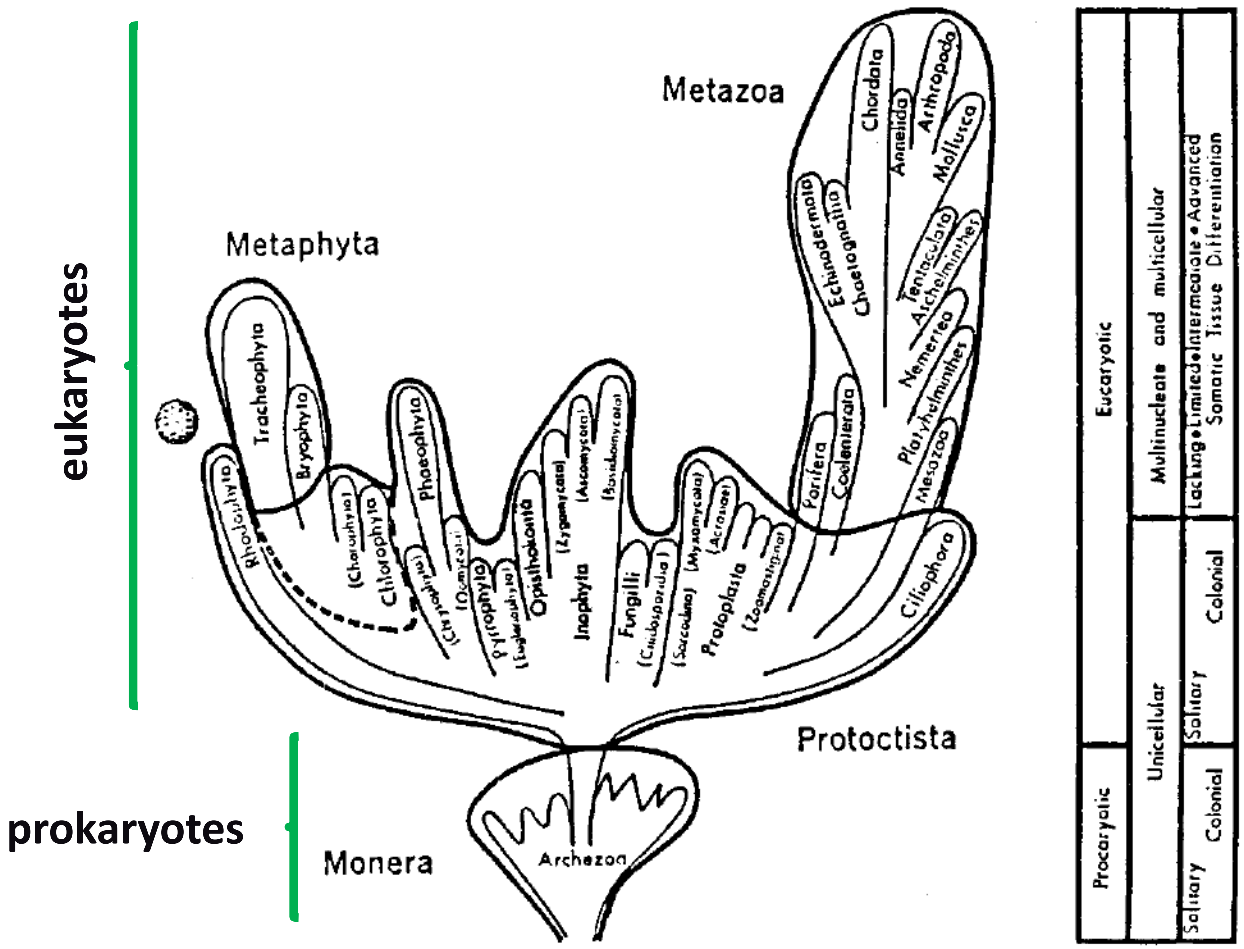
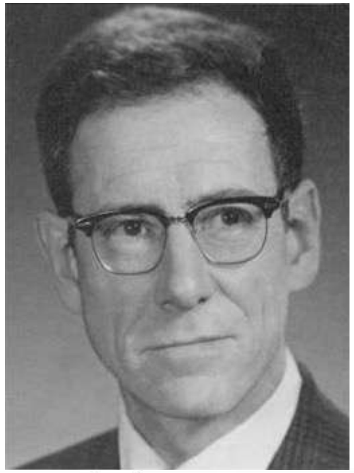


Fig. 2. The Copeland system, with relationships of phyla to kingdoms and levels of organization. In the Protoctista the names not in parentheses are Copeland's phyla; some major groups of protoctists that Copeland includes in these are indicated in parentheses. The Opisthokonta equal the Chytridiomycota, the Inophyta equal the Amastigomycota, and the Fungilli equal the Sporozoa of Table 1 and Fig. 3. Only major animal phyla are indicated. Alternative treatments of the Chlorophyta and Charophyta are indicated; these are included in the Metaphyta by Copeland (3), but in the Protoctista by other authors.

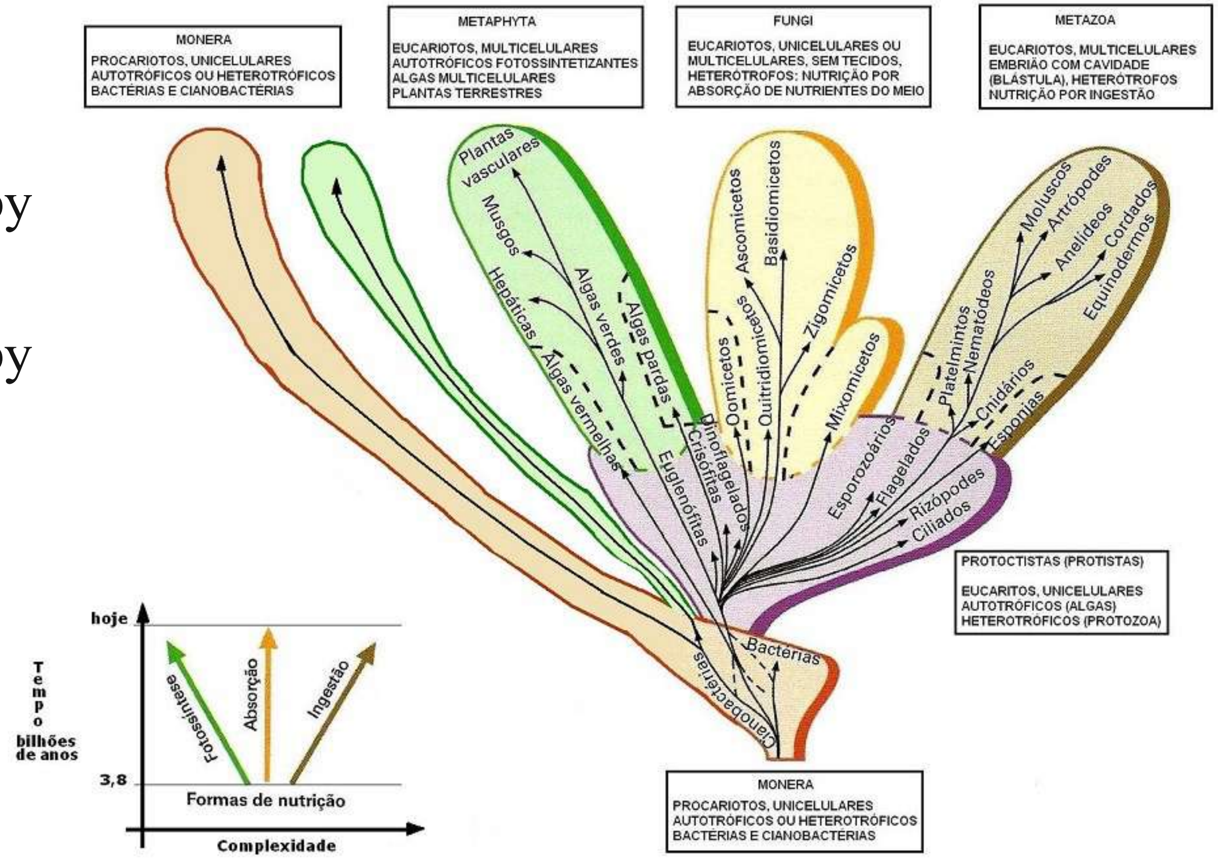
Tomado de Whittaker, 1969

Plants and fungi in the Tree of Life

- In **1969 Whittaker**
  - divided pluricellular and complex eukaryotic living beings into **three kingdoms** based on their distinct nutritional strategies:

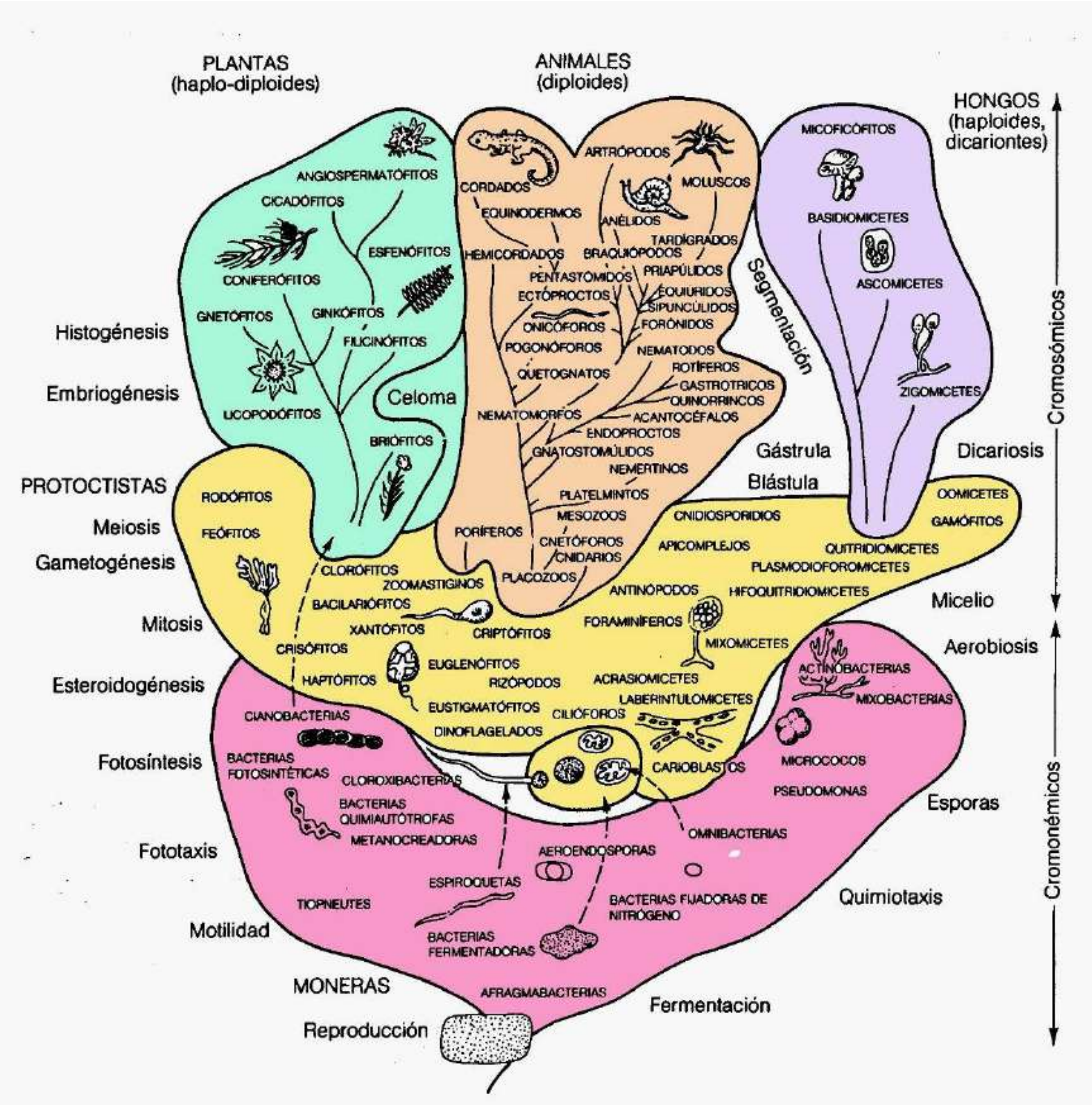


  - **heterotrophs** that are nourished by **ingestion**: **Animals**
  - **heterotrophs** that are nourished by **absorption: Fungi**
  - **Photoautotrophs: Plants**



ÁRVORE FILOGENÉTICA PROPOSTA POR WHITTAKER (1969) MODIFICADA.

Plants and fungi in the Tree of Life

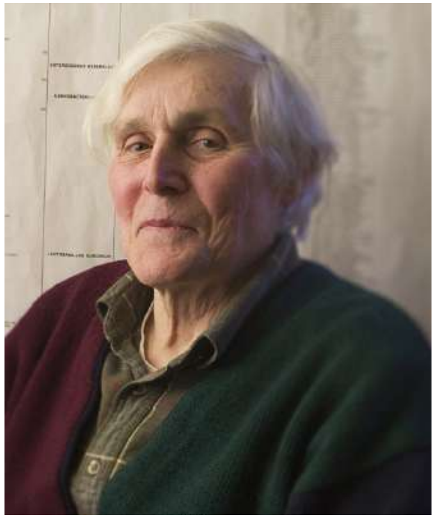


Lynn Margulis

In **1982, Margulis & Schwartz** put forward a classification system based on Whittaker's proposal but based on **five kingdoms**.

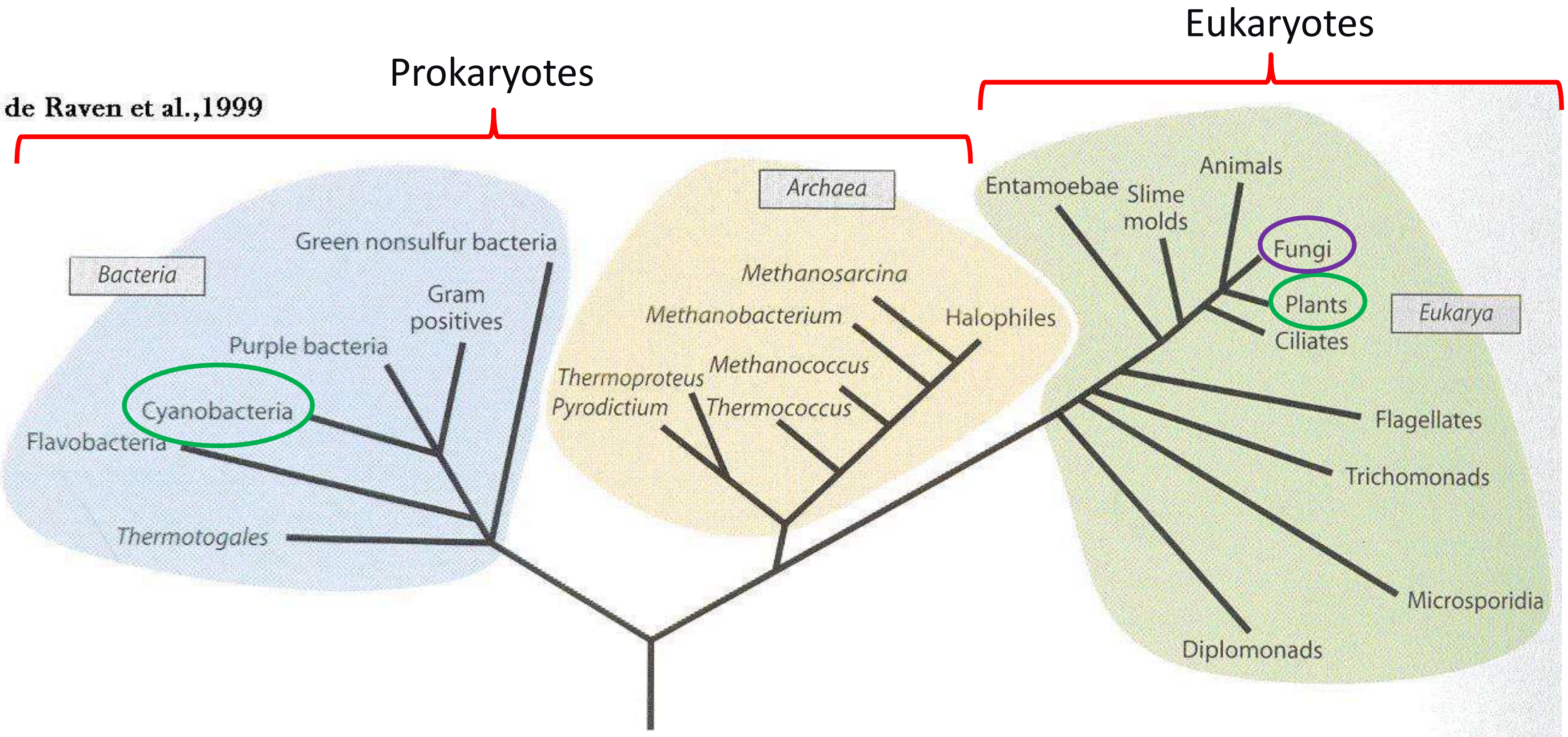
This novel Five-Kingdoms system incorporated the importance of **endosymbiosis as the origin of the eukaryotic cell**.

Plants and fungi in the Tree of Life



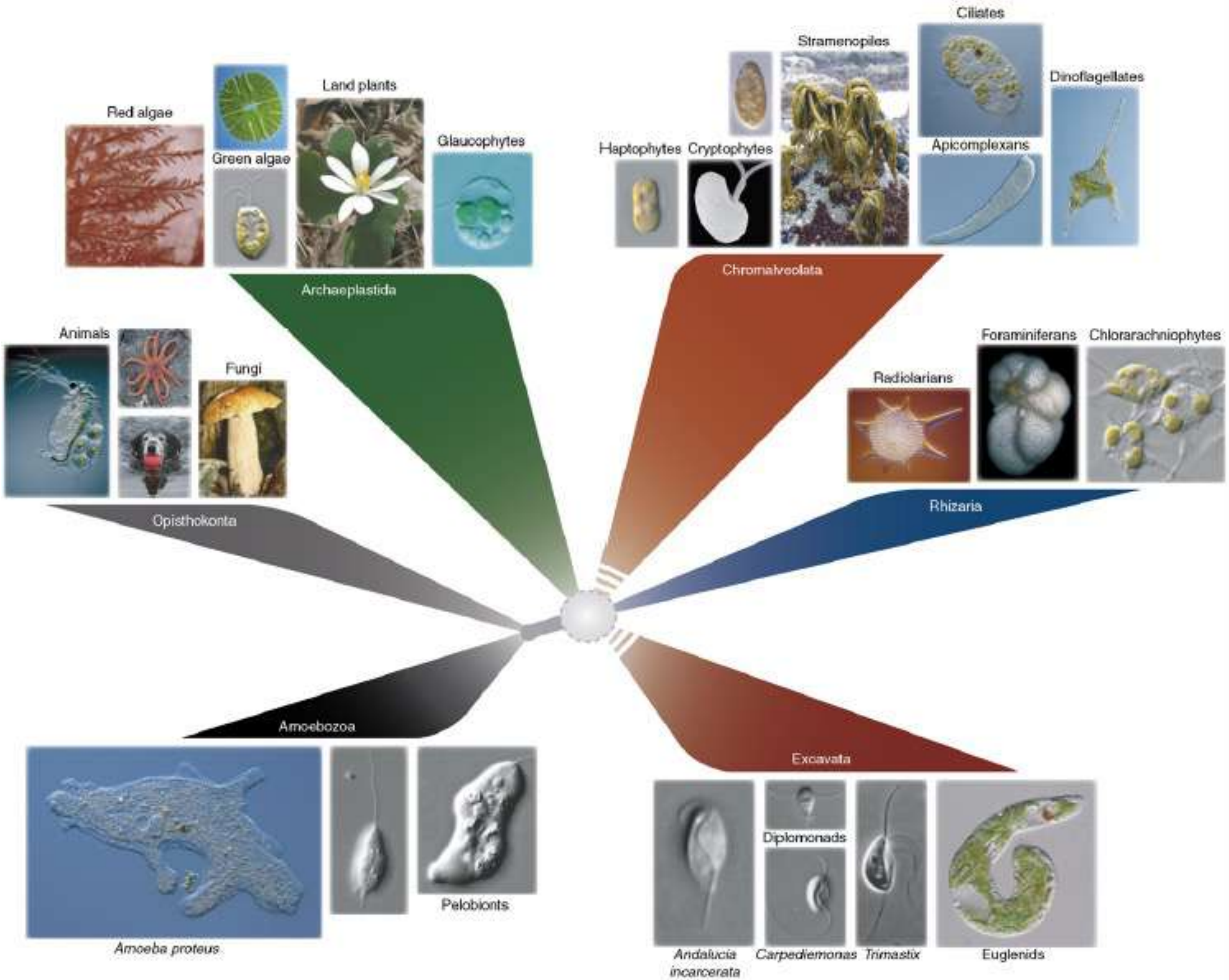
- Based on the comparison of genetic sequences of the small subunit of the ribosomal RNA, three domains were proposed by Woese et al. (1990):
  Bacteria, ***Archaea*** and ***Eukarya***

Tomado de Raven et al.,1999



Plants and fungi in the Tree of Life

Lane and Archibald's (2008) <u>phylogenetic tree</u> depicting the evolutionary relationships among eukaryotes. The groupings indicated the existence of at least:



6 supergroups:

ARCHAEPLASTIDA

CHROMALVEOLATA

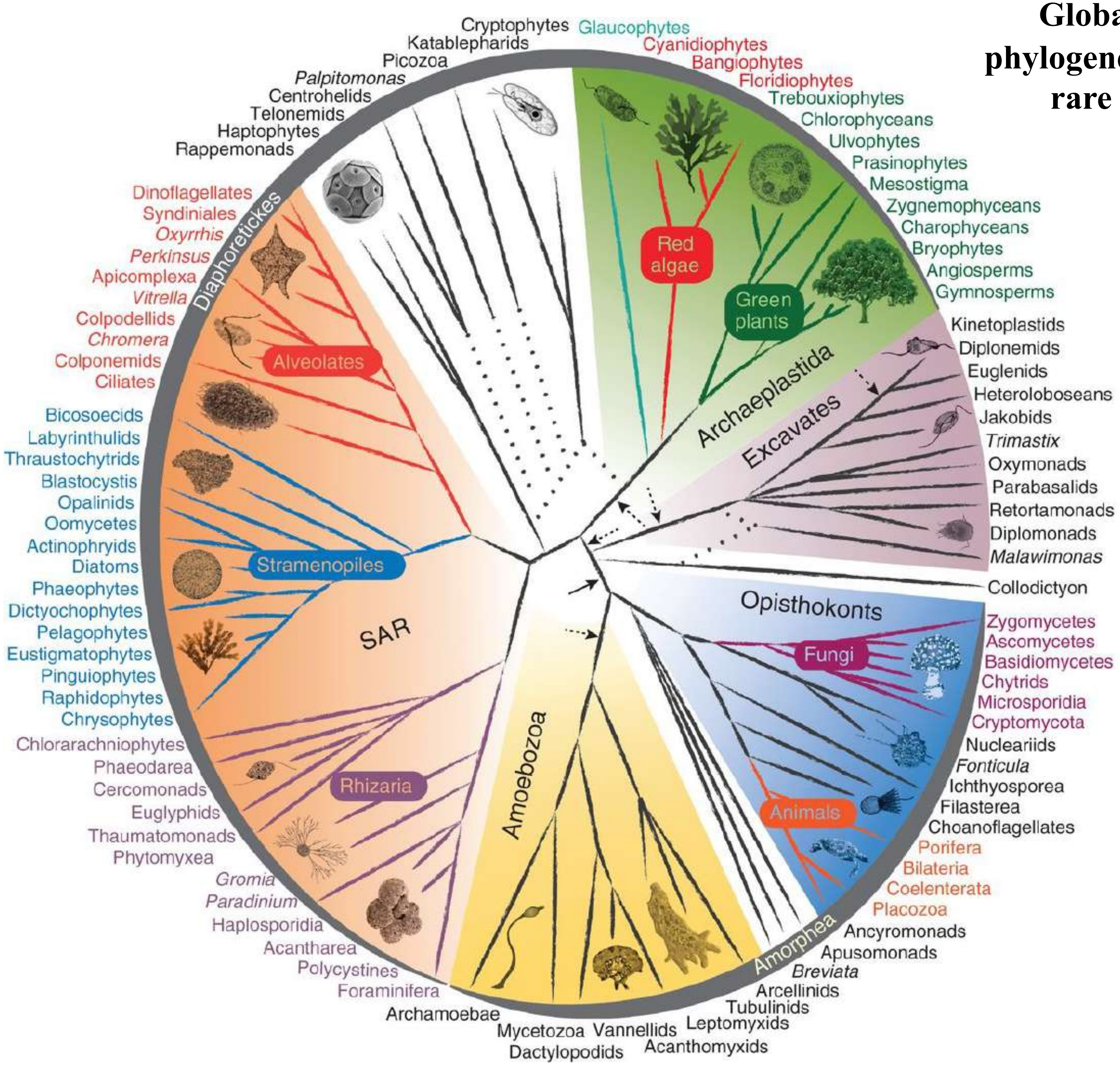
RHIZARIA

EXCAVATA

AMEBOZOA

OPISTHOKONTA

Plants and fungi in the Tree of Life



Global tree of eukaryotes from a consensus of phylogenetic evidence (in particular, phylogenomics), rare genomic signatures, and morphological characteristics (Burki 2014).

ARCHAEPLASTIDA

GROUP SAR:

- ***STRAMENOPILES***
- ***ALVEOLATA***
- ***RHIZARIA***

EXCAVATA

AMEBOZOA

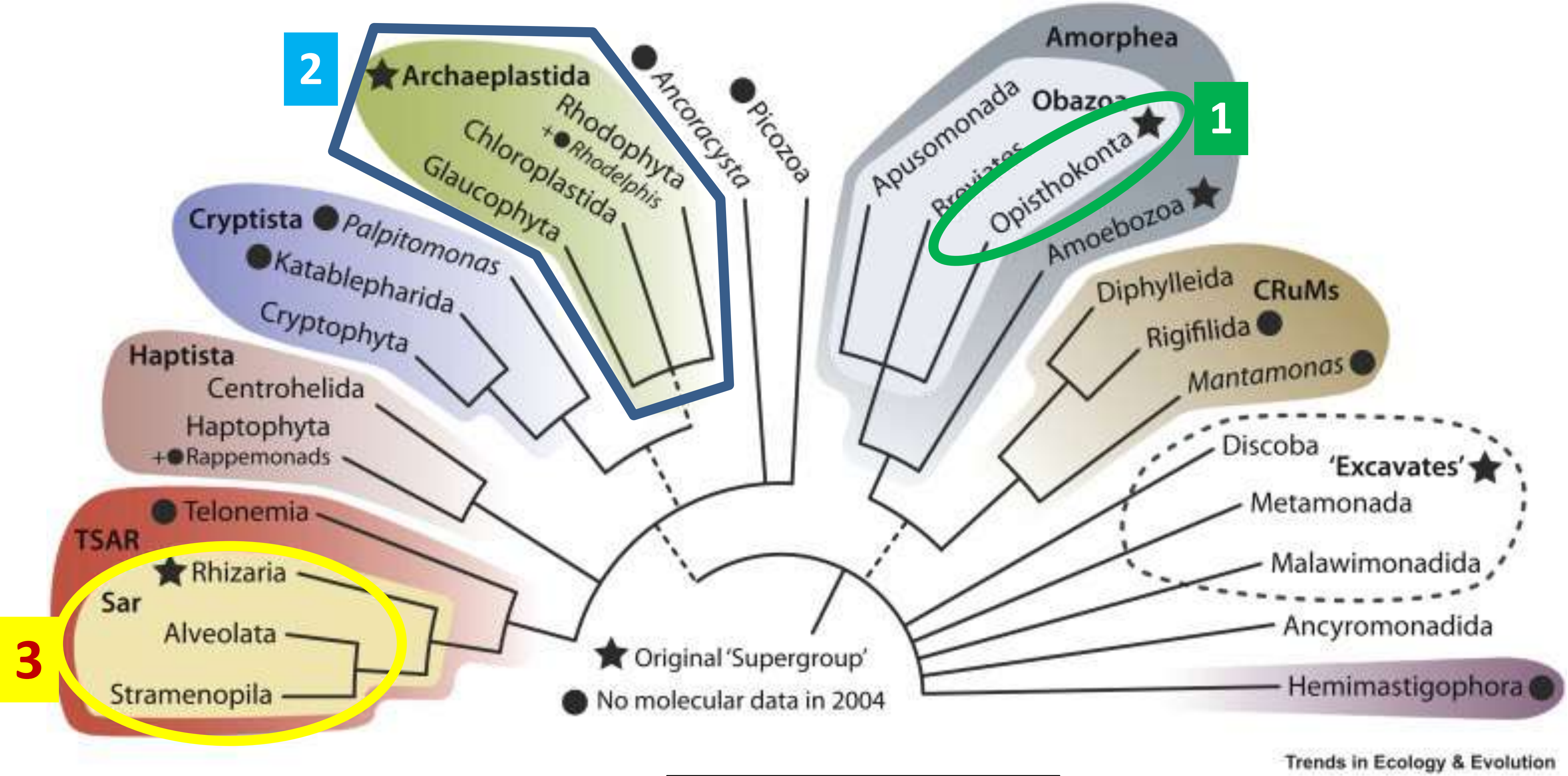
OPISTHOKONTA

ORPHANS

Burki 2014. Cold Spring Harb Perspect Biol 6:a016147

Plants and fungi in the Tree of Life

The latest Tree of Life of Eukaryotes, based on phylogenomic analyses (Burki et al. 2020)



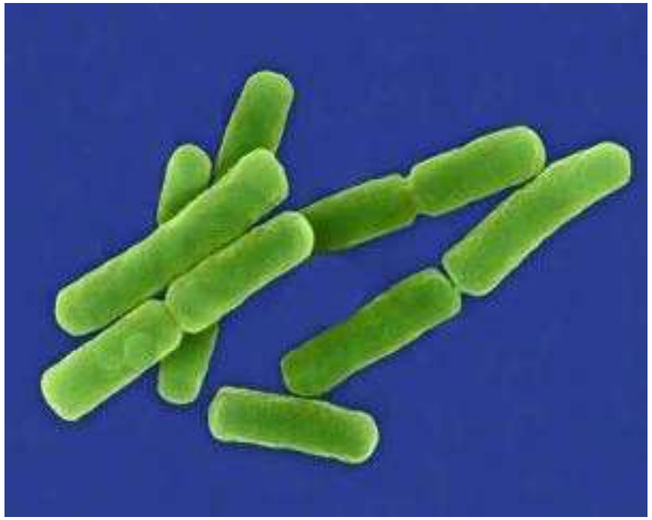
1 **OPISTHOKONTA**
FUNGI and animals
Topic/Lecture 4

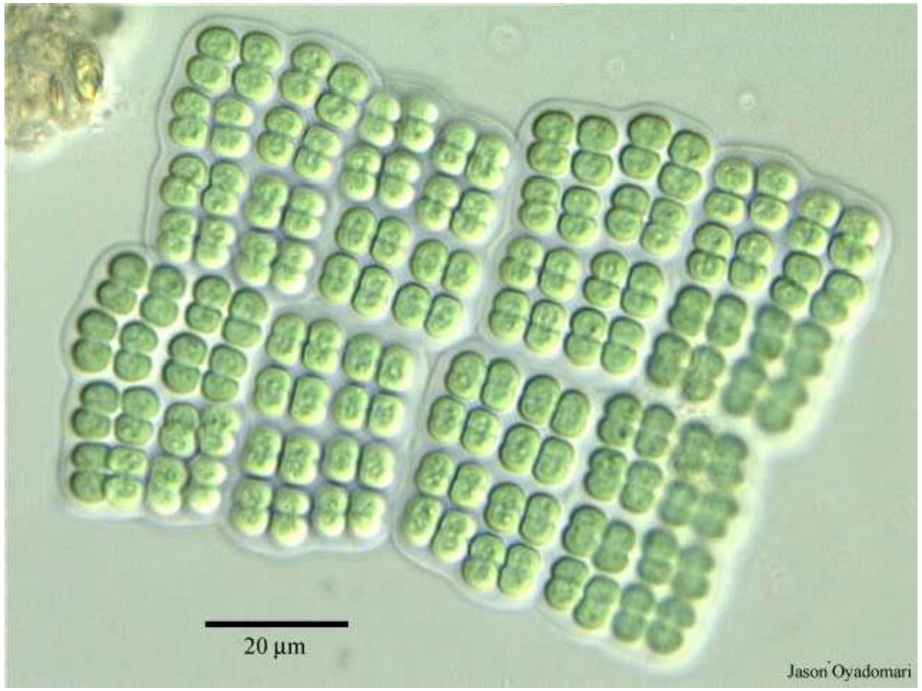
2 **ARCHAEPLASTIDA**
Plants and algae (green, red and blue)
Topics/Lectures 6-16

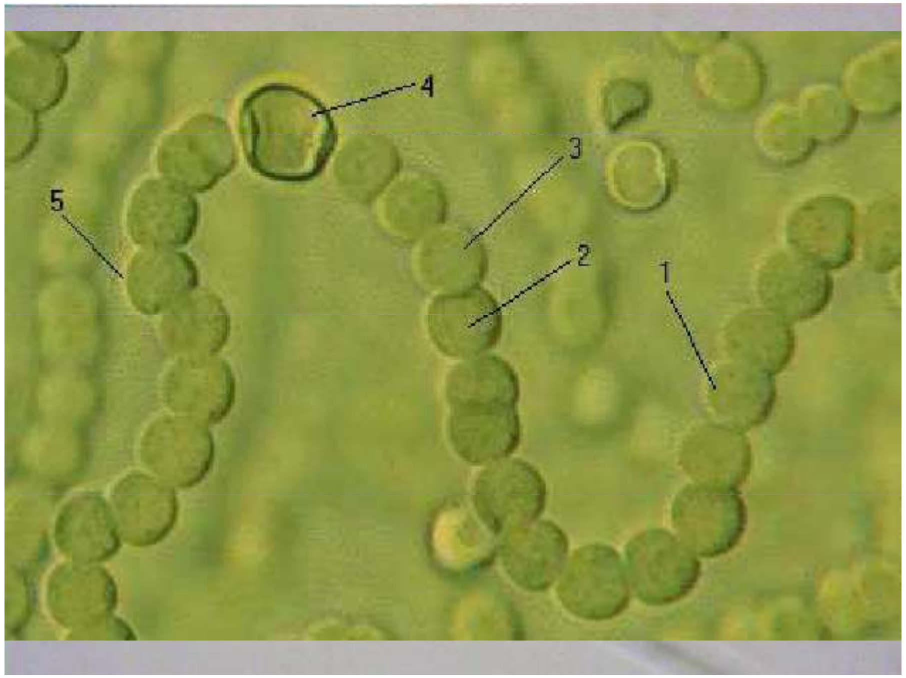
3 **Group SAR**
Brown algae
Topic/Lecture 6

Domain *Bacteria*: the CYANOBACTERIA, or blue-green algae

- **Unicellular or colonial** organisms
- **Photoautotrophic** (oxygenic photosynthesis)

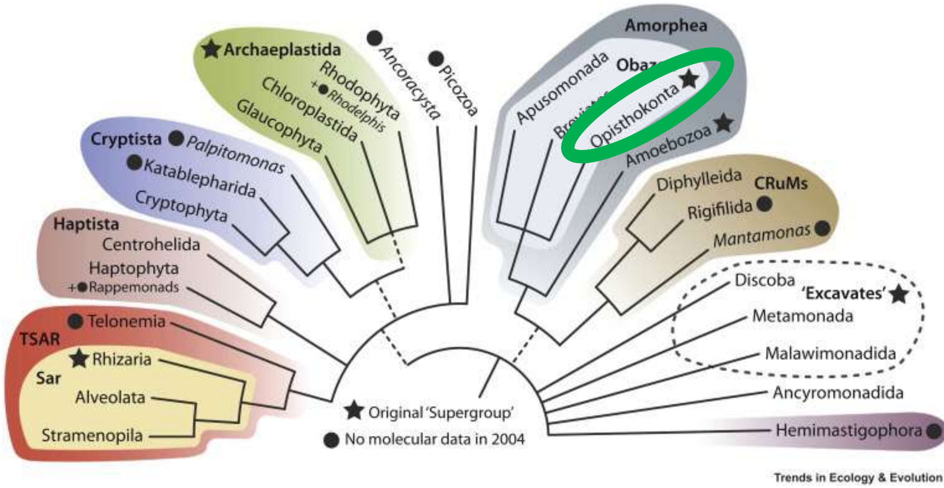


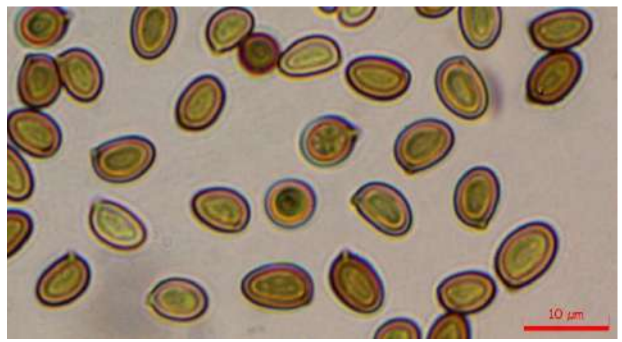


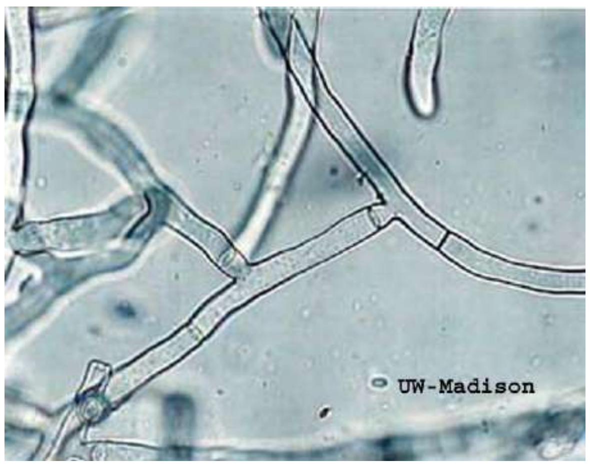


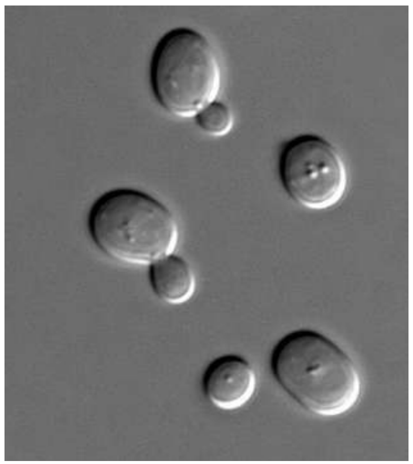
Domain *Eukarya*: the FUNGI

- **EUKARYOTES** (highly diverse: moulds, yeasts, mushrooms, rusts and smuts, etc.) ·
- **HETEROTROPHIC** for **CARBON** (nutrition).
- Food intake by **ABSORPTION**. Osmotrophy. Gradients.
- **NUTRITION**:
  - **SAPROPHYTISM** (Lysotrophy),
  - **SYMBIOSIS** (Osmotrophy)
- Complex enzymatic systems.
- External activity of secreted enzymes (**EXOENZYMES**)
- Vegetative body = unicellular (yeasts) or thalli or mycelia of hyphae (pluricellular).
- **STIFF CELL WALL** made up of chitin and beta-glucans.
- **REPRODUCTION BY SPORES** Efficient dispersal.
- Poikilotherms and Poikilohydric.
- **DECOMPOSERS AND RECYCLERS** These drive most biogeochemical cycles, especially those of CARBON and PHOSPHOROUS.





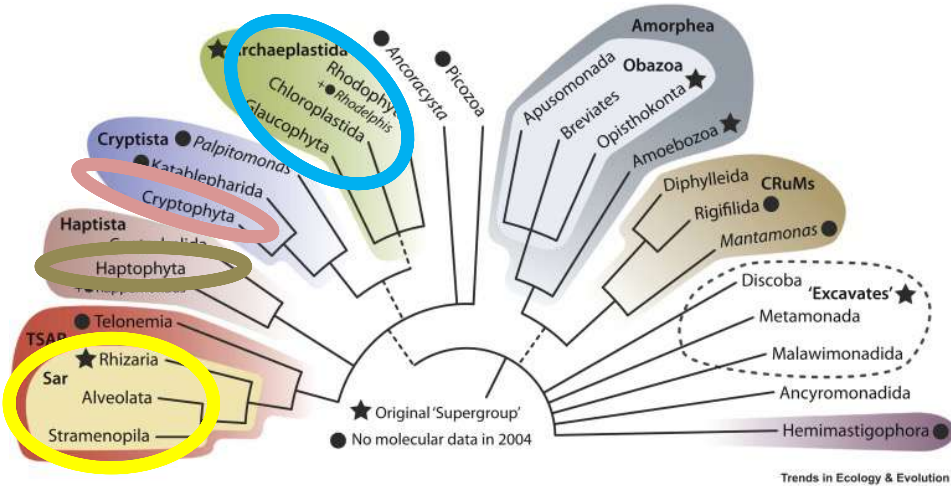


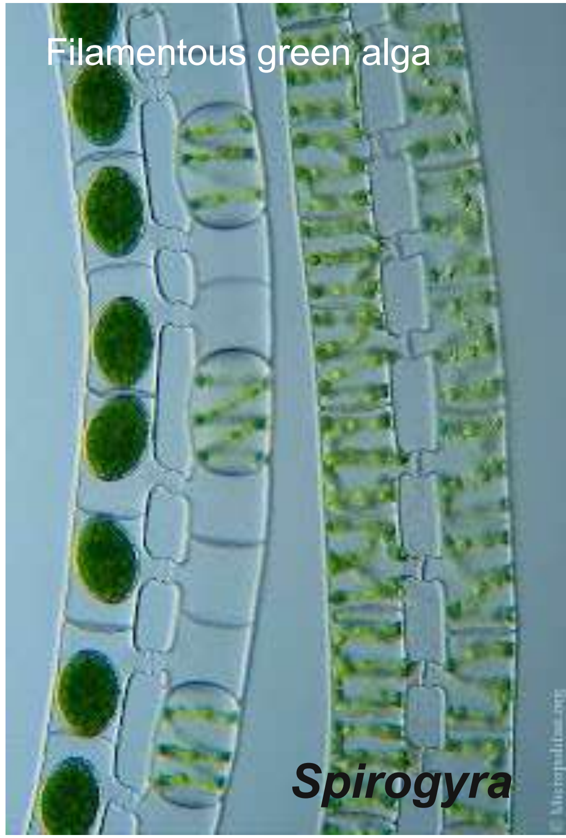


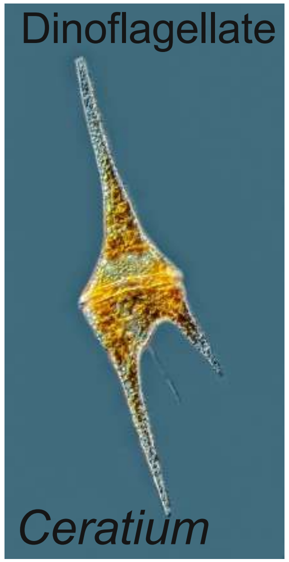
Domain *Eukarya*: the ALGAE

Unicellular or pluricellular eukaryotic organisms, with autotrophic nutrition, and generally <u>without well-differentiated tissues</u>. These organisms are members of various supergroups:

- **SAR**: Brown algae, diatoms and dinoflagellates
- **HAPTISTA**: Haptophytes
- **CRYPTISTA**: Cryptophytes
- **ARCHAEPLASTIDA**: Green, blue and red algae





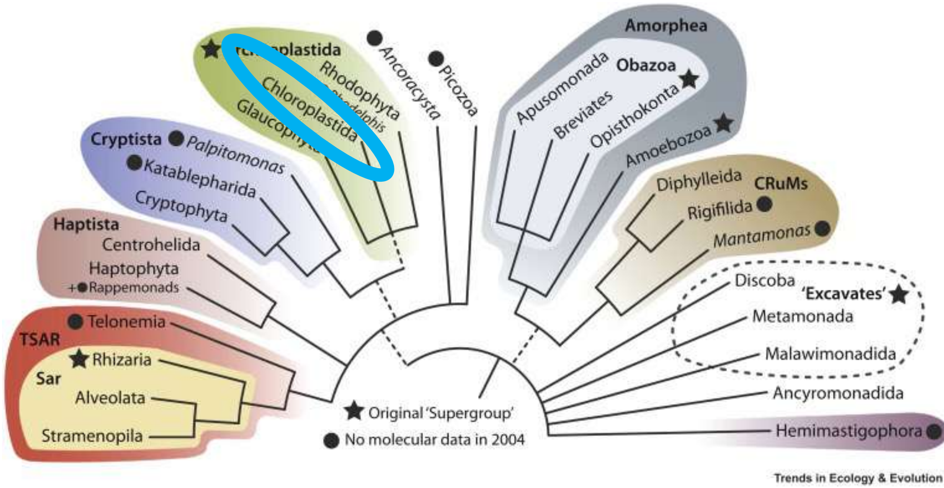


Domain *Eukarya*: the PLANTS

(ARCHAEPLASTIDA-CHLOROPLASTIDA)

Eukaryote organisms:

- Pluricellular
- Photoautotrophic
- The zygote enters an embryonic phase (**embryophytes**)
- High structural complexity
- Mainly terrestrial but some species inhabit aquatic environments.



Without lignin (the gametophyte dominates)

With lignin (cormophytes; the sporophyte dominates)

Reproduction by spores

Reproduction by seeds

Bryophytes (mosses, liverworts and hornworts)

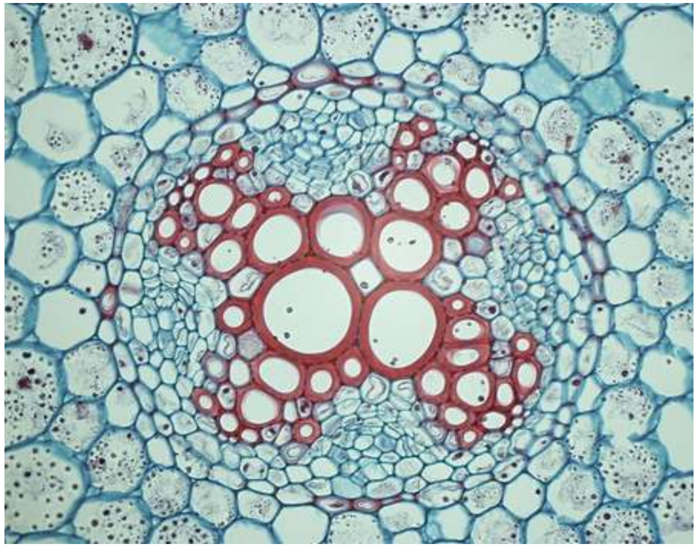
Pteridophytes (ferns)

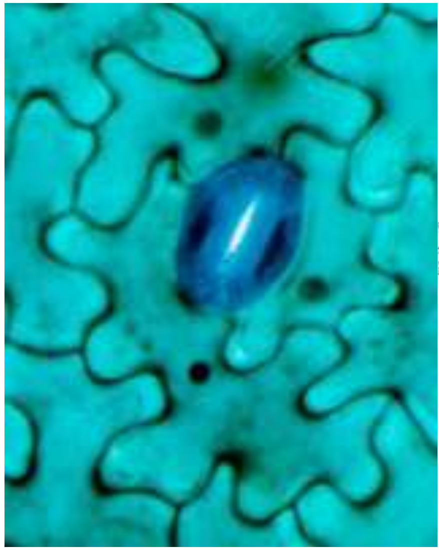
Spermatophytes (gymnosperms and angiosperms)

What are CORMOPHYTES?

Discriminatory traits of this group of plants:

- Great anatomical differentiation: **ROOTS, SHOOT, LEAVES.**
- Most are terrestrial, **HOMEOHYDRIC**, and do not depend on moist environments.
- Cell walls composed of **CELLULOSE**, though **LIGNIN**, **CUTIN** and **SUBERIN** may be also present**.**
- Development of **STOMATA**.
- Complex systems for transporting dissolved nutrients and water (e. g. **xylem** and **phloem**).
- These are the most complex plants and currently dominate all terrestrial ecosystems.
- Cormophytes are **MONOPHYLETIC** (i.e. they share a common ancestor).





Eucalyptus globulus

121 m (height)

300 tonnes (weight)

Sequoiadendron giganteum

112 m (height)

270 tonnes (weight)

Which traits are shared between FUNGI, ALGAE and PLANTS?

- **STIFF CELL WALLS** (cellulose or chitin)

- **MOTIONLESS**: "Permanently" adhered to substratum.

However, biological dispersal occurs. This refers to the movement of offspring away from their original parental organism. This dispersal of an individual has consequences not only for the fitness of that individual but also for population dynamics, population genetics, and species distribution.

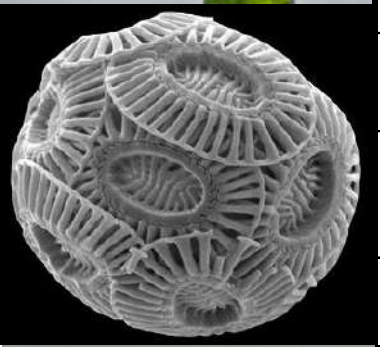
  - Dispersal is done by DIASPORES: these are plant dispersal units that assist dispersal (e.g. seeds, fruits or spores plus any additional tissues).

- **UNLIMITED GROWTH** (theoretically) and high surface/volume relationship.

- **CAPACITY TO REGENERATE** new individuals by:
  - Fragmentation. In this very common type of vegetative reproduction in plants new individuals are produced from small parts of the organism.
  - Propagules: Reproductive particles released by an organism that may germinate into another.

- **REPRODUCTION** by **SPORES** = spores are reproductive structures that are adapted for dispersal and survive for extended periods of time in unfavourable conditions. Spores are part of the life cycles of many bacteria, plants, algae and fungi and may have a sexual or asexual origin.

- **POIKILOTHERMS**.
- **BIOINDICATORS** of the quality of environmental conditions.


Main groups studied in BOTANY and their diversity



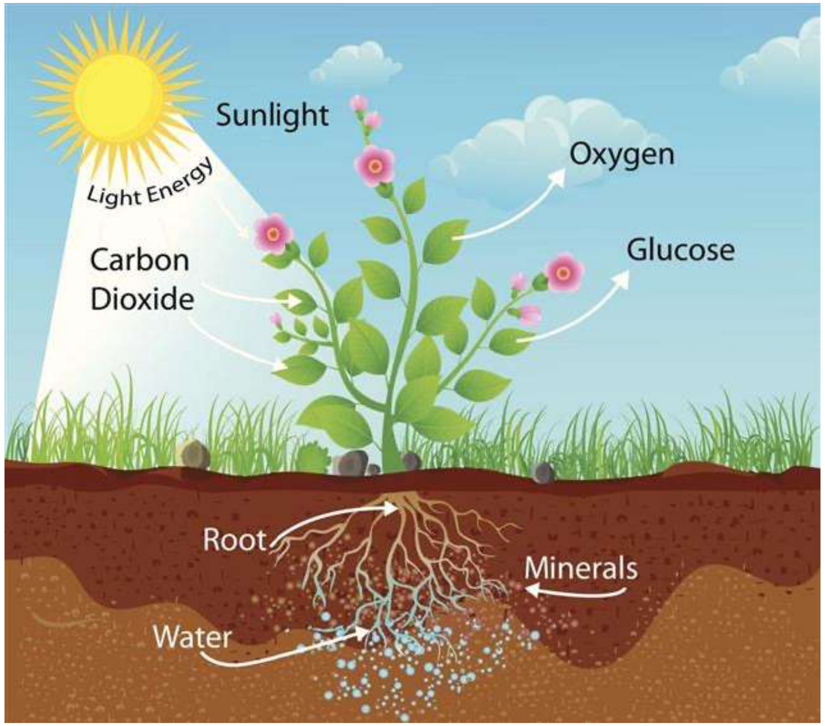


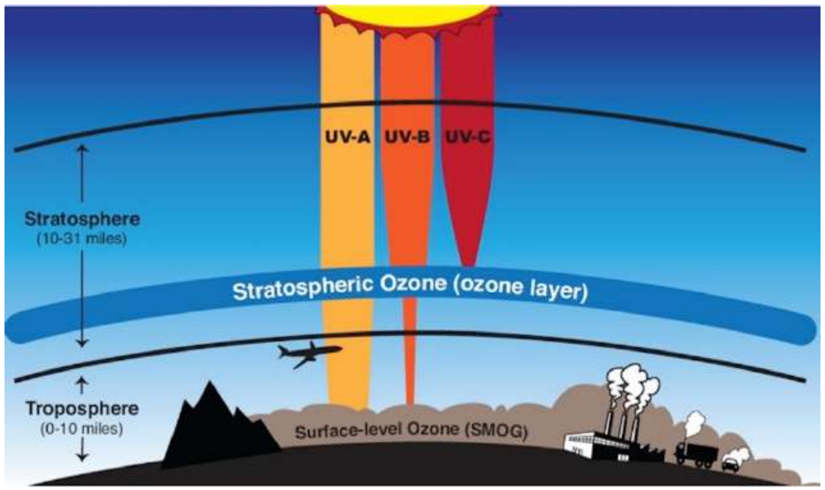
PROKARYOTIC DOMAINS	Functional group	Groups of organisms	Approximate number of species
Archaea			
Bacteria	**Photoautotrophic bacteria**	**Blue-green algae or cyanobacteria**	2000
EUKARYOTIC DOMAIN			
Eukarya **PROTISTS**	**Heterotrophic protists**	**Ameboid fungi, oomicetes and slime molds**	
	Autotrophic protists	**Unicellular and pluricellular algae**	43.900-73.000
Eukarya **FUNGI**		**True fungi**	>100.000
Eukarya **PLANTS**	**Non-vascular plants**	**Bryophytes**	18.800-20.850
	Vascular plants without seeds	**Ferns, pteridophytes**	>11.800*
	Vascular plants with seeds but without flowers	**Gymnosperms**	1.079*
	Vascular plants with seeds and flowers	**Angiosperms**	>295.000*

Data obtained from Graham & Wilcox (2000) and Vargas & Zardoya (2012)
*Christenhusz & Byng (2016)

The role of plants in the biosphere

- **Photoautotrophic**
- Change from **reducing to oxidising** atmosphere
- **CO_2 fixation** and **O_2 release**, thus helping to maintain the levels of these gases in the atmosphere (climate change, greenhouse effect)
- Increase in O_2 concentration and **formation of the ozone layer** that **allowed** organisms **to colonise the terrestrial environment**
- Transform **sunlight energy** into **chemical energy (organic matter)**, which is a step in the food chain
- Contribute to **habitat formation** for animals and other organisms
- Contribute to **soil formation and protection** and to **water regulation**.





The role of fungi in the biosphere

- Organic matter decomposition
- The establishment of symbiotic relationships with different phototrophic organisms, such as plants and algae (mycorrhizae and lichens)
- The recycling of mineral elements
- Biogeochemical cycles

The importance of plants and fungi for humans

FUNGI:

- food and drinks

  fermentation and maturation (bread, wine, beer, cheese)

- the production of several **compounds**:
  - toxins
  - antibiotics
  - cyclosporins
  - vitamins

The importance of plants and fungi for humans

- Plants as a source for food: ***Fabaceae*** (legumes), ***Gramineae*** (cereals), ***Rosaceae*** (almonds, apples), ***Solanaceae*** (vegetables)









The importance of plants and fungi for humans

- Other raw materials: wood, textile fibres (linen, cotton, jute, hemp), natural dyes, paper pulp, building materials, etc.

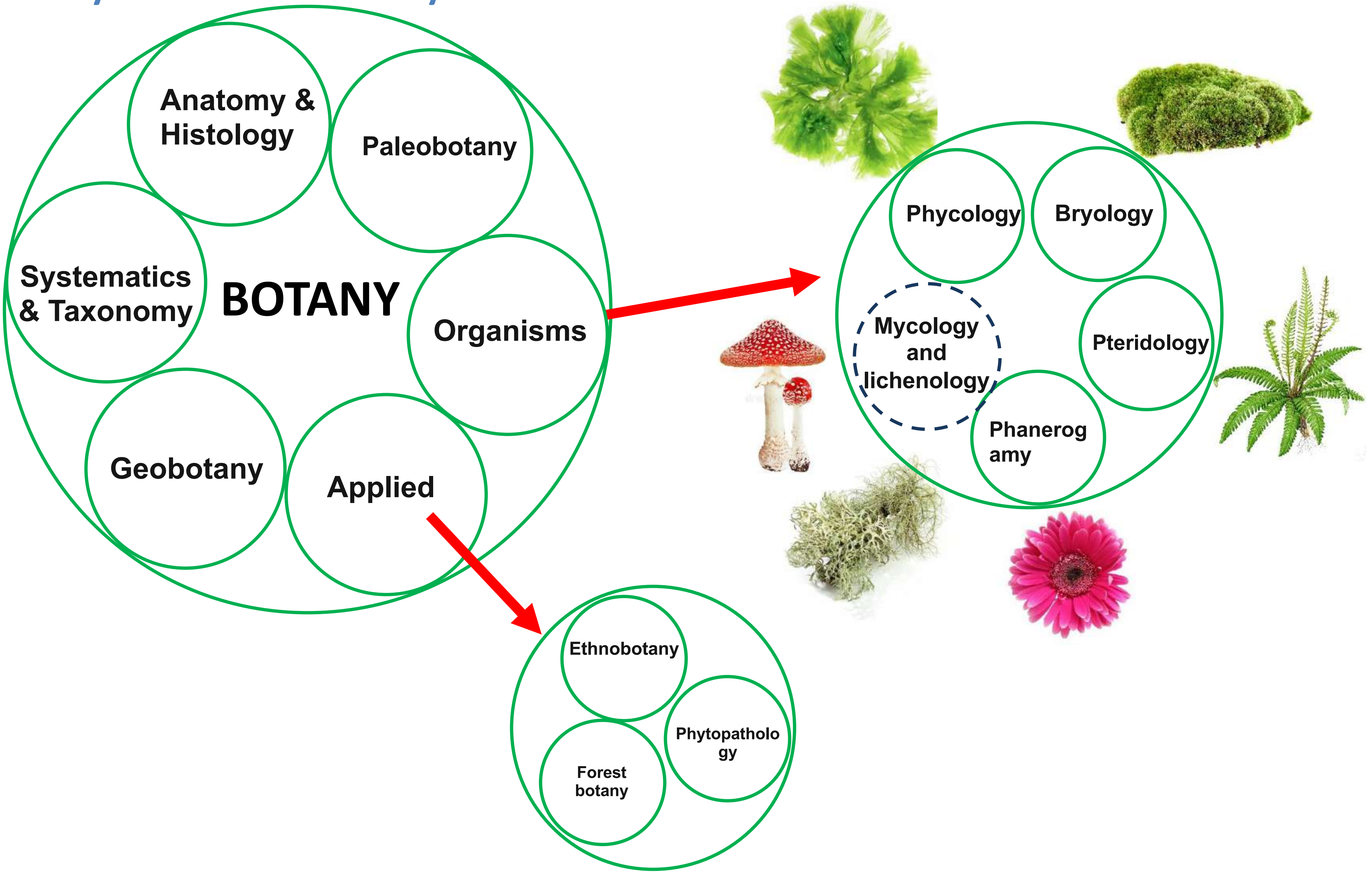
The importance of plants and fungi for humans

- Fossil fuels derived from living beings. Wood and biofuels

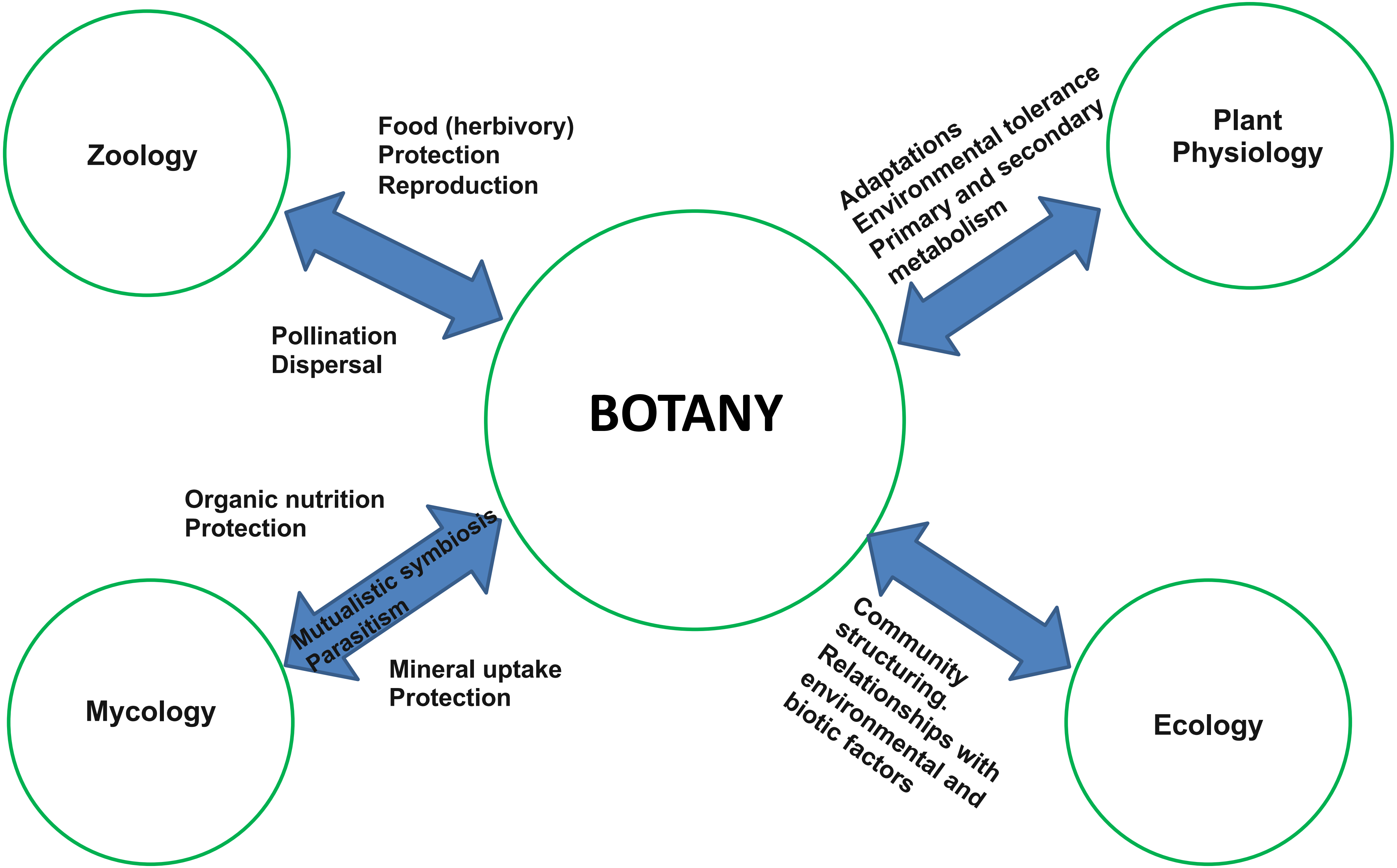
The importance of plants and fungi for humans

- Plants as medicines, and products for pharmaceutical industries

Study areas within Botany



Relationships between Botany and other scientific disciplines



Key steps in the development of Botany as a scientific discipline

- Agricultural societies appeared in the **Neolithic period** roughly 6,000 B.C.

- Around 4,000 B.C. in **Babylonia** and **Mesopotamia**, medicinal plants began to be registered.

- In Egypt, cereals were cultivated as early as 3,200 B.C. **Egyptian papyri** also suggest the medicinal use of some plants (**Ebers papyrus**, 1,500 B.C.).

- **Theophrastus** (372-287 B.C.), a disciple of Aristotle, wrote ***Historia Plantarum***, in which he proposed an **arrangement by biological types**.

- **Dioscorides** (40-90 A.D.) wrote ***De Materia Medica*.**

Key steps in the development of Botany as a scientific discipline

13th century: foundation of the first universities.

16th century: emergence of the first botanical gardens.

ORTO BOTANICO "GIARDINO DELLA MINERVA" (Salerno)

In medieval Salerno, at the beginning of the 1300s, an "orchard of simples" was created by physician Matteo Silvatico at the service of the teachers of the Scuola Medica.

Key steps in the development of Botany as a scientific discipline

- In Italy in the 16th century **Lucca Ghini** (1500-1556) invented the **herbarium**.

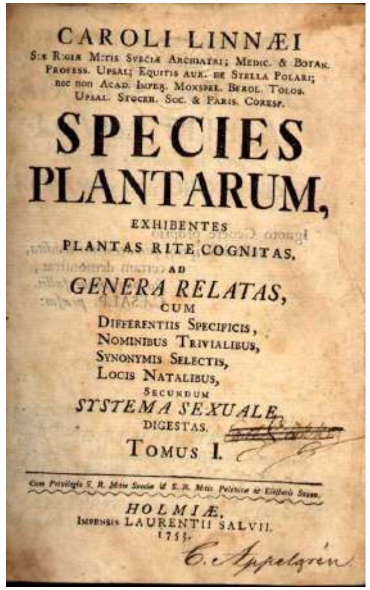
- **Cesalpino** (1519-1603) produced the first classification based on reproductive organs.

- **Gaspard Bahuin** (1560-1624) published ***Pinax theatri botanici***, in which he uses for the first time a **binomial** to refer to plants.

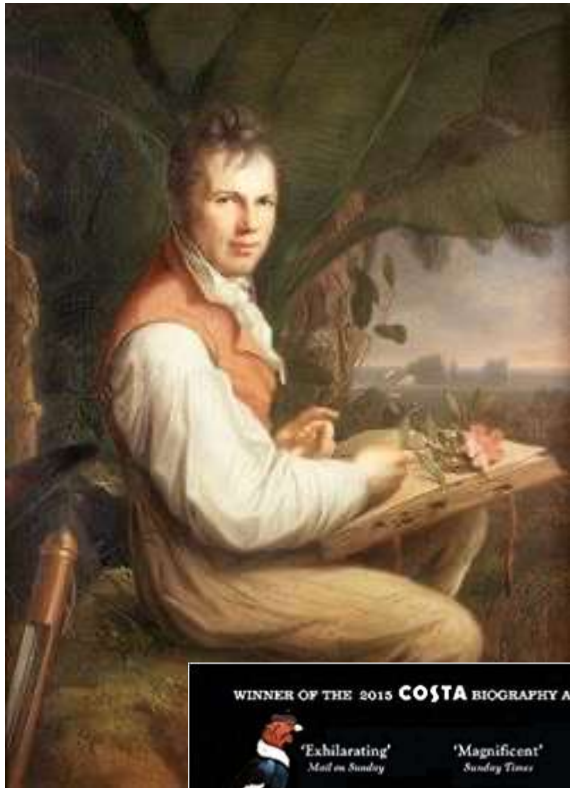
- **John Ray** (1617-1705) proposed a **natural classification** using numerous characters and the **binomial** to designate plants.

- **Joseph de Tournefort** (1656-1708) proposed a highly **artificial system** and used the **polynomial** to name plants.

- **Linnaeus** (1707-1778) published ***Species Plantarum***, in which he established a system for classifying plants in 24 groups and definitively established the use of **binomial nomenclature**.



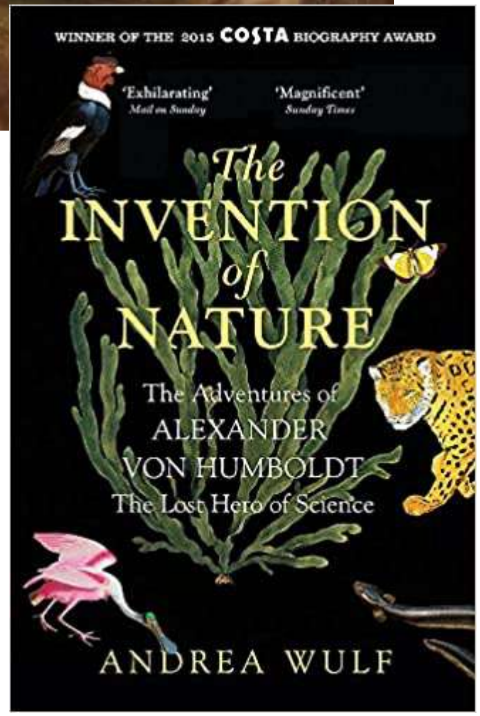
Key steps in the development of Botany as a scientific discipline



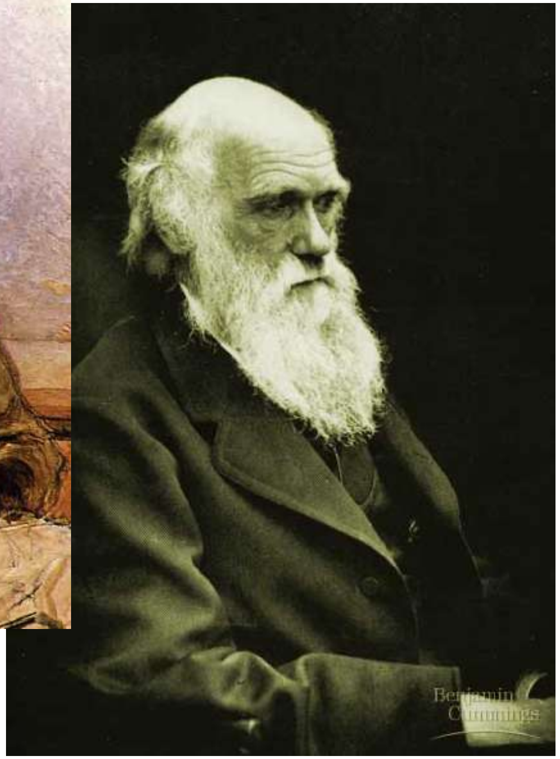
- **Jean-Baptiste Lamarck** (1744-1829): natural system and the Theory of the Inheritance of Acquired Characteristics.
- **Carl Willdenow** (1765-1812): the first phytogeography.
- **Johann Hedwig** (1730-1799): the first studies on cryptogams with classification proposals based on morphological and sexual characters.

- **José Celestino Mutis** (1732-1808): a representative of the botanical expeditions of the eighteenth century.

- **Alexander von Humboldt** (1769-1859) studied the causes of the geographical distribution of plants: **geobotany**.



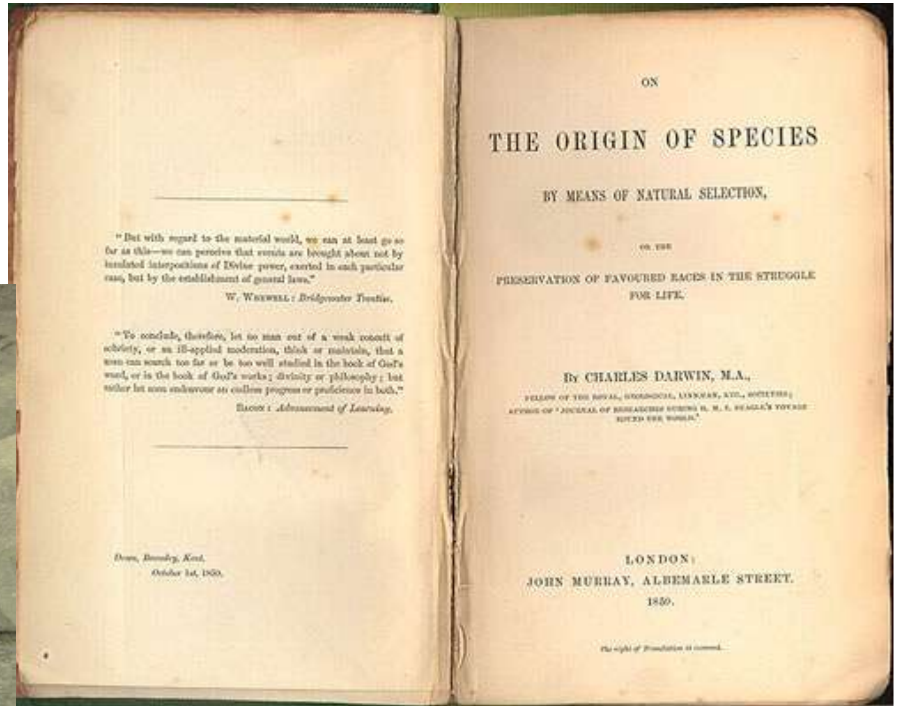
Key steps in the development of Botany as a scientific discipline



Charles Darwin (1809-1882)

The Origin of Species (1859)

Natural selection as driver of evolution. Approximately 200,000 plant and animal specimens.



"But with regard to the material world, we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws."

W. Whewell: *Bridgewater Treatise.*

"To conclude, therefore, let no man out of a weak conceit of sobriety, or an ill-applied moderation, think or maintain, that a man can search too far or be too well studied in the book of God's word, or in the book of God's works; divinity or philosophy; but rather let men endeavour an endless progress or proficience in both."

Bacon: *Advancement of Learning.*

Down, Bromley, Kent,
October 1st, 1859.

ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

Key steps in the development of Botany as a scientific discipline

- **Edouard Strasburger** (1844-1912) became interested in plant cytology and described the mechanism of fertilisation in seed-bearing plants.

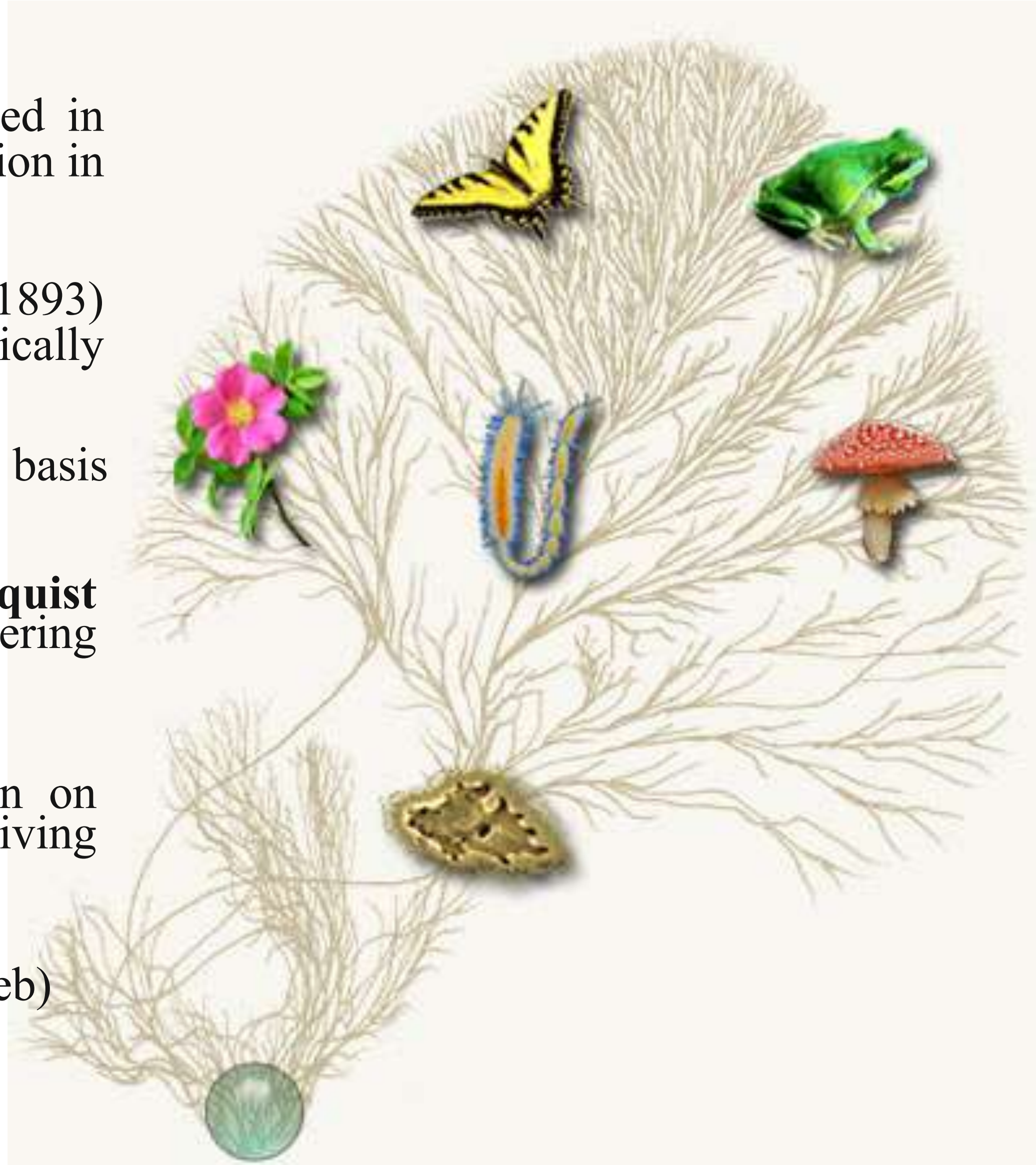
- **Adolf Engler** (1844-1930) and **Karl Prantl** (1849-1893) published a work with all known plants phylogenetically ordered.

- **Josias Braun-Blanquet** (1884-1980) established the basis for the study of vegetation (phytosociology).

- **Armen Takhtajan** (1910-2009) and **Arthur J. Cronquist** (1919-1992) made two proposals for managing flowering plants that have been widely followed.

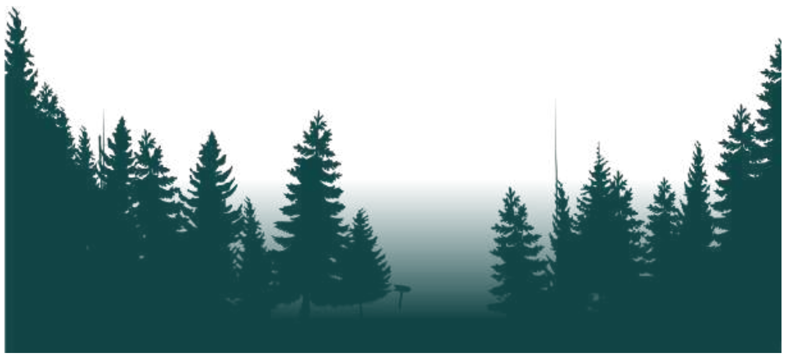
- **Tree of Life:** a coordinated system of information on contributions to our knowledge of the diversity of living organisms http://tolweb.org/tree/

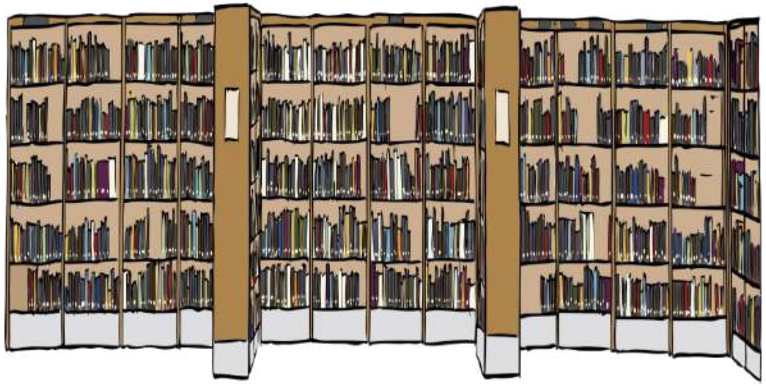
- The **Angiosperm Phylogeny Group** (1998; 2002; web) keeps the systematics of angiosperms up to date on a molecular basis. http://www.mobot.org/mobot/research/apweb/"



Sources of information in Botany

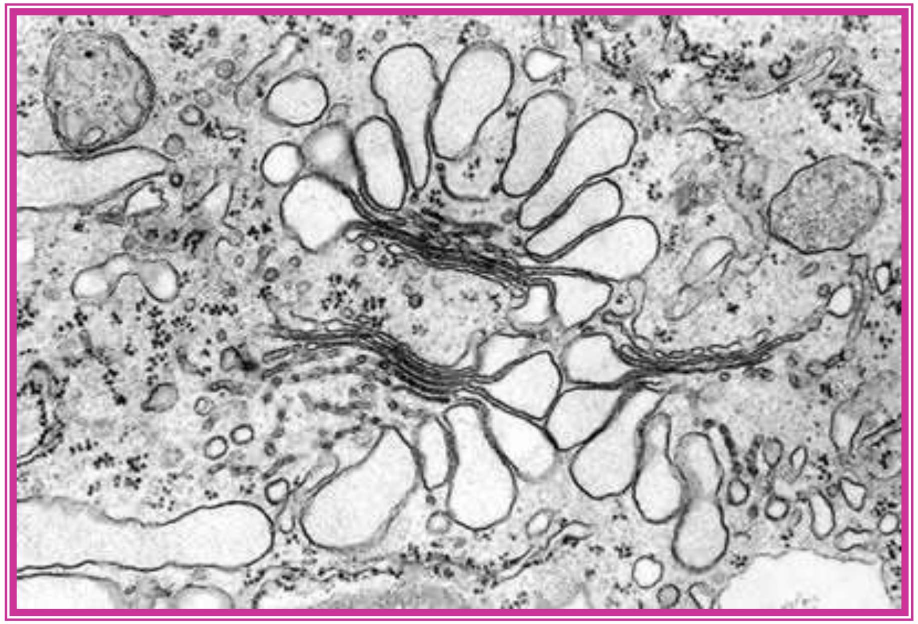
- **Studies in wild conditions:** ecology, reproductive biology, geographic distribution.
- **Studies in laboratories:** morphology, anatomy, karyology, palynology, phytochemistry, molecular biology.
- **Libraries:** descriptions, revisions.
- **Herbaria:** typification, materials for comparison, evidence.
- **Botanical Gardens:** cultures, development, germination, seed banks.
- **Certificate collections:** Type references. Samples used in research studies must be stored for the future confirmation of results.
- **TYPE CULTURE COLLECTIONS** of fungi and algae.





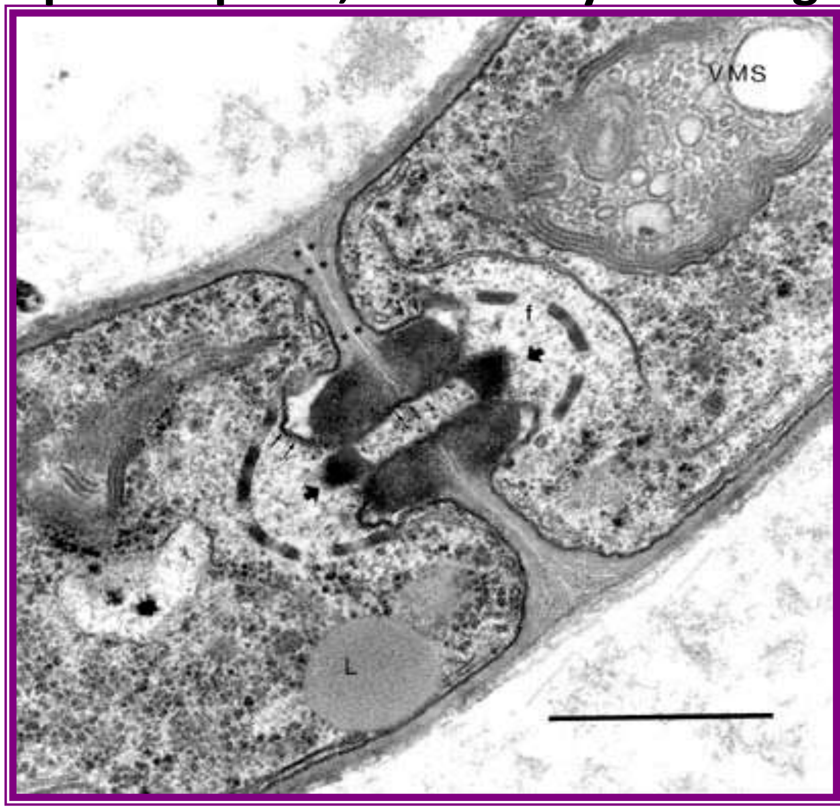
Official Herbaria

Transmission Electron Microscopy
TEM



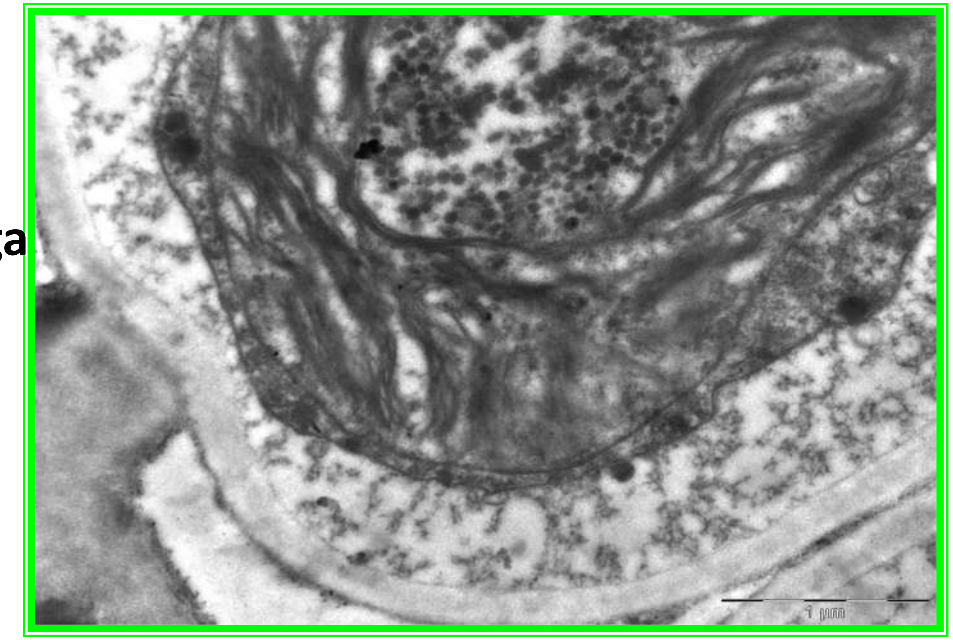
Golgi in maize roots. Vesicles of secretion

Dolipore septum, basidiomycete fungi

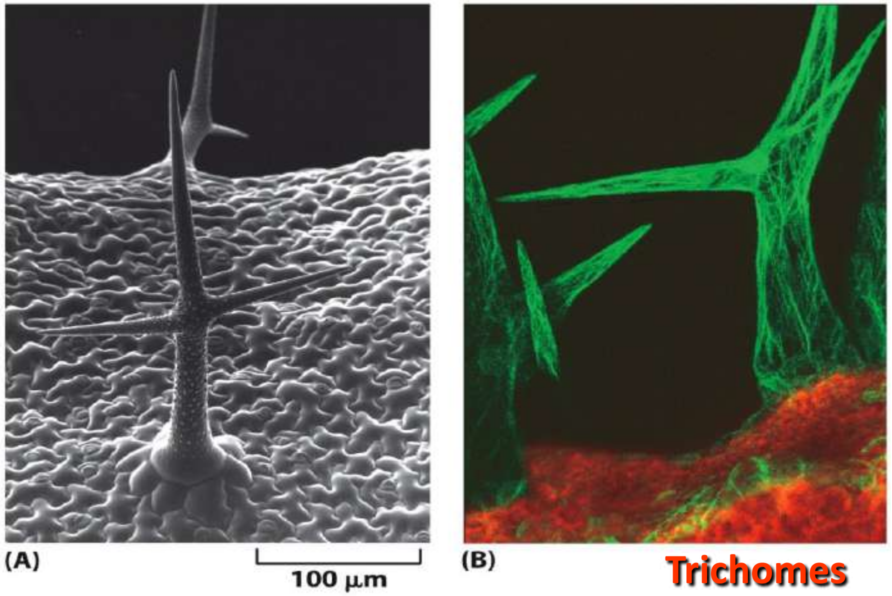


Cell of a symbiotic alga

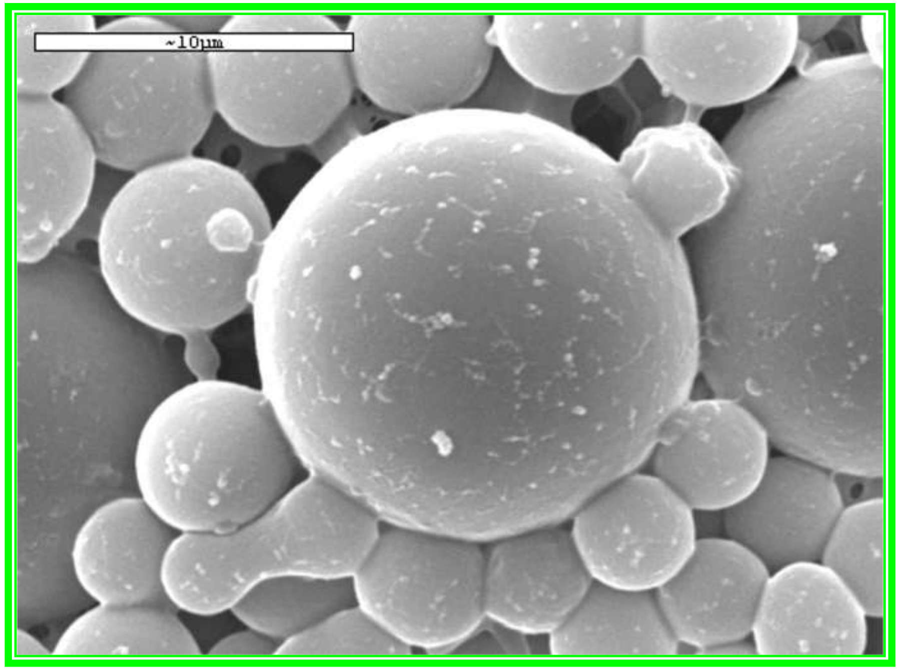
Trebouxia



Scanning Electron Microscopy (SEM) and “Cryoscanning” (LTSEM)

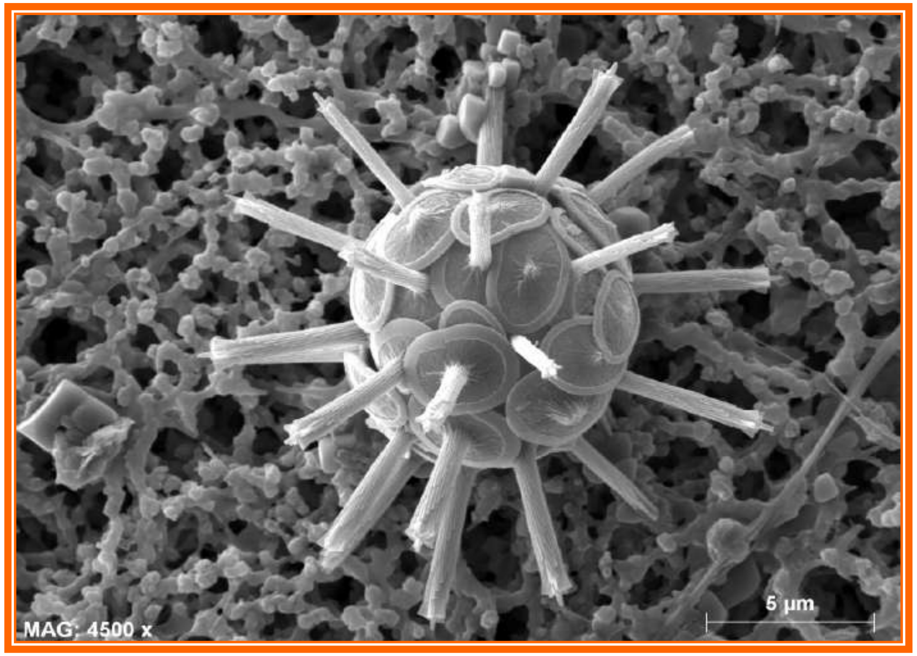


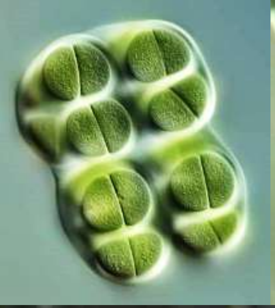
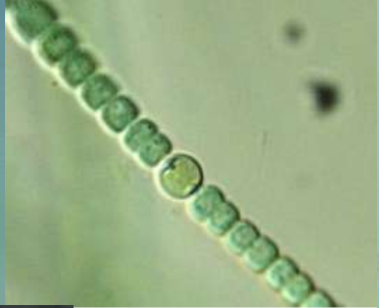
Trichomes

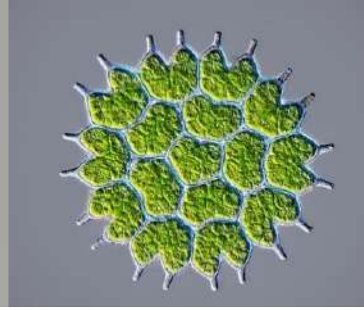


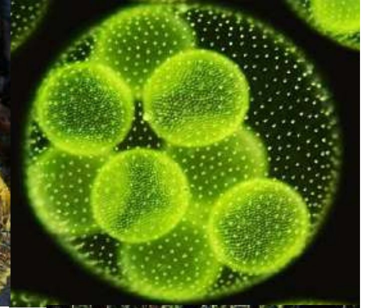
Trebouxia

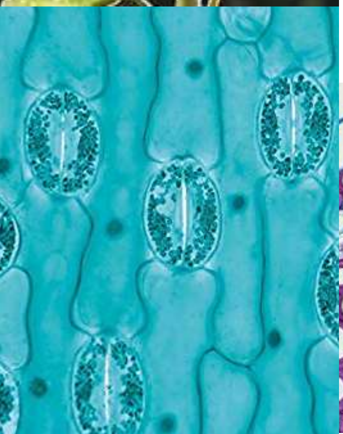
Rhacla



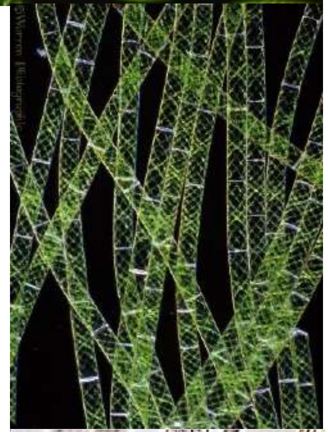
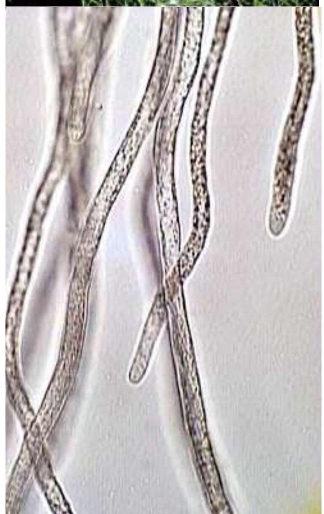
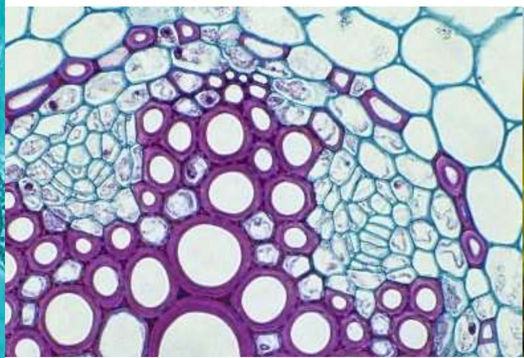


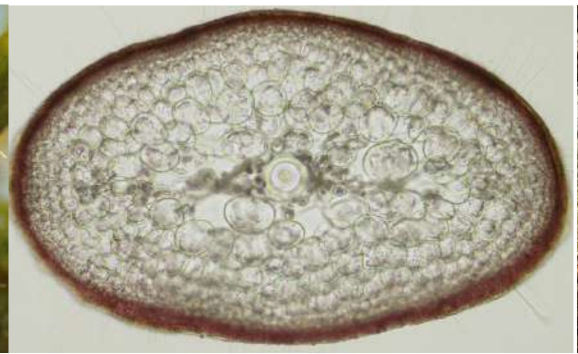


Lecture 02

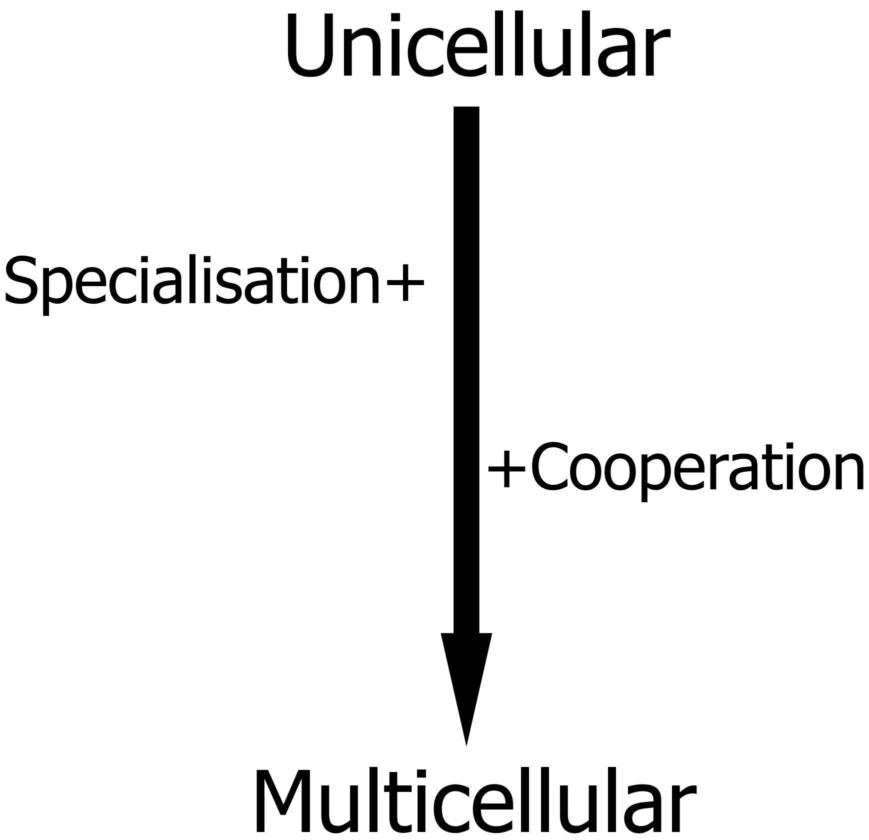
part 1

Structural complexity of plants and fungi

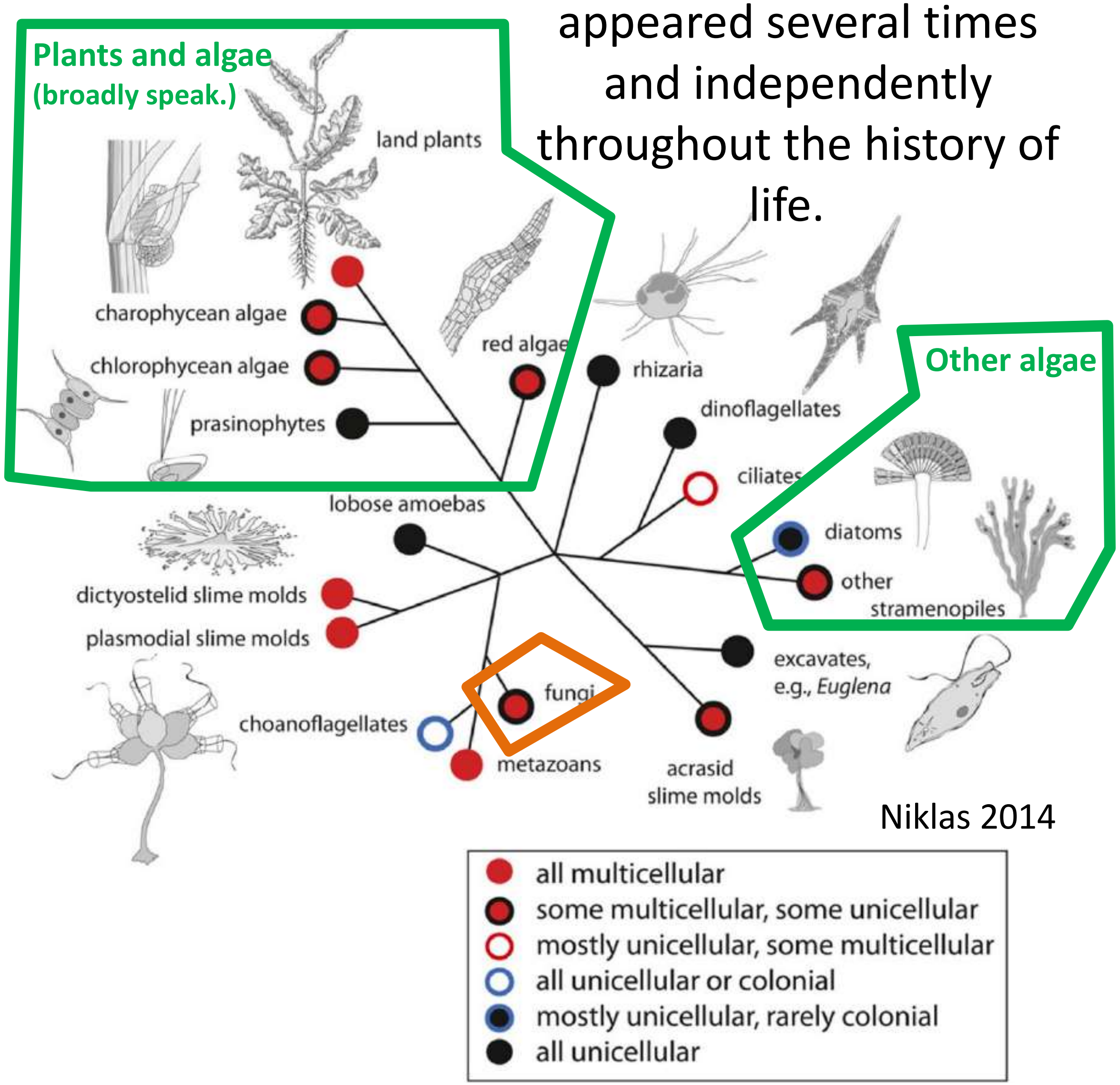







From a unicellular to a multicellular organisation



Multicellularity has appeared several times and independently throughout the history of life.



Niklas 2014

Further reading: Niklas, K. J. (2014). The evolutionary-developmental origins of multicellularity. *American Journal of Botany*, *101*(1), 6-25.

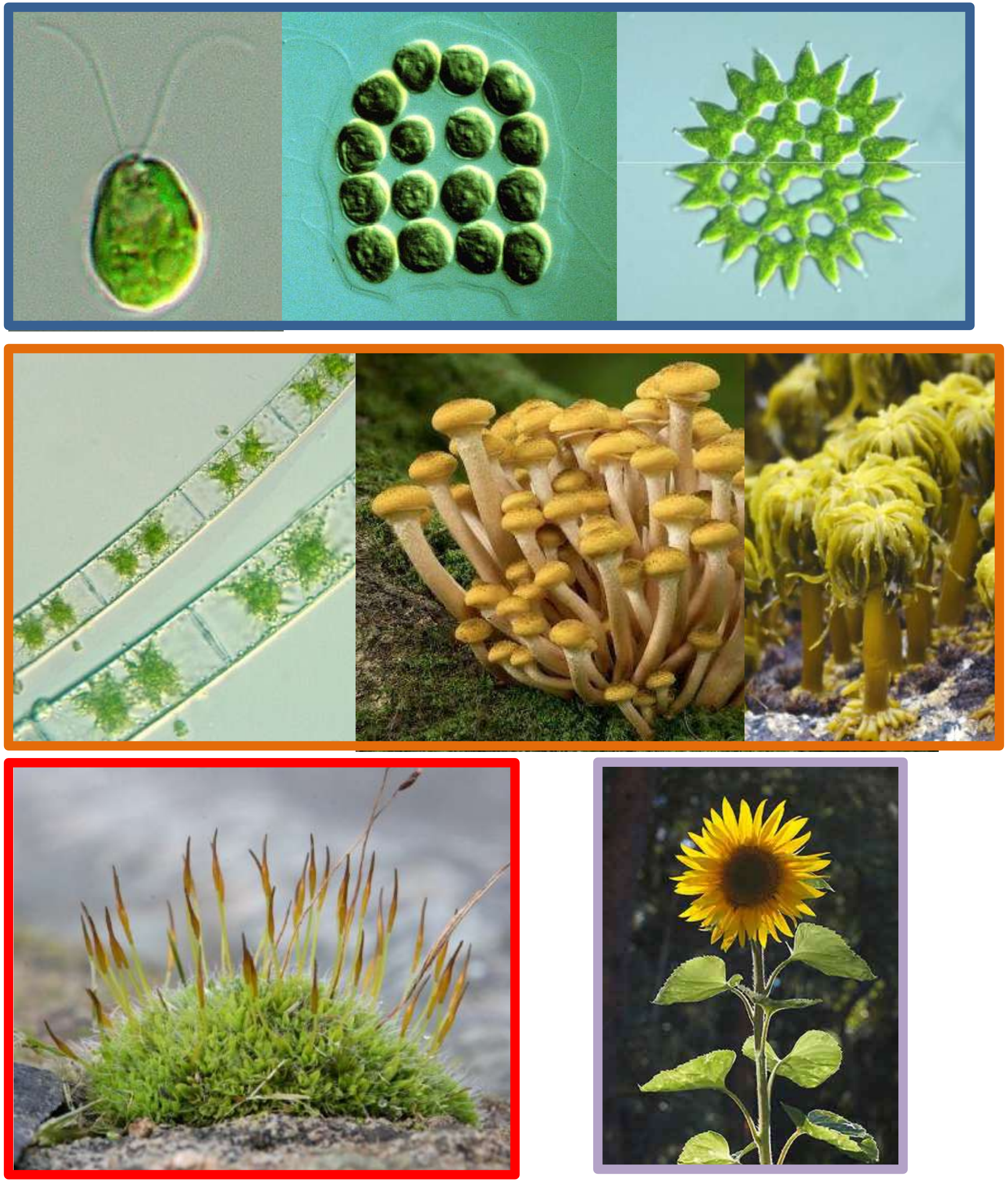
Levels of structural complexity based on morphology (Strasburger's classical view)

PROTOPHYTES

THALLOPHYTES

BRYOPHYTES

CORMOPHYTES

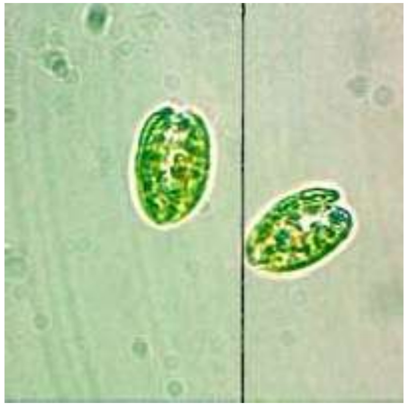


Structural complexity in plants and fungi

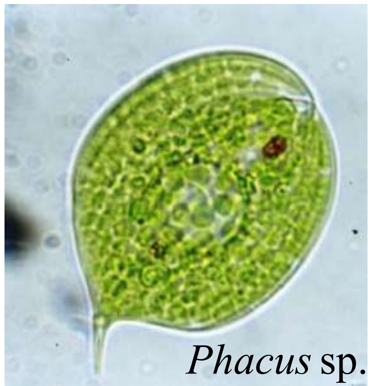
PROTOPHYTES (I): unicellular organisms

mobile (flagellated or ameboid)

Ceratium sp.



Cryptophyceae

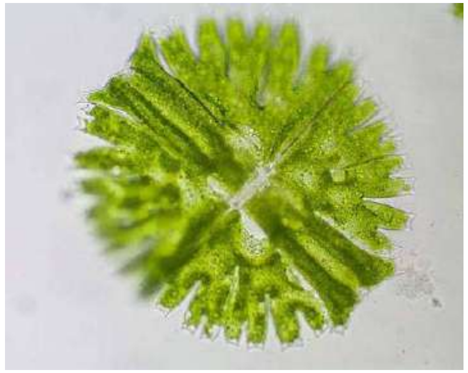


Phacus sp.

Euglenophyceae

motionless

Chlorophyceae



Zygnematophyceae

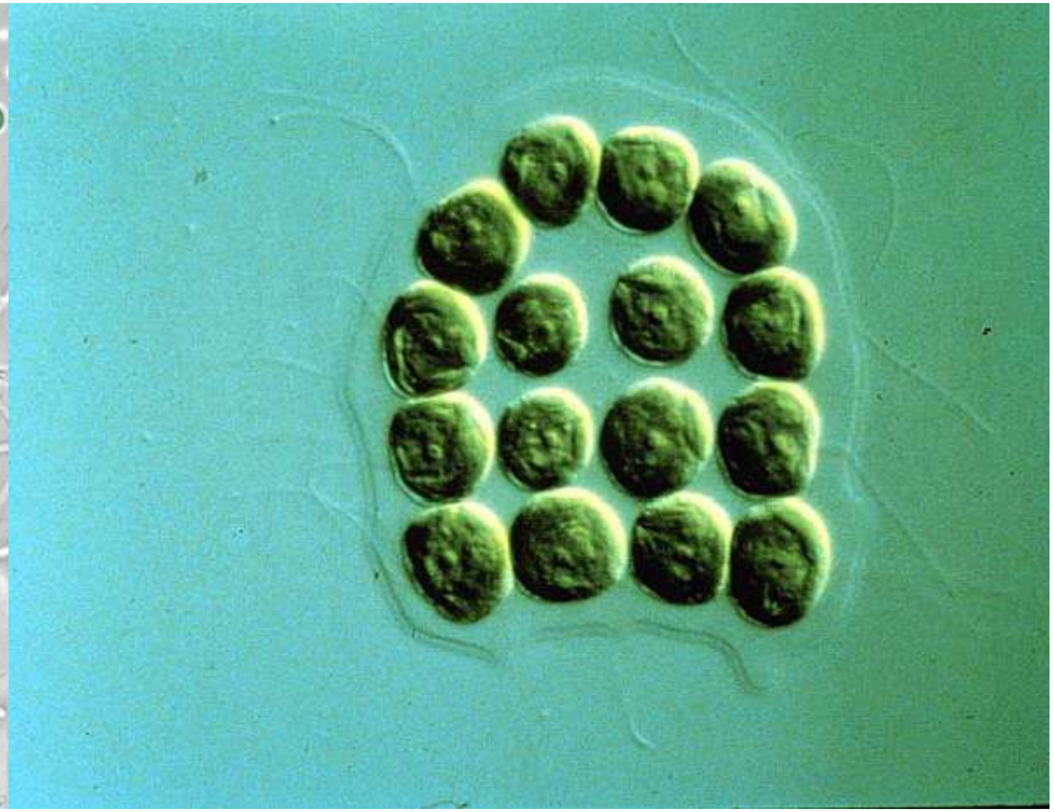
Rhodophyceae

Saccharomyces
(fungal yeast)

Structural complexity in plants and fungi

PROTOPHYTES (II): cell aggregates with an undefined cell number and appearance, or **colonies** (sing. colony)

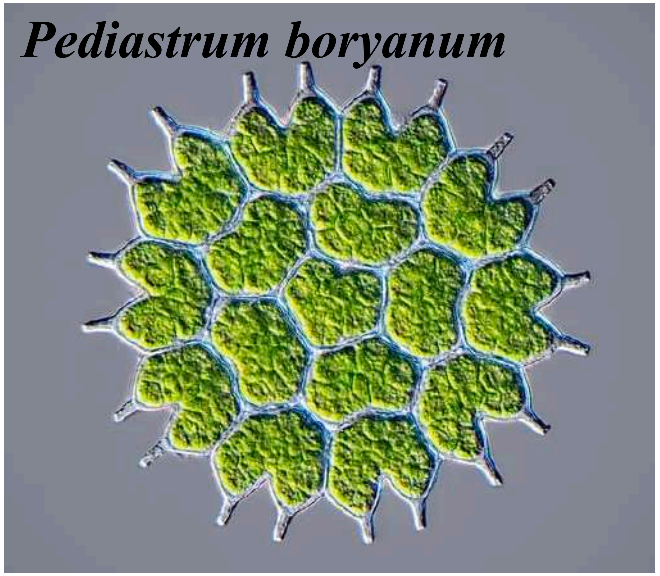
Gloeocapsa sanguinea (*Cyanobacteria*)

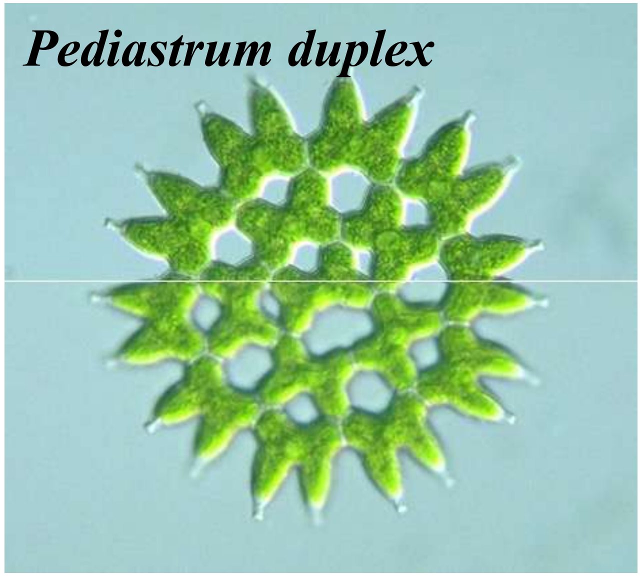


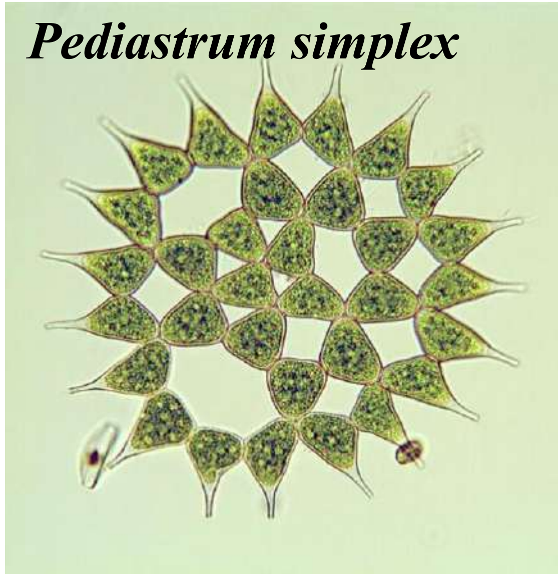
Platydorina sp. (*Chlorophyceae*)

Structural complexity in plants and fungi

PROTOPHYTES (III): colonies with a defined cell number and appearance, or **coenobia** (sing. coenobium)



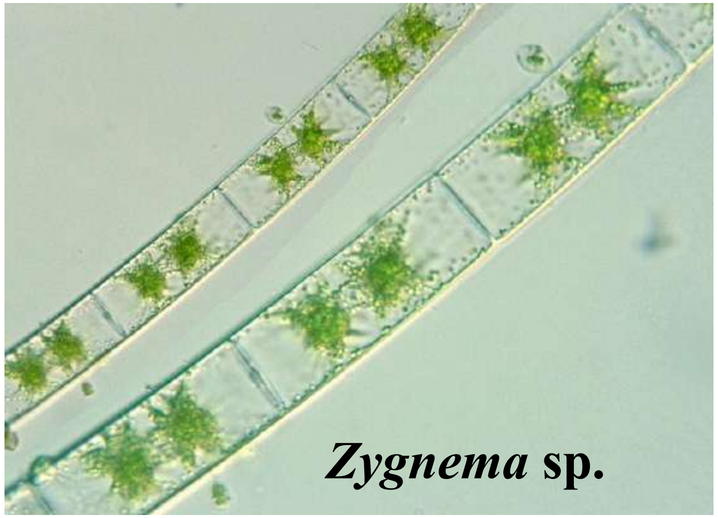




Different coenobia of *Pediastrum* (*Chlorophyceae*) and diatoms (*Bacillariophyceae*)

Structural complexity in plants and fungi

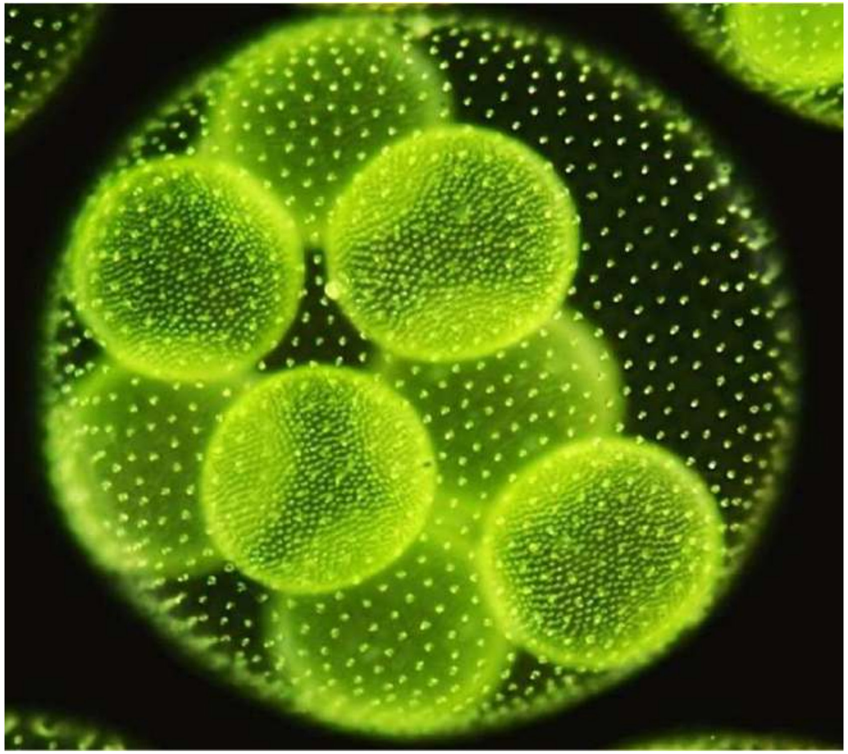
THALLOPHYTES: congenital multicellular or coenocytic (multinucleate) organisms with cells that specialise and cooperate.

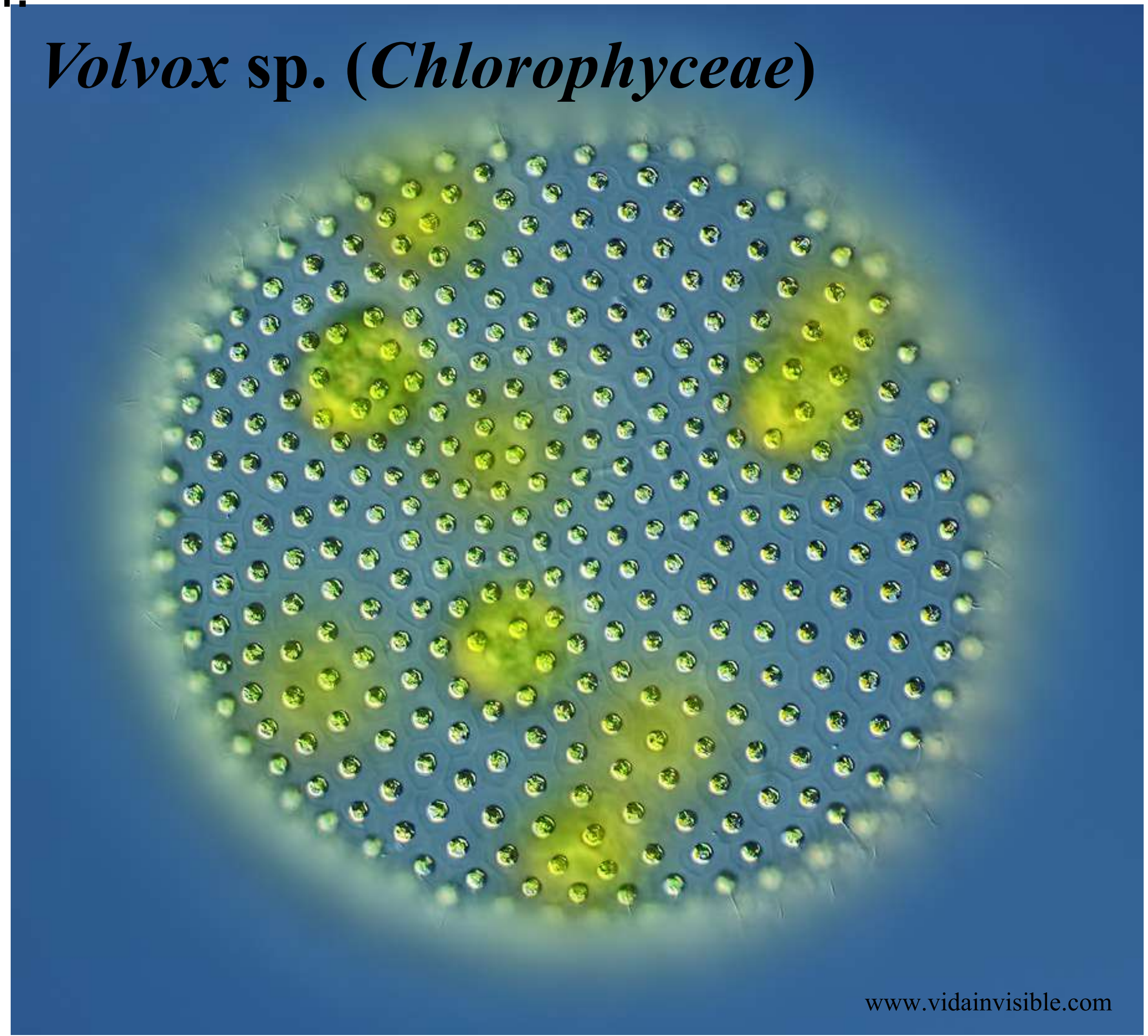


The body of these plants is called the **THALLUS (pl. thalli).** It is poikilohydric and mostly aquatic, since it is well adapted to marine or freshwater aquatic environments, or to other aqueous environments (e.g., wet soil, plant inner tissues).

Structural complexity in plants and fungi

THALLOPHYTES (I): cell colonies of the *Volvox* type. The images below each show a single specimen. Each specimen consists of a large number of cells arranged in a hollow sphere. Some cells specialise in reproduction while others are, for example, motile. Therefore, cells show a certain connection among them.

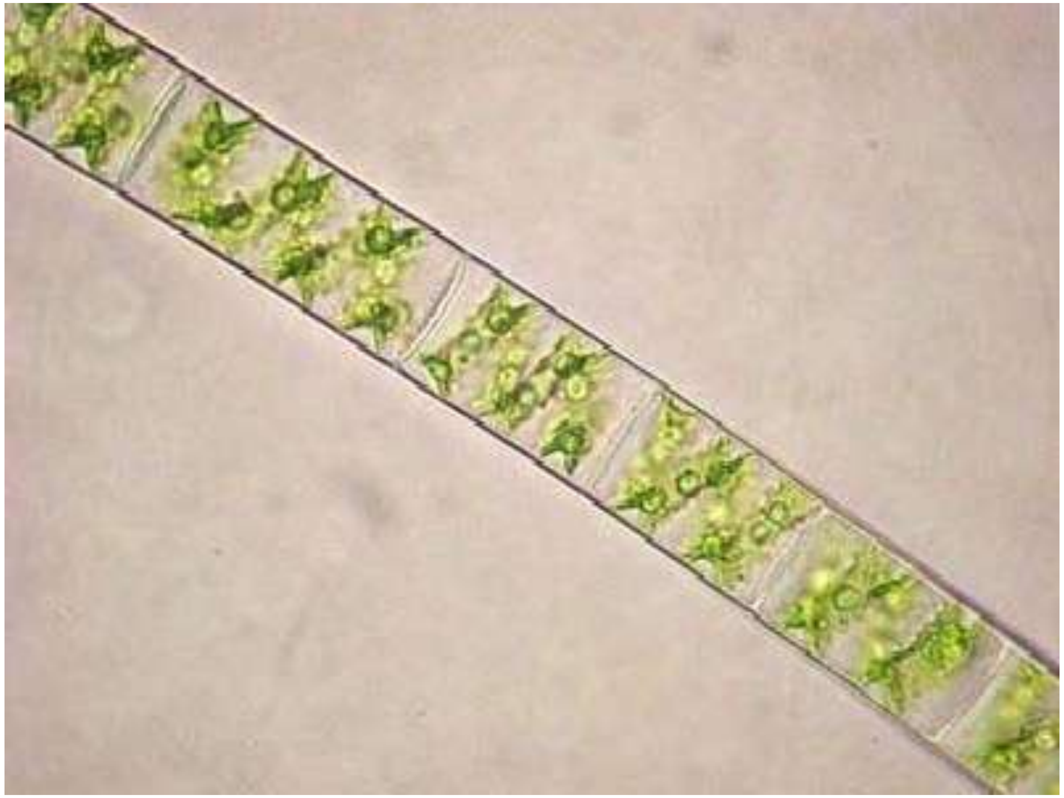




Structural complexity in plants and fungi

THALLOPHYTES (II): rows of cells one after another, or **cellular filaments**. There are two types:

- **single**: the plane of division does not change.
- **branched**: the plane of division rotates.

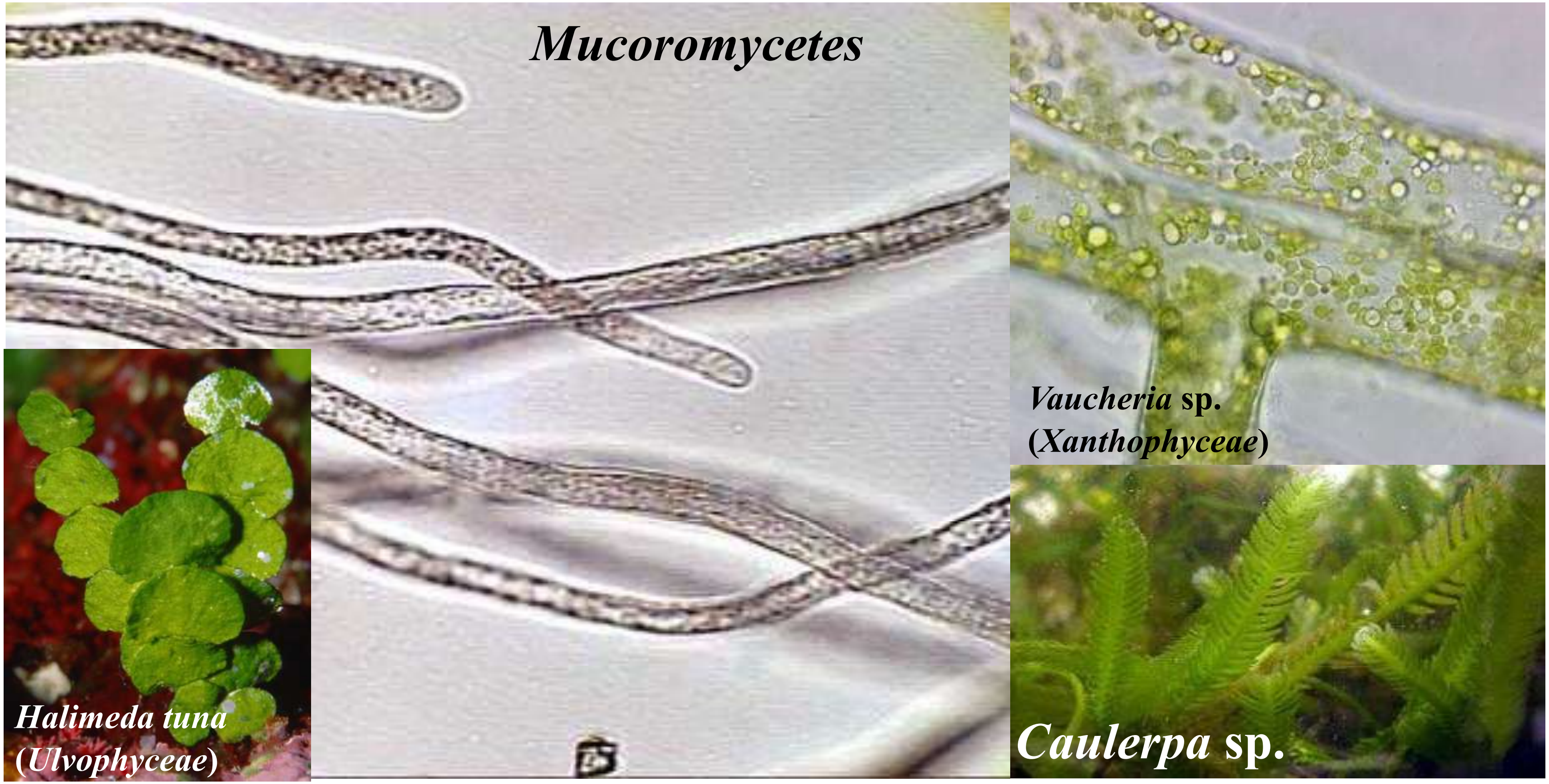


Spirogyra sp. (*Charophyta*, green alga)

Ectocarpus sp. (*Phaeophyceae*, brown alga)

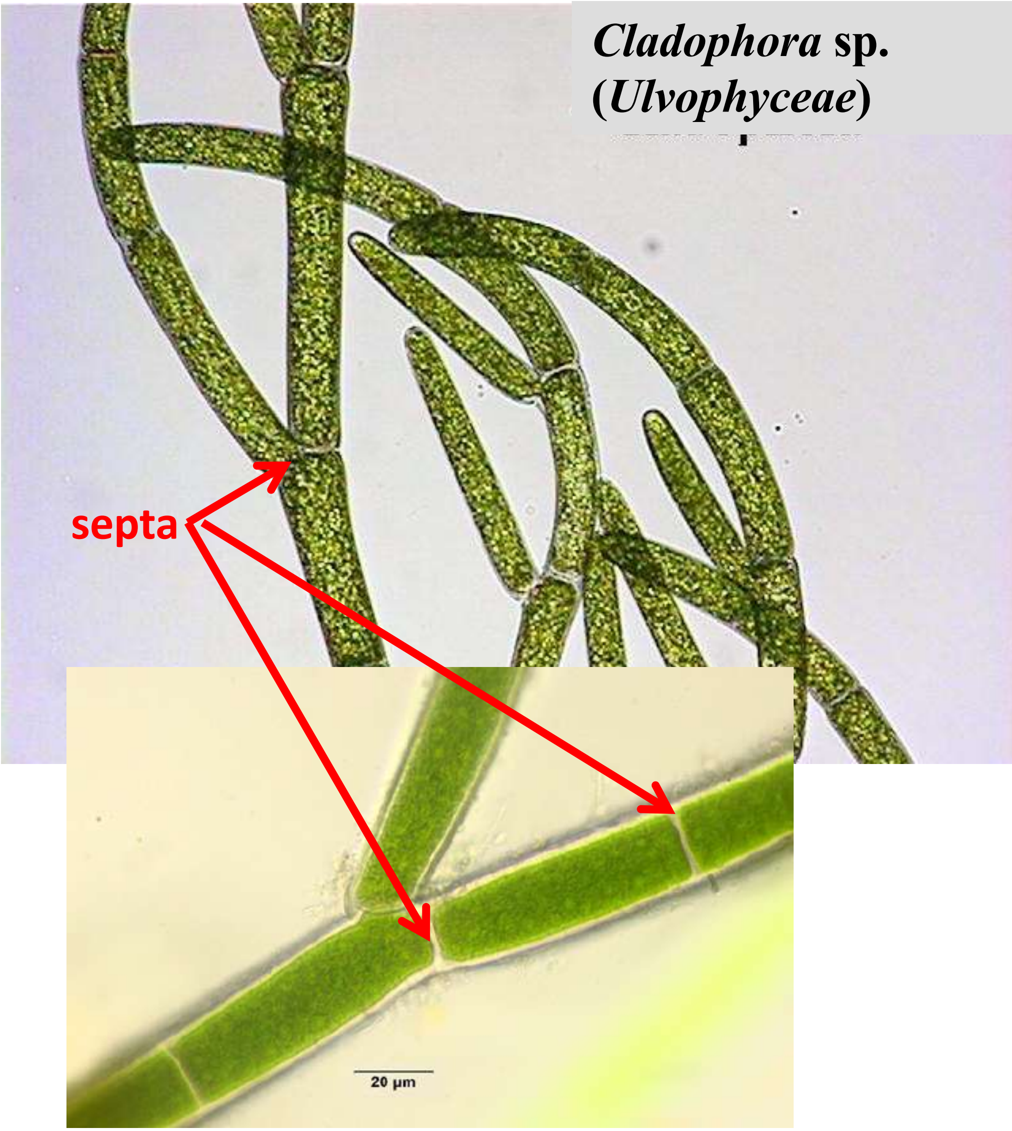
Structural complexity in plants and fungi

THALLOPHYTES (III): siphonous filaments. After mitosis, no partitions or cell-delimiting membranes are formed. Examples: some green algae and some fungi.



Structural complexity in plants and fungi

THALLOPHYTES (IV): siphonocladous (aka **hemisiphonous**) **thalli**. Single or branched filaments with a few septa (sing. septum) that delimite multinucleate portions. These are present in some green algae.



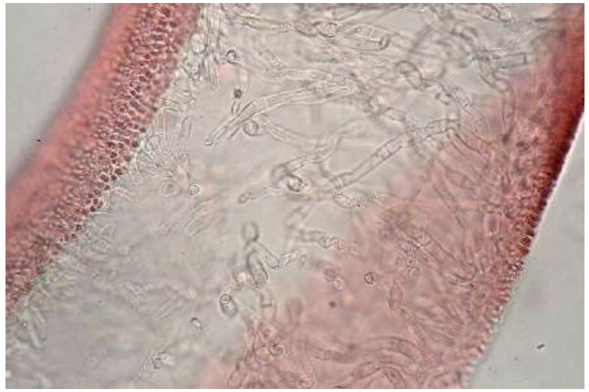
Cladophora sp. (*Ulvophyceae*)

Apical portion of a fertile thalli of *Chara vulgaris* (*Charophyceae*, green alga)

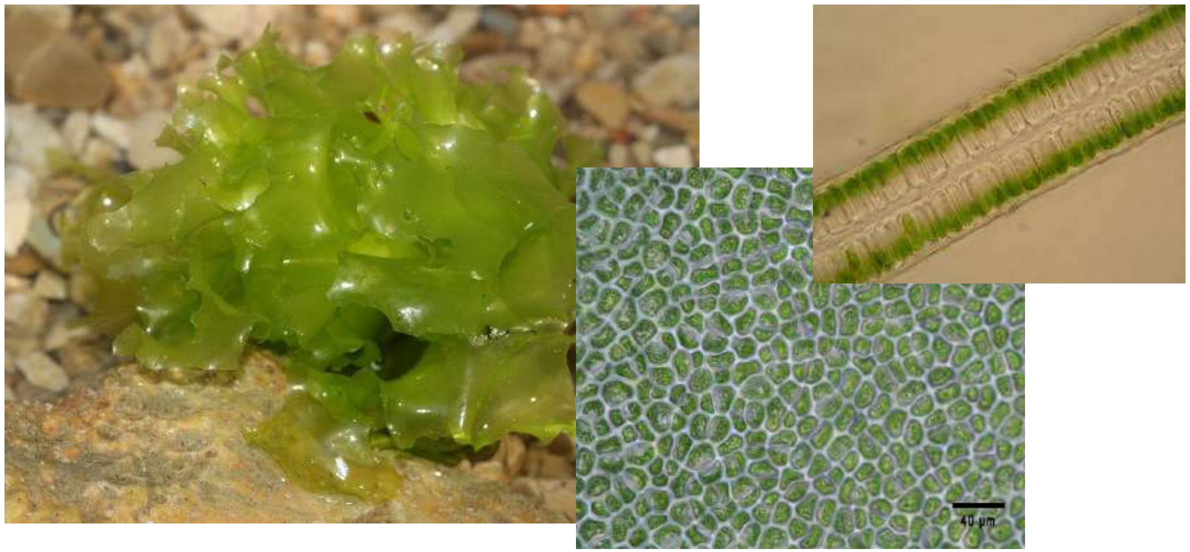
Structural complexity in plants and fungi

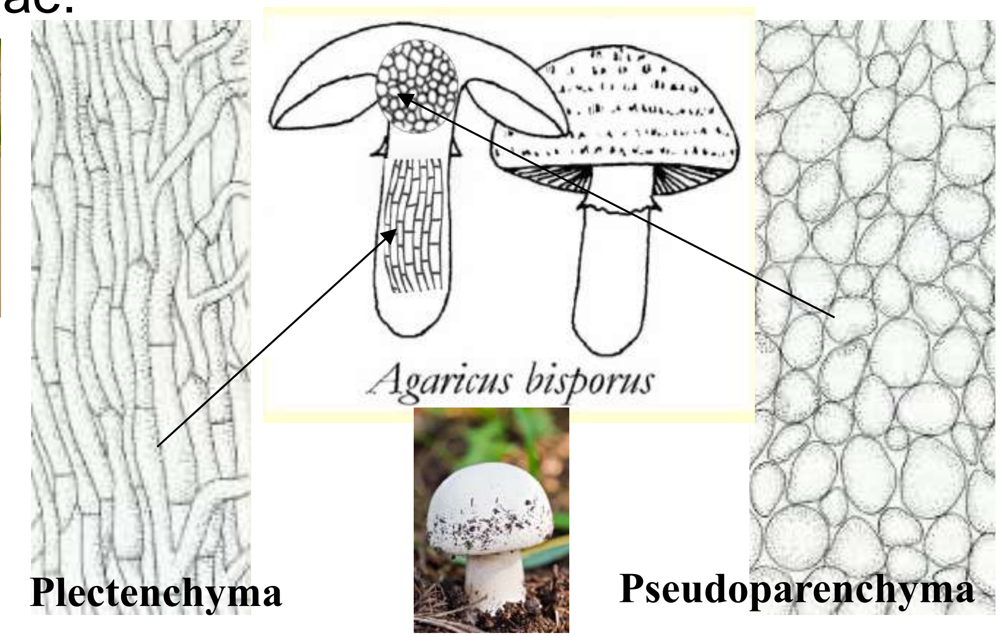
THALLOPHYTES (V):

- **Plectenchyma (“false tissue”)**: this forms from compacted, intertwined filaments. However, individual filaments can still be recognised.



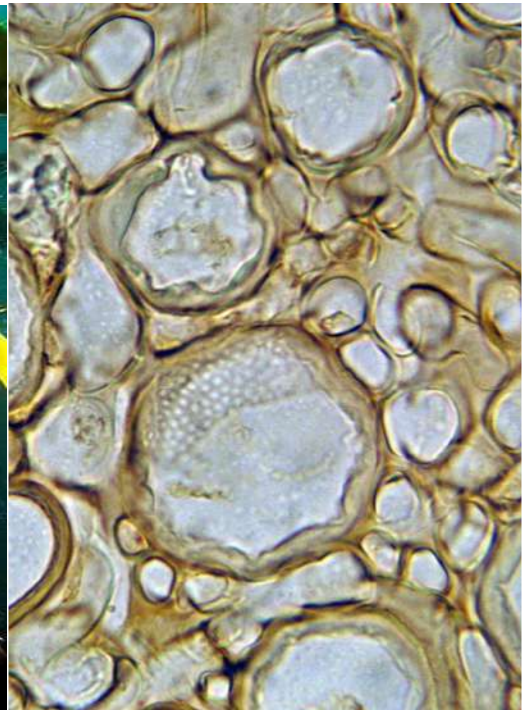
- **Pseudoparenchyma**: this forms when the degree of compaction of plant filaments or fungal hyphae is so great that individual filaments or hyphae are no longer recognisable (= superficially, it resembles plant parenchyma). Examples of pseudoparenchymatous structures are certain parts of the fruiting bodies (mushrooms, toadstools, etc.) of many fungi, and the leaf-life (lamellar) and corticated thalli of certain red and brown algae.





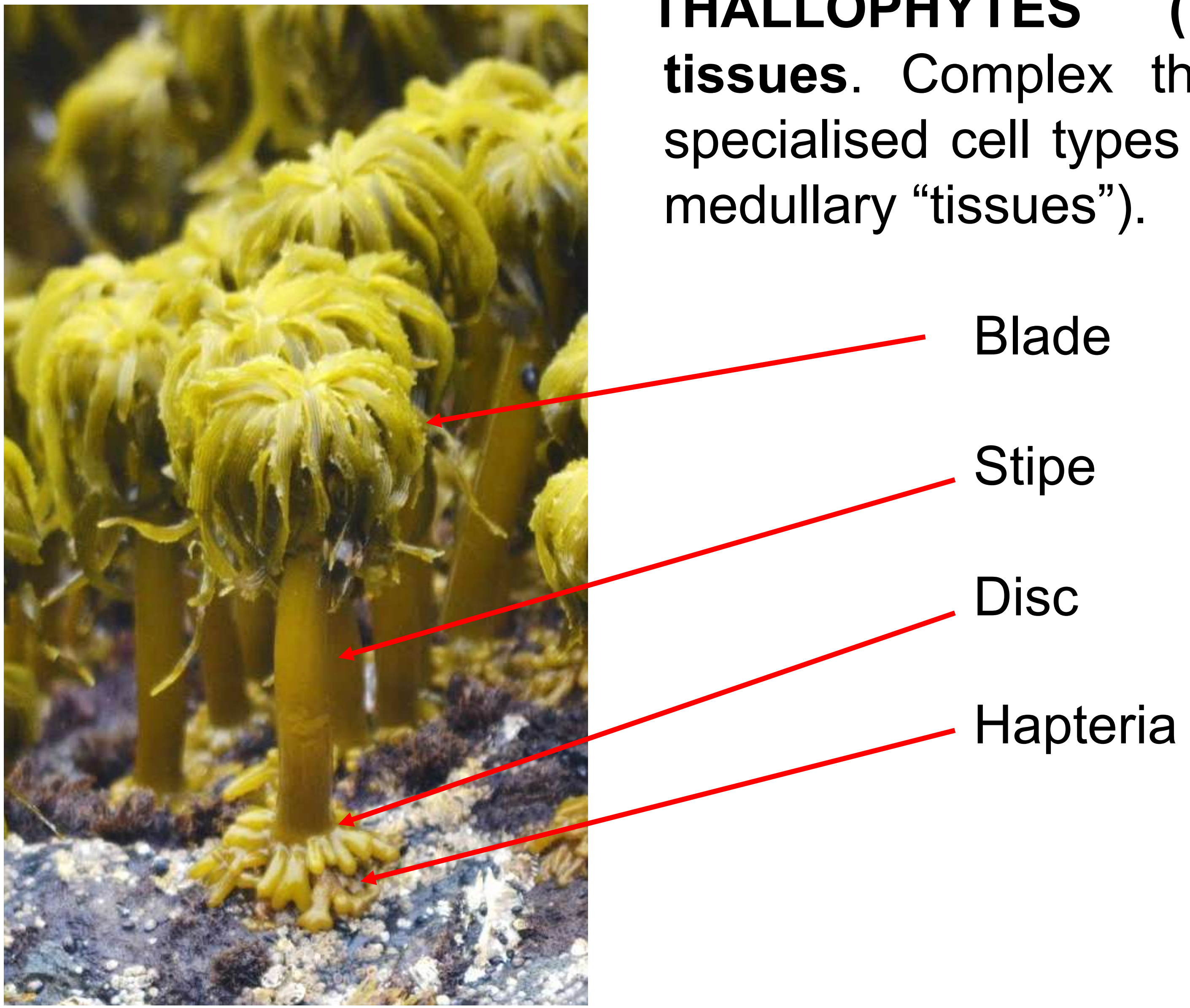
Structural complexity in plants and fungi

THALLOPHYTES (VI) with **authentic tissues**. Complex thalli that display some specialised cell types (insulating, cortical and medullary "tissues").



Structural complexity in plants and fungi

THALLOPHYTES (VI) with **authentic tissues**. Complex thalli that display some specialised cell types (insulating, cortical and medullary “tissues”).



These thalli often show more complex structures that can be observed by the naked eye.

Postelsia palmaeformis (*Phaeophyceae*, brown alga)

Structural complexity in plants and fungi

BRYOPHYTES:

- are mostly terrestrial
- have simple organisation
- lack complex transport systems (sometimes hydroids and leptoids)
- are **poikilohydric** and many of them are tolerant to desiccation

Organisms with a bryophyte level of organisation belong to terrestrial plants (embryophytes)

Structural complexity in plants and fungi

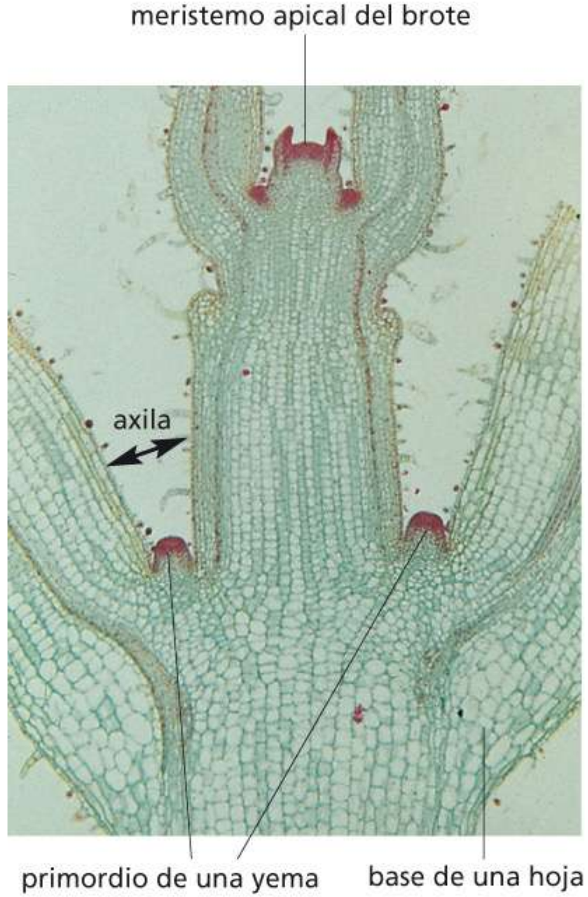
CORMOPHYTES: these structurally complex organisms are mostly terrestrial. Their body comprises:

- the root (*raíces*)
- the shoot (*vástago*):
  - the stem (*tallo*)
  - leaves (*hojas*)

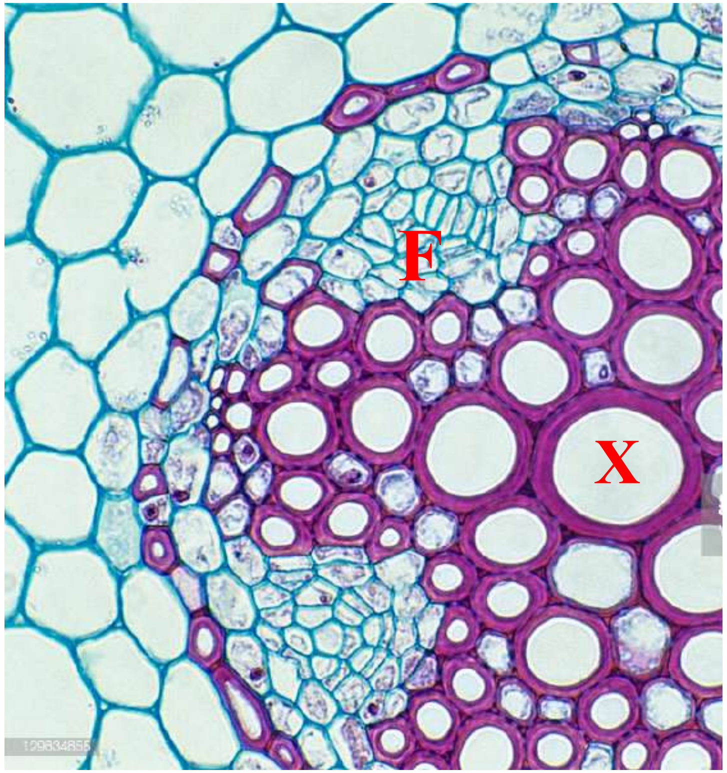
Structural complexity in plants and fungi

CORMOPHYTES: these are the most complex plants. They have a complicated inner structure and organs made up of different tissues. In addition, they:

- are **homeohydric** and dominate terrestrial ecosystems
- have **conductive systems** (xylem and phloem; the former is **lignified**)
- are named **VASCULAR plants (**because of these conductive systems)
- have embryonic tissue regions called **meristems**.



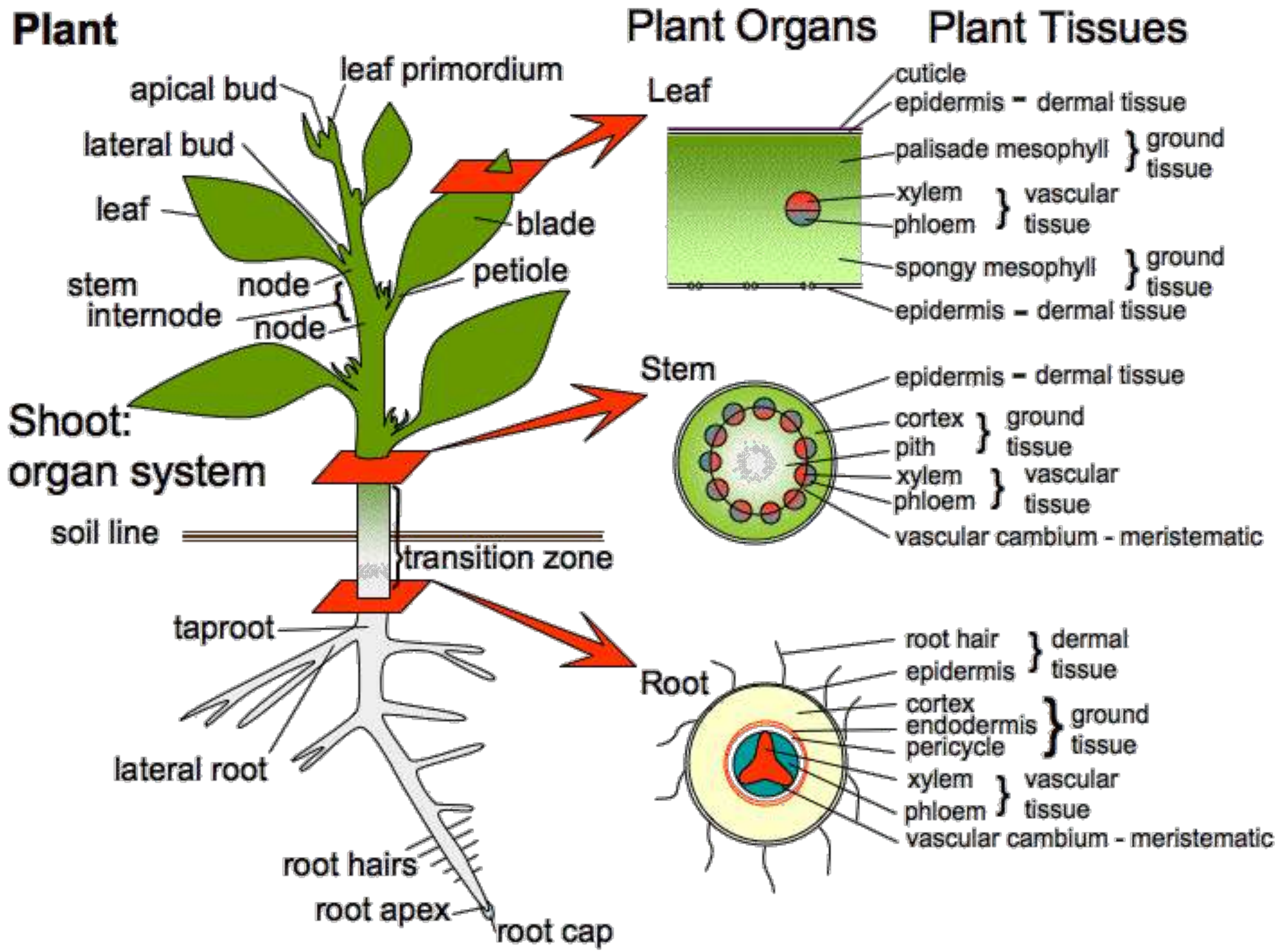
Unlike animals, plants continue to grow throughout their lives.



Vascular cylinder of a primary root of *Ranunculus* sp.

Structural complexity in plants and fungi

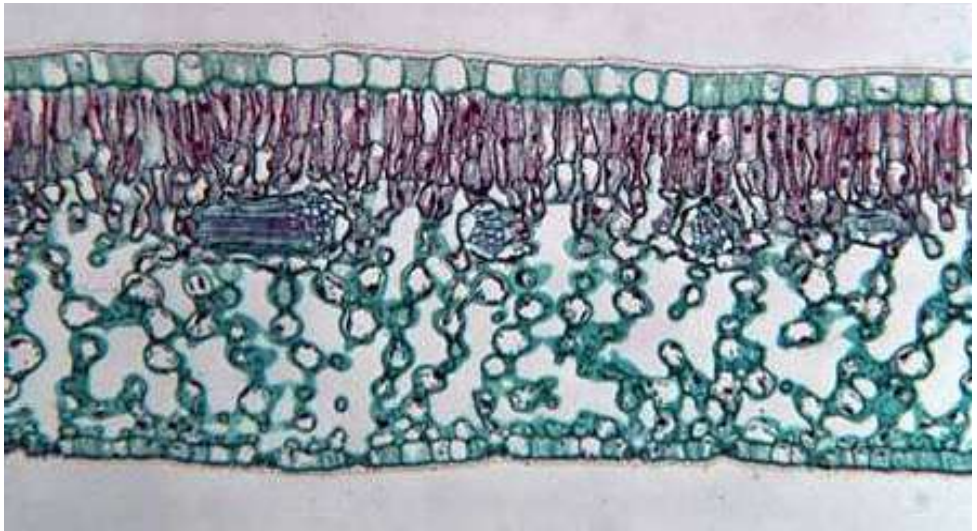
CORMOPHYTES: typical organs and tissues of a plant

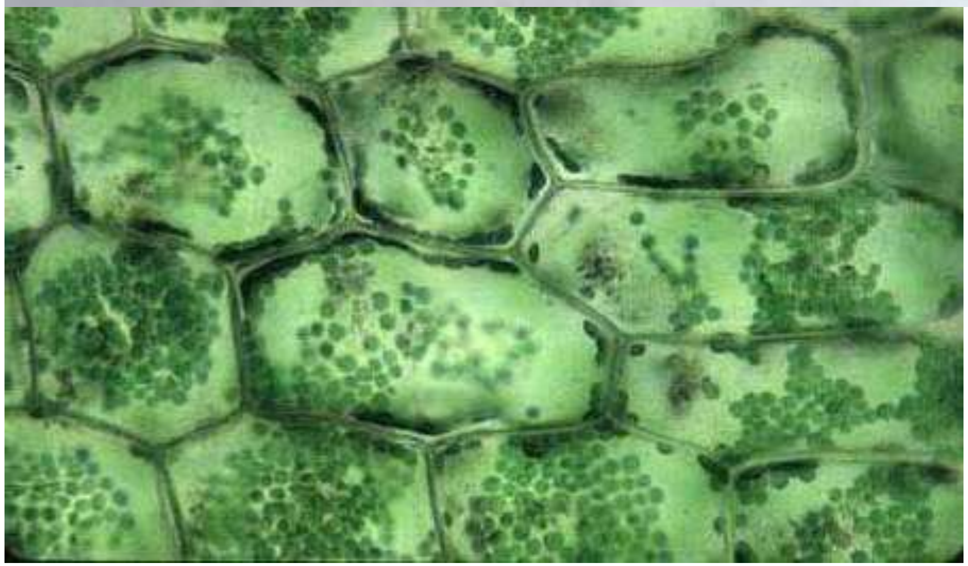


Structural complexity in plants and fungi

CORMOPHYTES: mature tissues (examples with **pharmaceutical importance**):

a) Parenchyma: poorly differentiated cells that perform various functions (e.g. photosynthetic [palisade, spongy]; reservoirs (water, starch, etc.)





b) Secretory cells and tissues:

- glandules
- nectaries
- laticiferous vessels
- resin channels
- oil glands of *Citrus*

Structural complexity in plants and fungi

CORMOPHYTES include:

Seed plants (Spermatophytes)

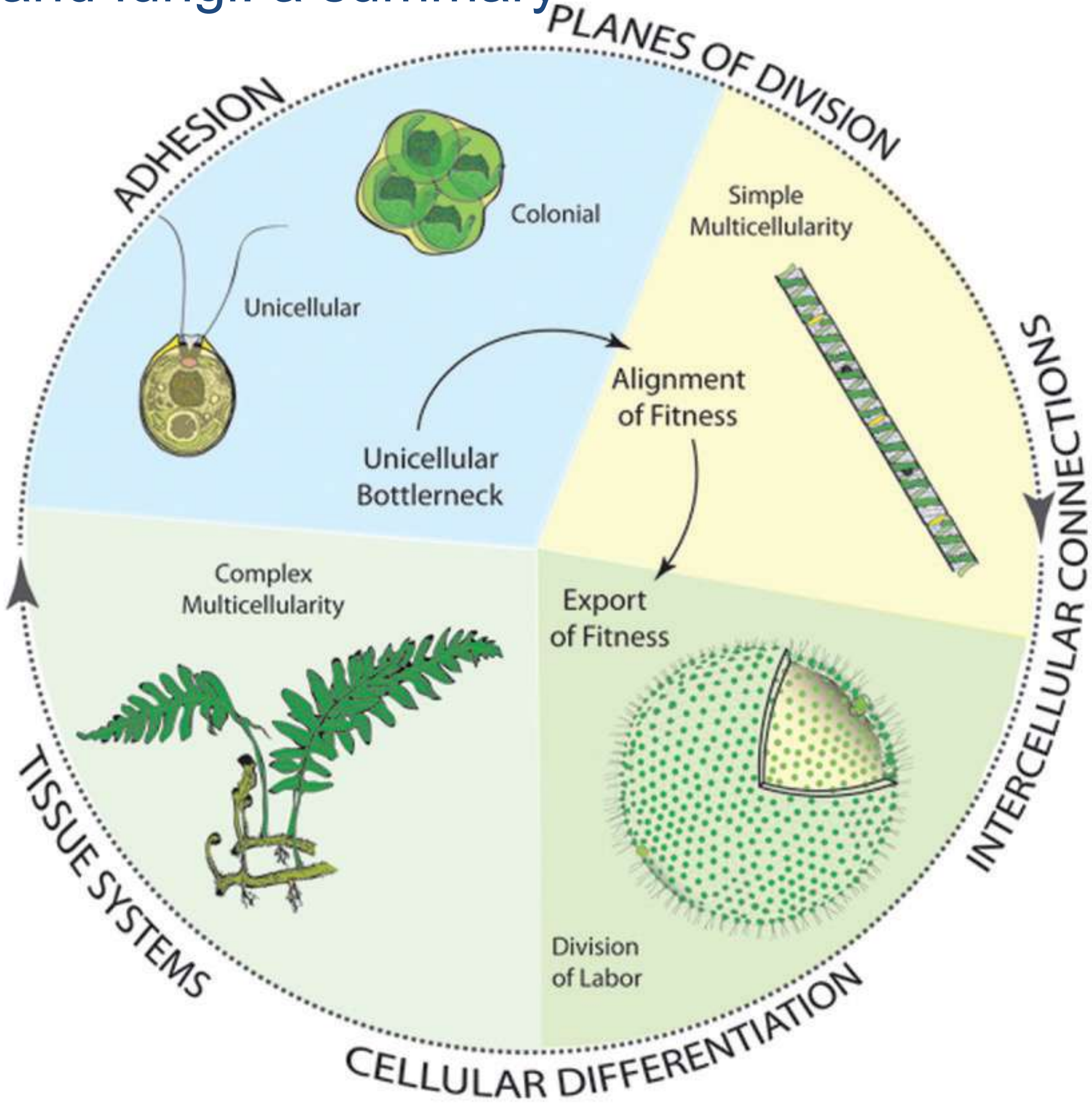
Pteridophytes (ferns s.a.)

Gymnosperms

Angiosperms

Structural complexity in plants and fungi: a summary

"The standard model for a unicellular-to-multicellular transition involves a colonial body plan intermediate, a unicellular bottleneck, and an export of fitness from the cellular to the multicellular level of organization. The taxa shown in this image are not phylogenetically closely related and are used only to illustrate key innovations."
From Niklas & Newman (2020)



Further reading: Niklas, K. J., & Newman, S. A. (2020). The many roads to and from multicellularity. *Journal of Experimental Botany*, *71*(11), 3247-3253.

Structural complexity in plants and fungi: a summary

Fungi

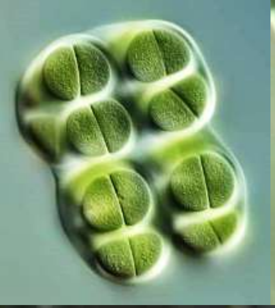
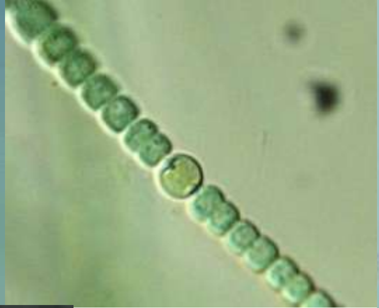
- Protophytes (unicellular)
- Thallophytes (filamentous-siphonous, plectenchymatous, pseudoparenchymatous)

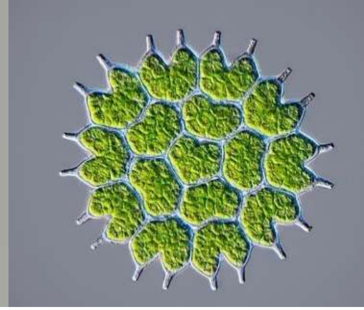
- Protophytes (unicellular)
- Protophytes (colonial)
- Protophytes (coenobial)
- Thallophytes (cell colonies)
- Thallophytes (filamentous-siphonous, siphonocladous)
- Thallophytes (pseudoparenchymatous)
- Thallophytes (parenchymatous, authentic tissues)

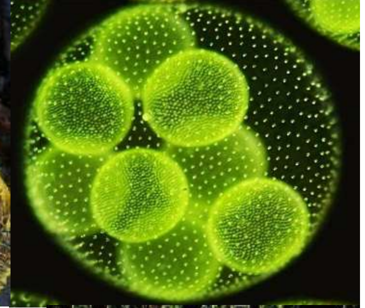
"Algae"

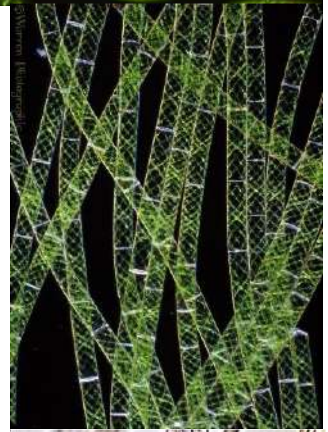
Vascular plants

Cormophytes

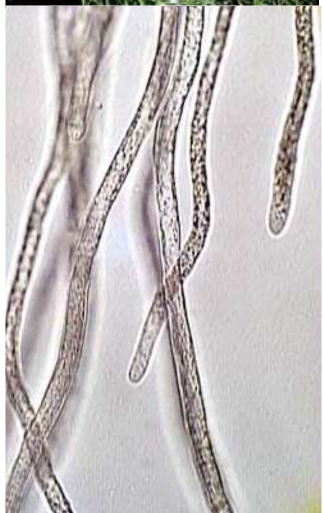
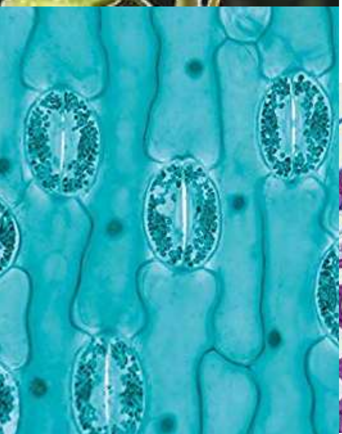
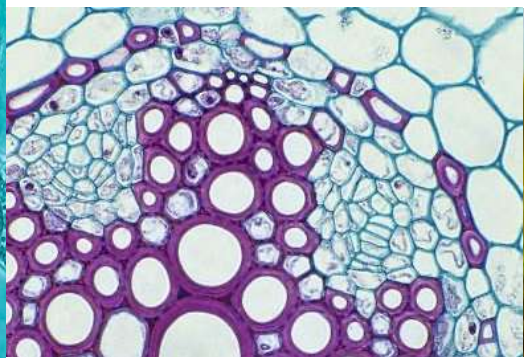



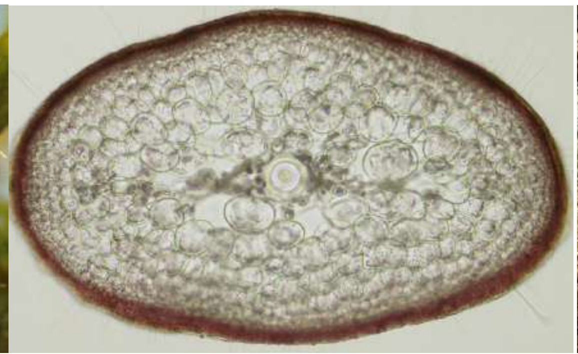







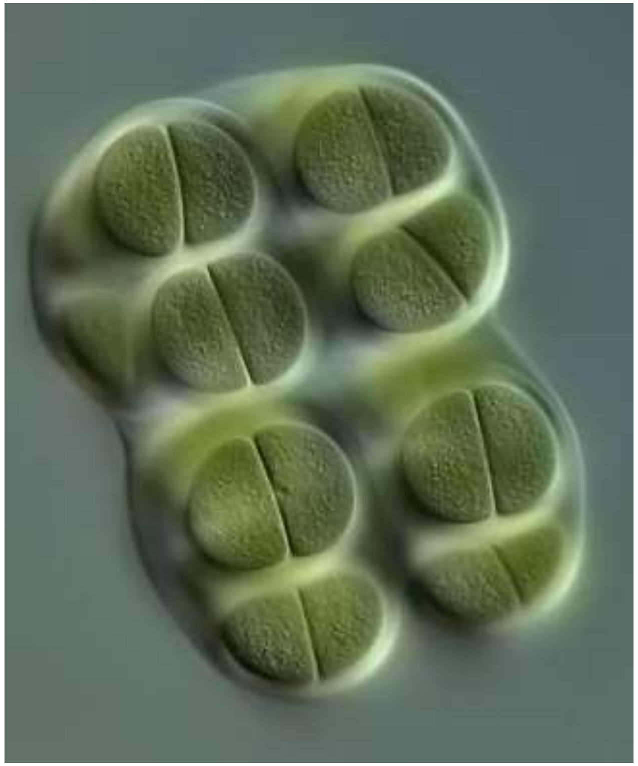
Lecture 02
part 2
Endosymbiosis

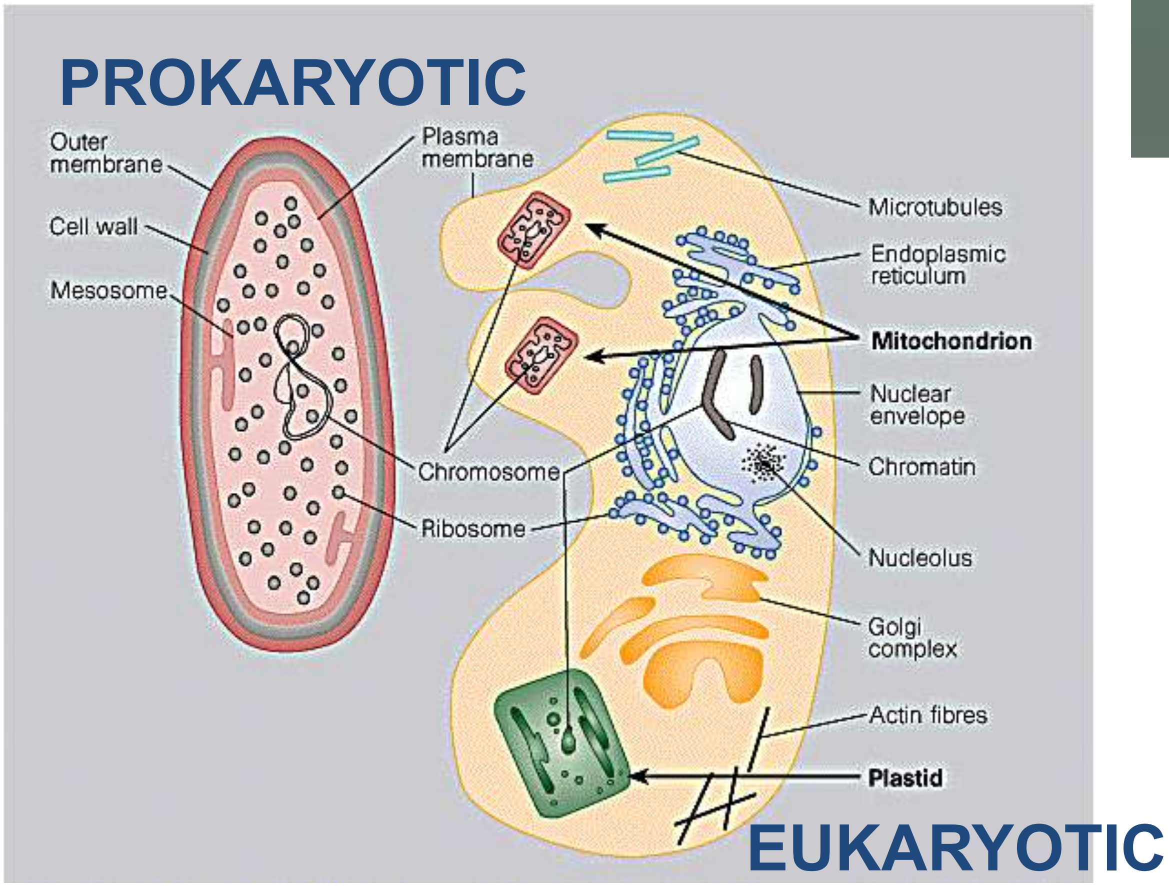



Prokaryotes and Eukaryotes

All living beings are made up of prokaryotic or eukaryotic cells.



Choorococcus turgidus
(cyanobacteria)
Prokaryote



Spirogyra sp.
(green alga)
Eukaryote

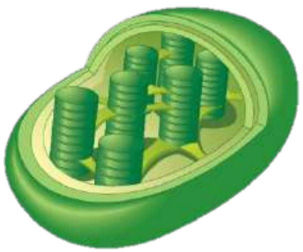
Symbiosis: "living together"

A permanent or long-lasting association between two or more species of organisms. These interspecific associations (or symbioses) occur when one or more species depend on each other for food, shelter or protection.

INTRACELLULAR

- Endocytosymbiosis: the origin of the eukaryotic cell containing organelles.

- Serial Endosymbiosis Theory (SET)
Mitochondria, chloroplasts and flagella are *transformed bacterial symbionts* that live within the host cell.



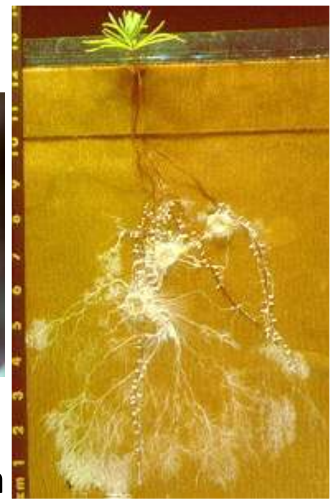
EXTRACELLULAR

Cells of the organisms remain separate, distinct.

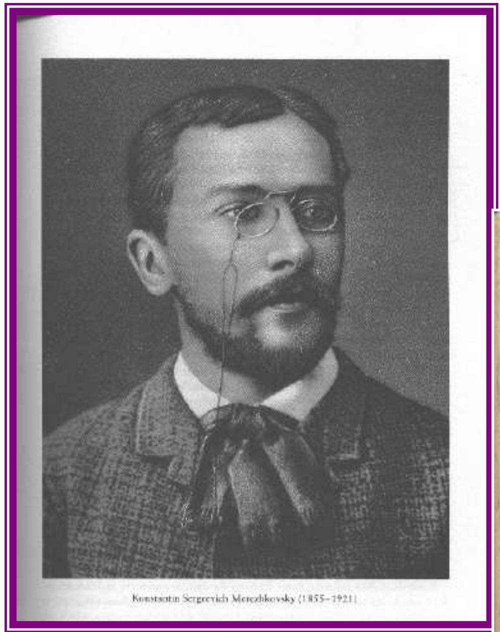
Ectosymbioses:
Carbon-fixing symbioses
- LICHENS
- MYCORRHIZAE

Endosymbioses
- rumen microorganisms
- fungal endosymbionts of insects

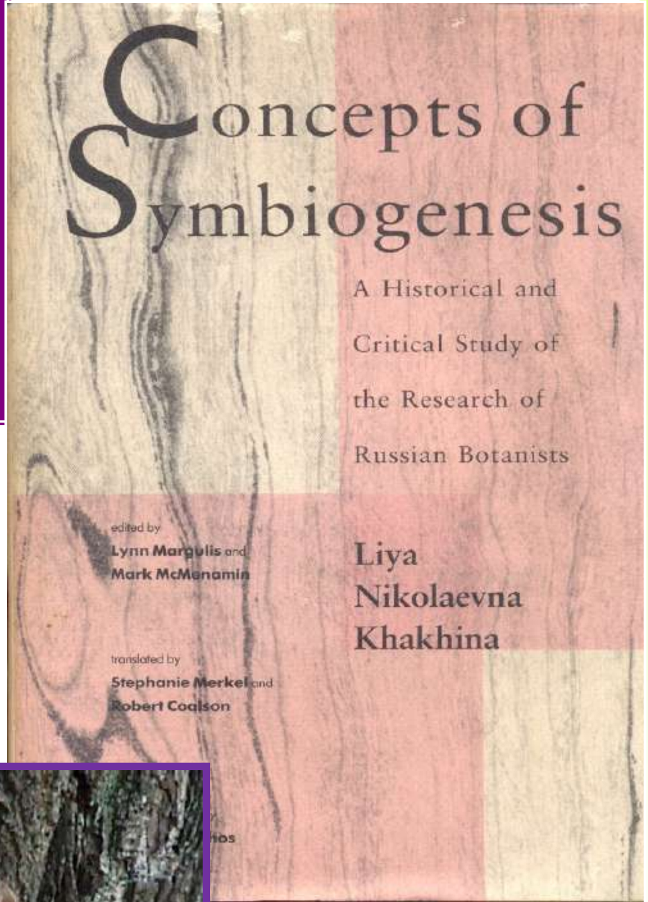
Lichen



Mycorrhiza



MEREZHKOWSKY



LYNN MARGULIS
University of Massachusetts Amherst

SYMBIOGENESIS

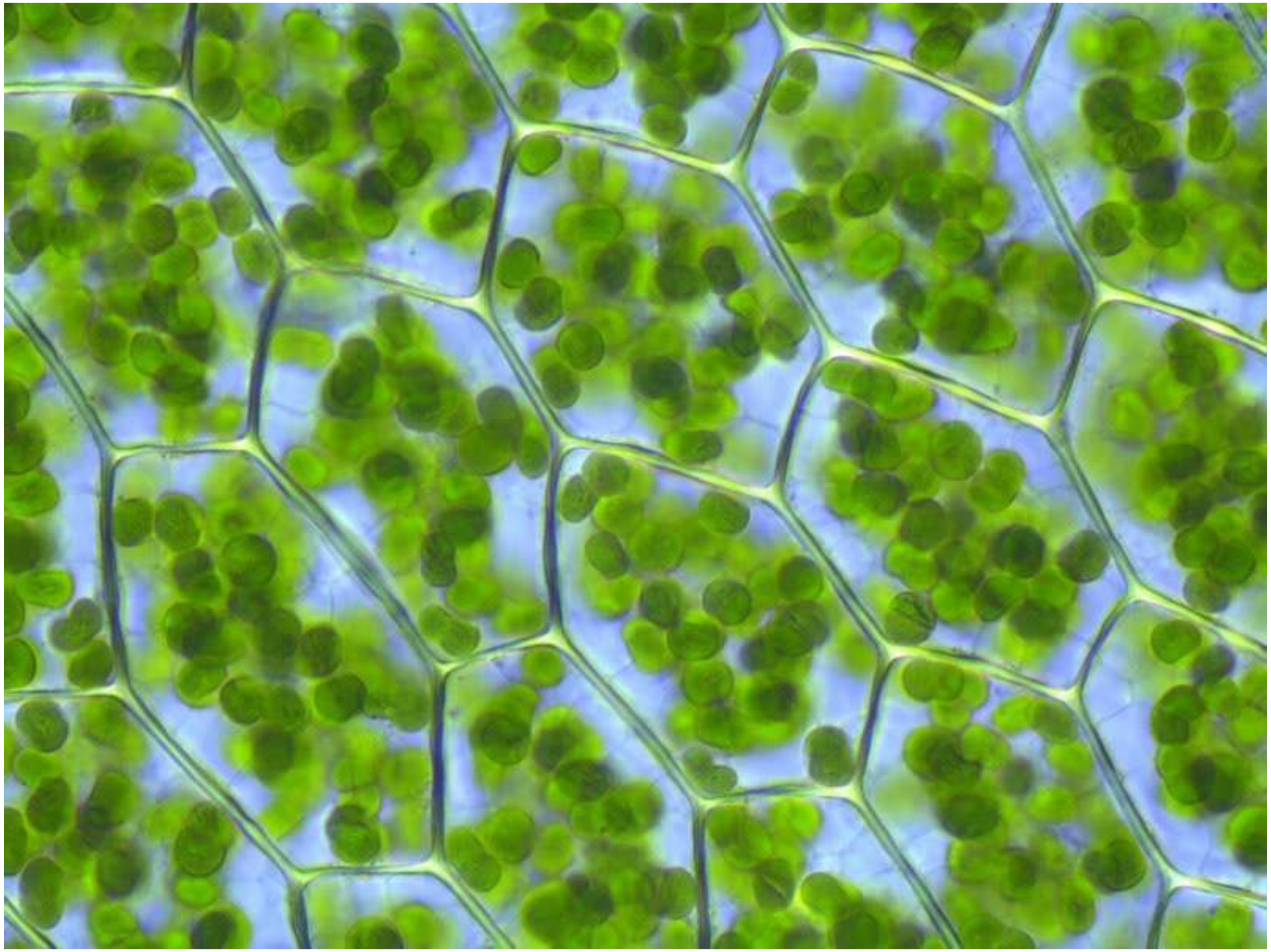
"EVOLUTIONARY INNOVATION" Re-interpreted by LYNN MARGULIS

* **Symbiogenesis** refers to the evolutionary origin of **new** MORPHOLOGIES (TISSUES, ORGANS) and PHYSIOLOGIES, and eventually **NEW SPECIES** of ORGANISMS, due to the **SYMBIOTIC INTERACTION** among **BIONTS** from **diverse** origins and kingdoms

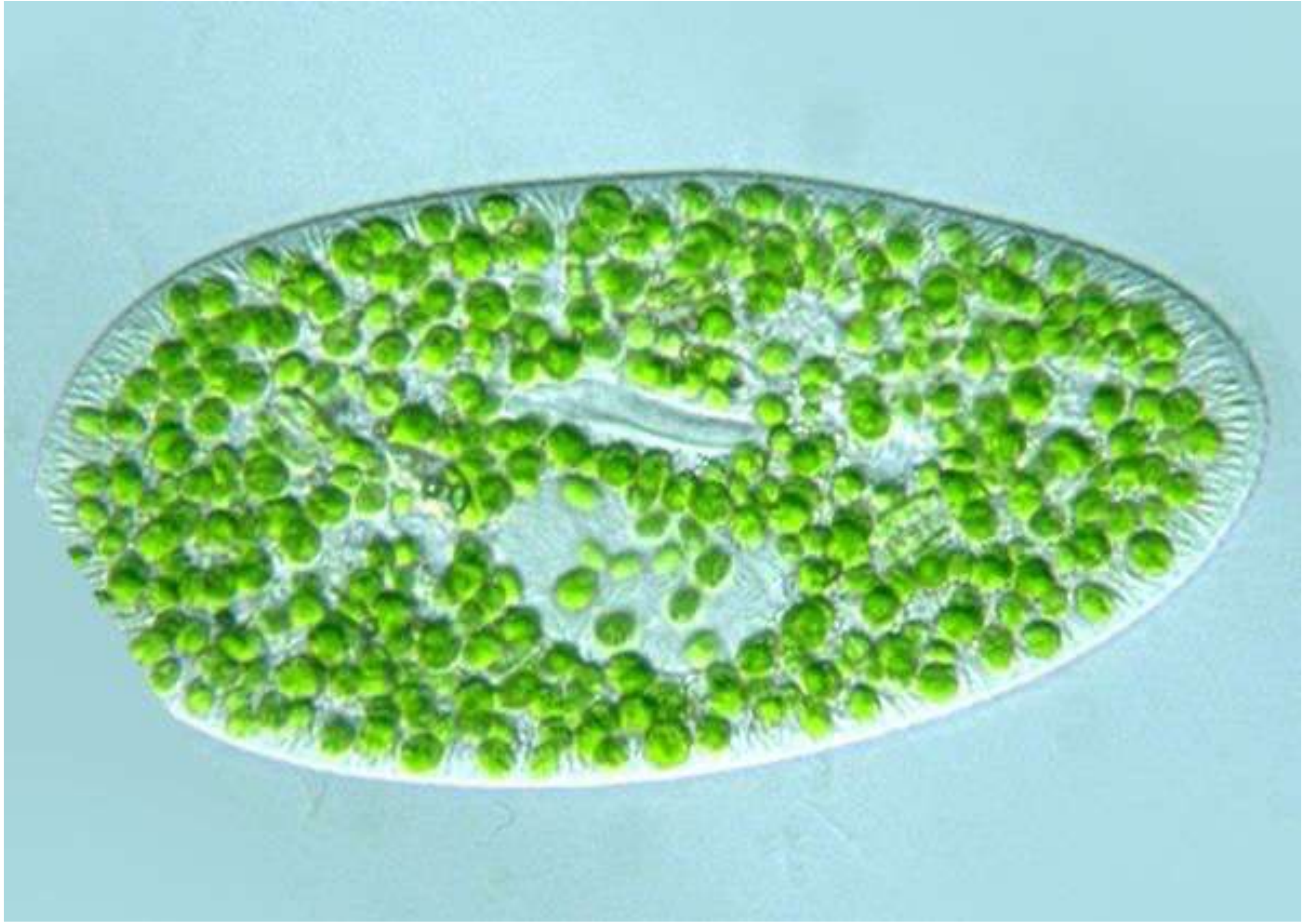
* **As a result,** an **HOLOBIONT** is generated**.** Example: a **lichen**.

Eukaryote organelles

The eukaryotic cell organelles **plastids** and **mitochondria** probably originated by **endosymbiosis** from prokaryotic organisms.

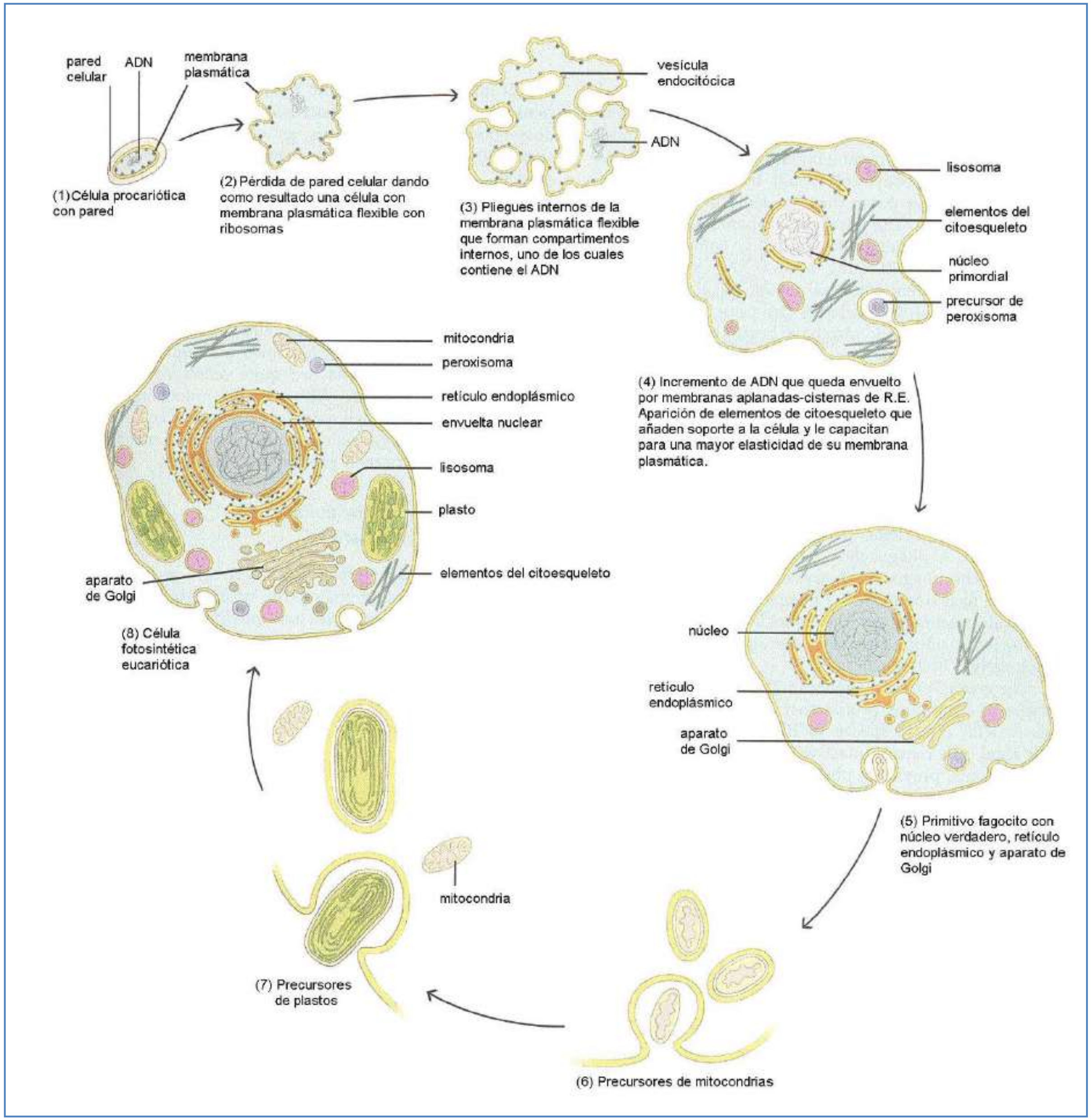


An early stage of endosymbiosis?



Paramecium bursaria is able to sustain green algae of the genus *Chlorella* for some time.

The origin of organelles and the Theory of Endosymbiosis



Illustrate of the possible origin of the eukaryotic cell and the process of endosymbiosis.

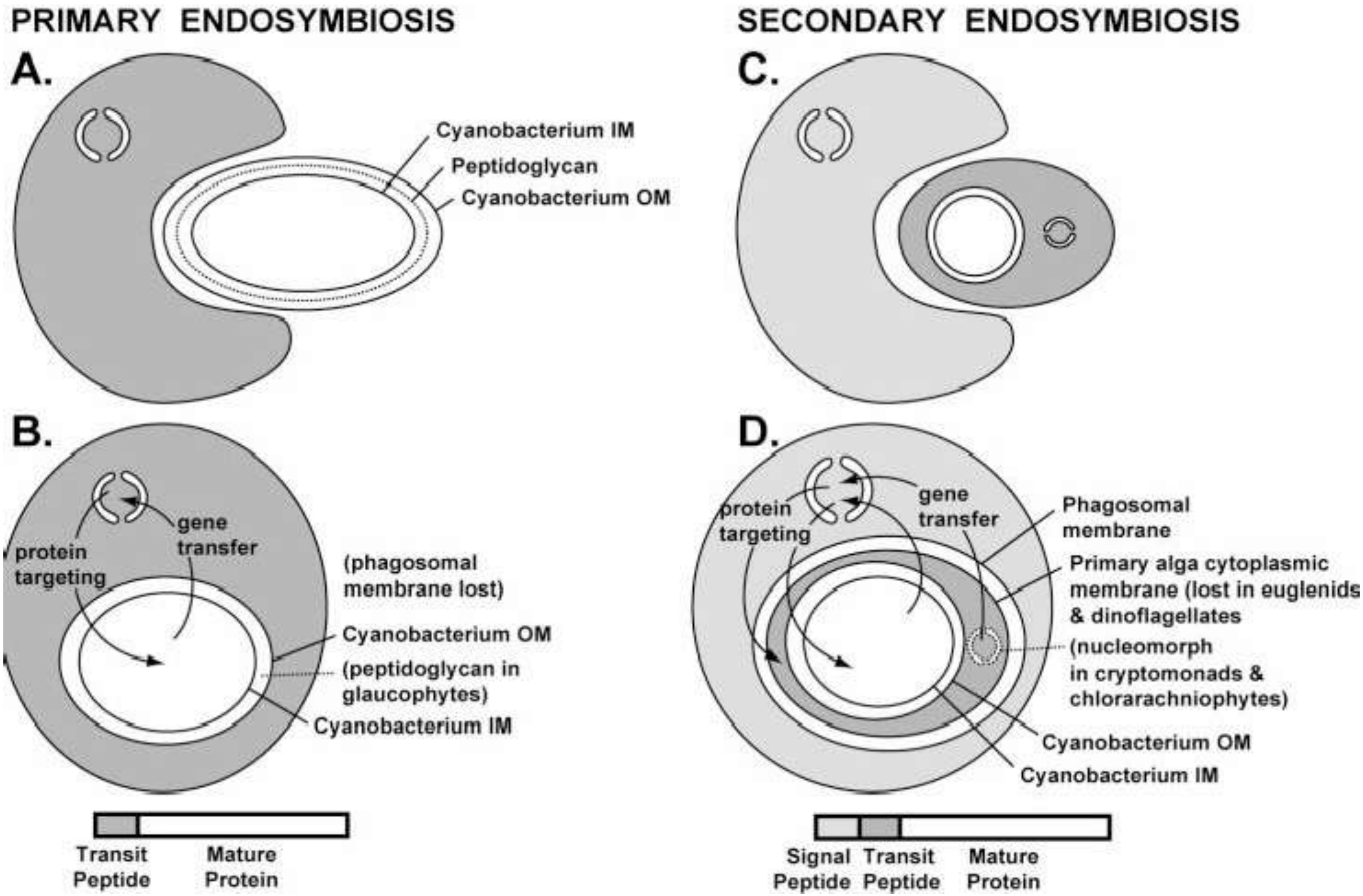
(Adapted from Raven et al., 1999: 230).

The origin of organelles and the Theory of Endosymbiosis

The characteristics of plastids and mitochondria support their symbiotic and prokaryotic origin:

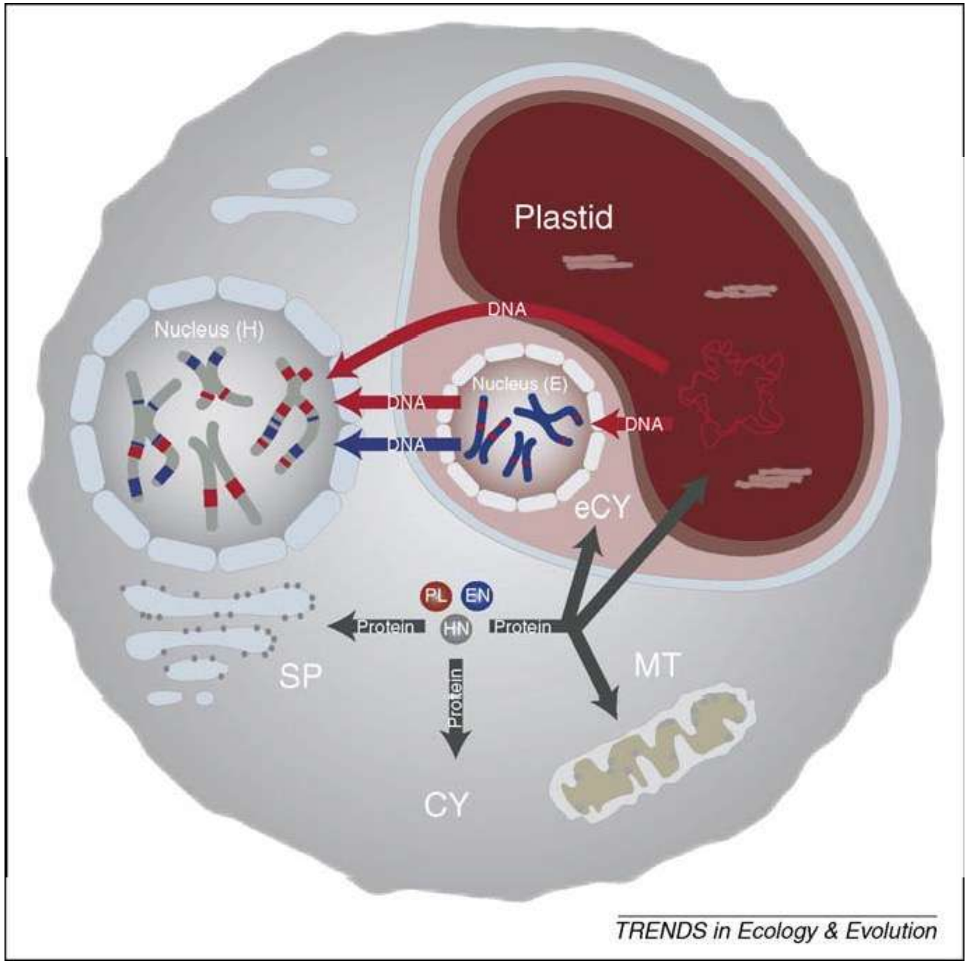
- they have a circular DNA molecule
- they divide by binary fission
- they have 70S prokaryotic ribosomes
- chloramphenicol inhibits protein synthesis

The origin of organelles and the Theory of Endosymbiosis



Keeling (2004, *American Journal of Botany* 91)

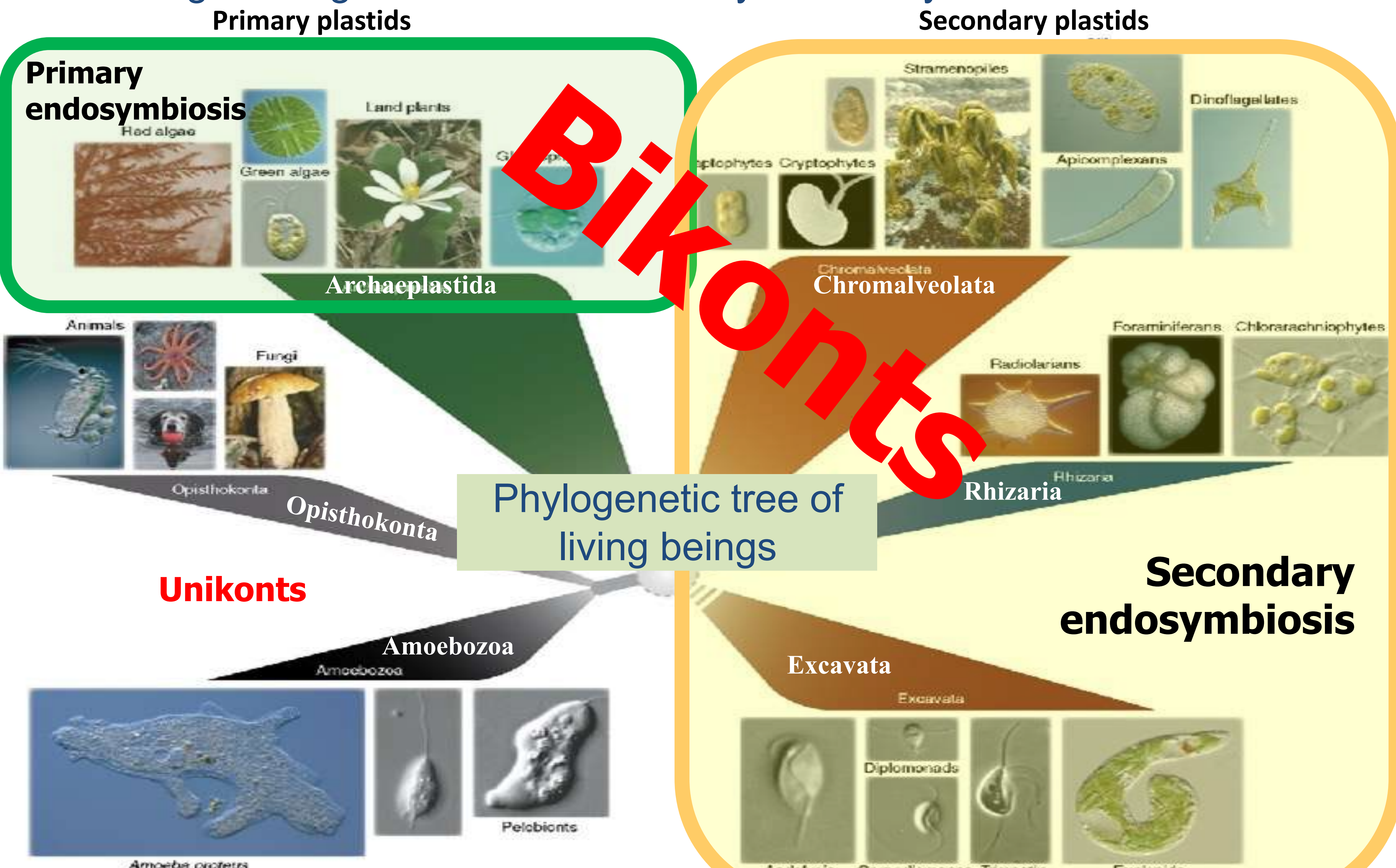
The origin of organelles and the Theory of Endosymbiosis



Endosymbiosis and genetic information flow in photosynthetic eukaryotes with plastids originating from secondary endosymbiosis.

PL = plastid; EN = endosymbiont; HN = host nucleus
(Adapted from: Lane & Archibald 2008; *Trends in Ecology and Evolution*).

The origin of organelles and the Theory of Endosymbiosis

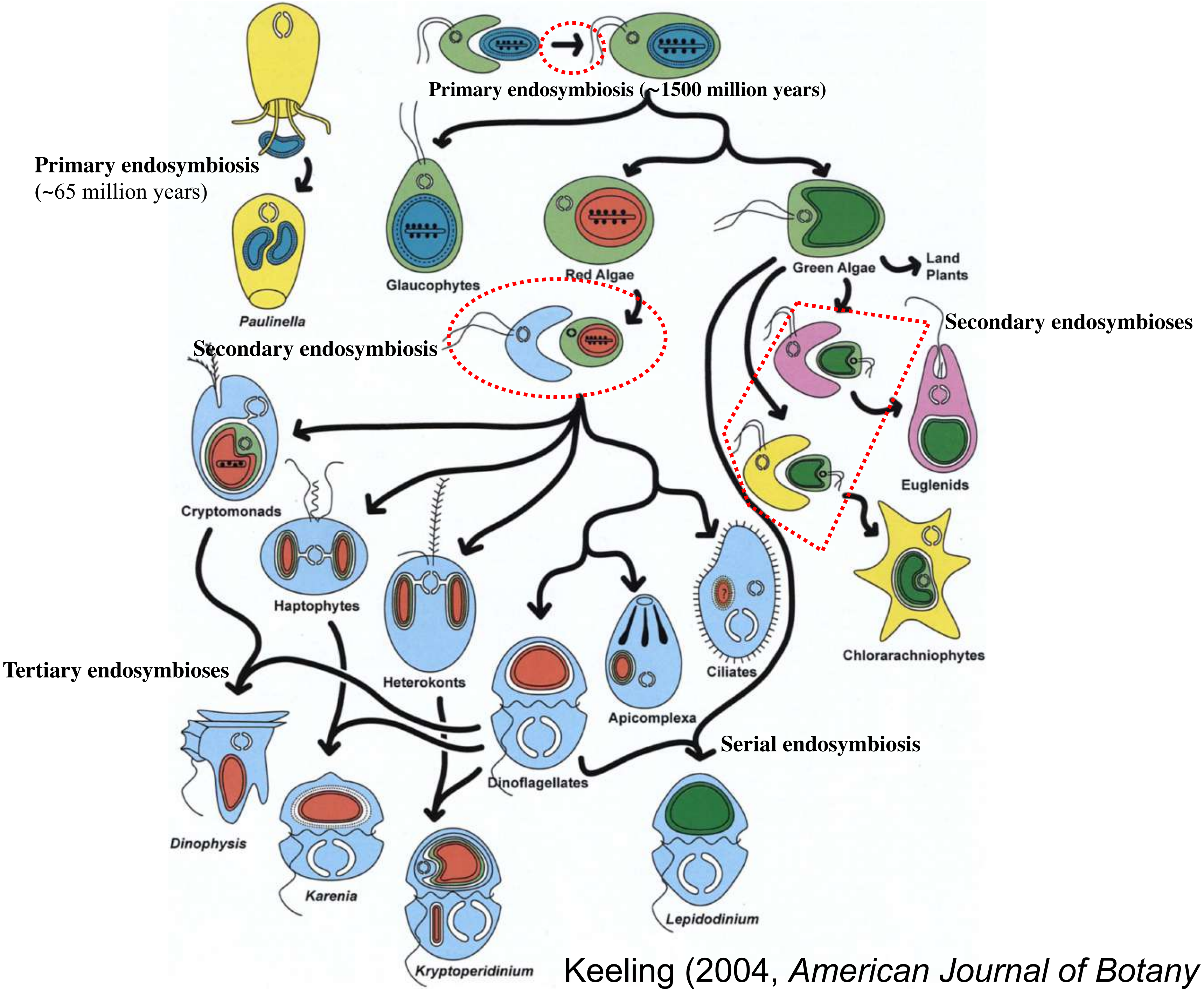


Lane & Archibald (2008) Trends in Ecology and Evolution

The origin of organelles and the Theory of Endosymbiosis

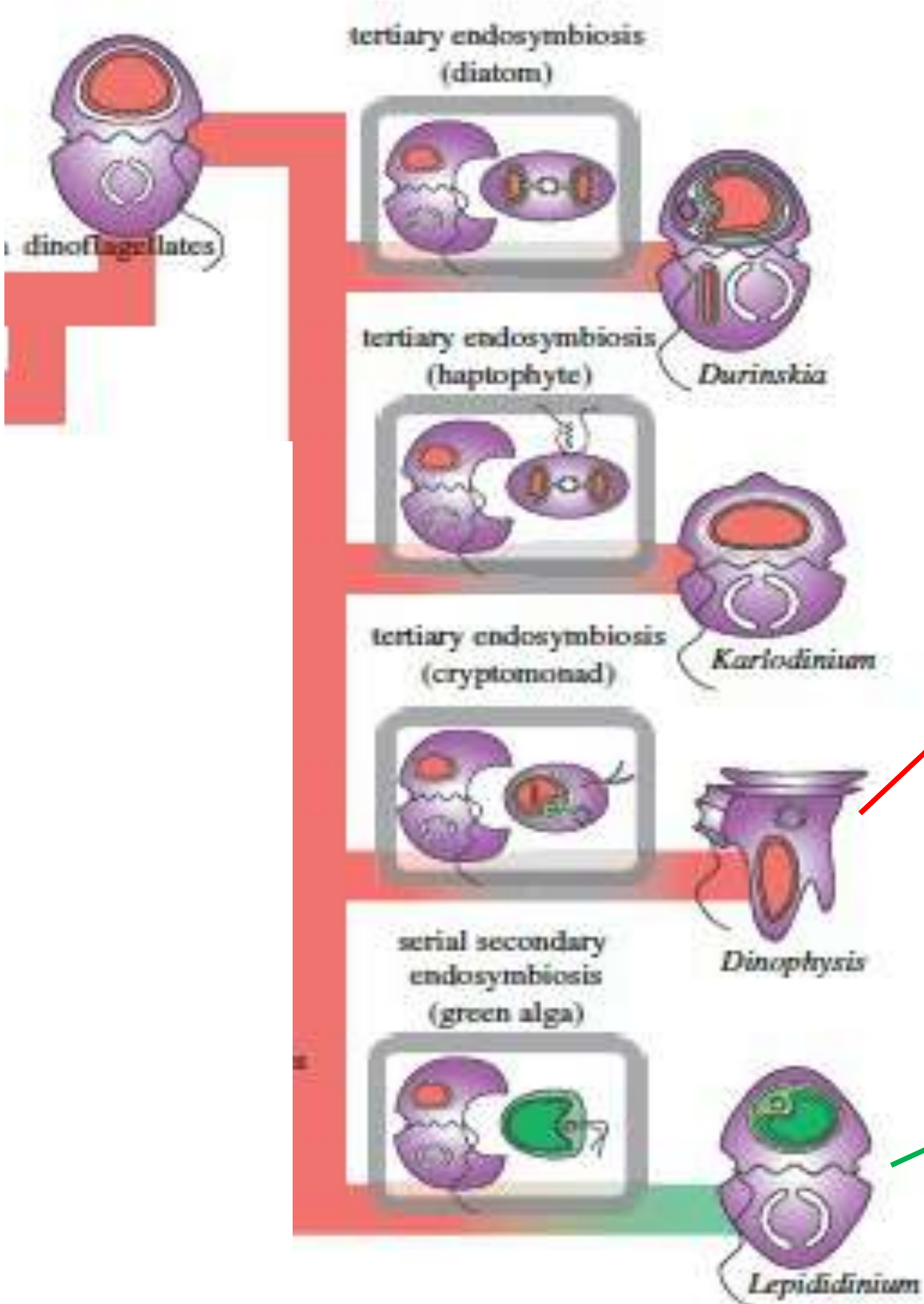
- Was primary endosymbiosis a single, random event?
- Has it taken place more times in the history of life?

Primary and secondary endosymbioses



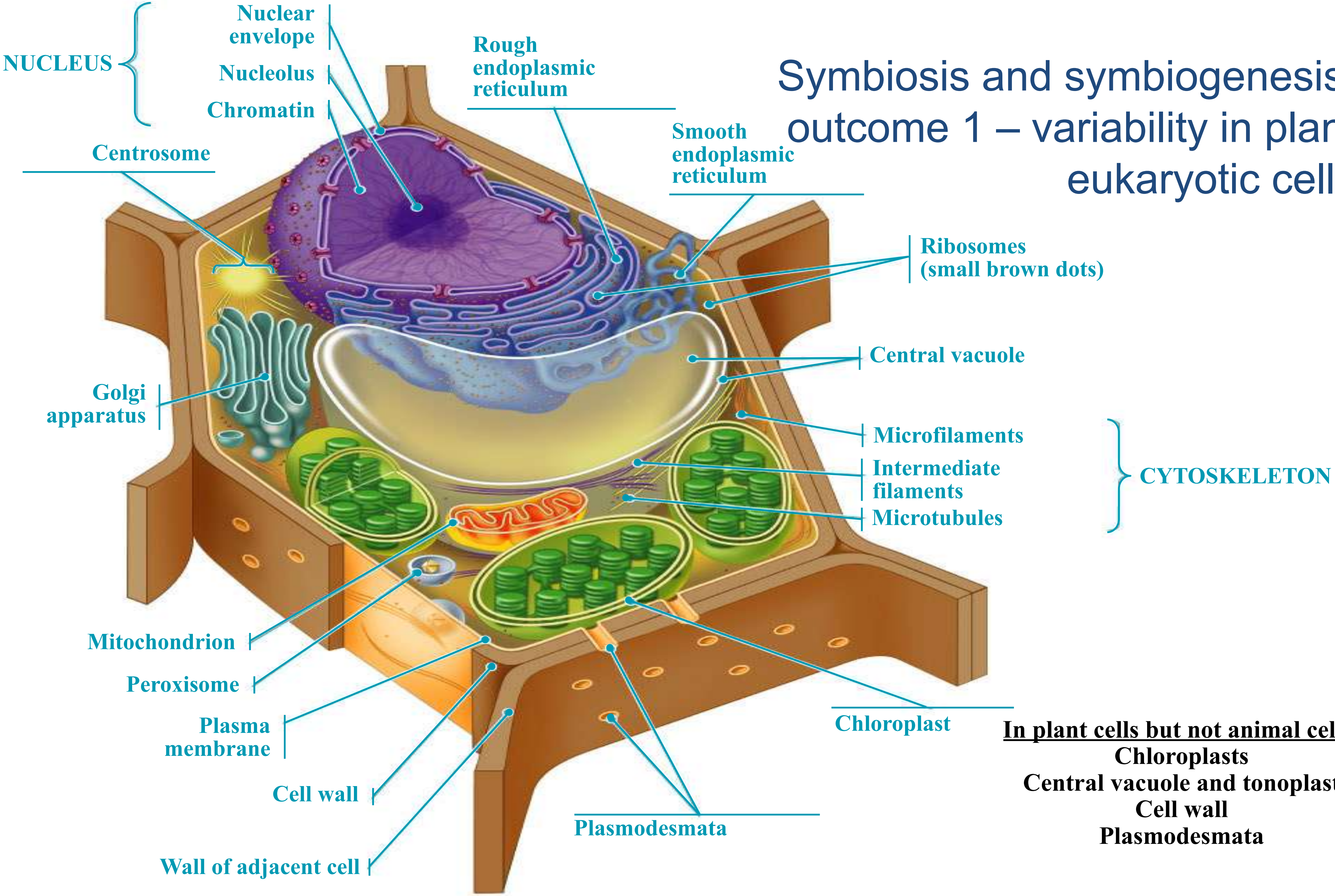
Keeling (2004, *American Journal of Botany* 91)

Tertiary and serial endosymbioses



Keeling (2004, *Philosophical Transactions B* 365)

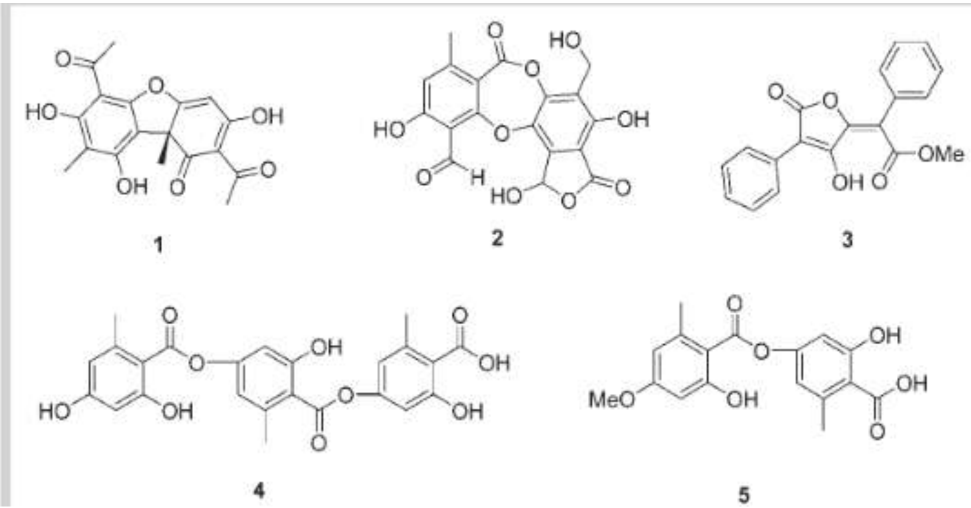
Symbiosis and symbiogenesis: outcome 1 – variability in plant eukaryotic cells



<u>In plant cells but not animal cells:</u>

Chloroplasts
Central vacuole and tonoplast
Cell wall
Plasmodesmata

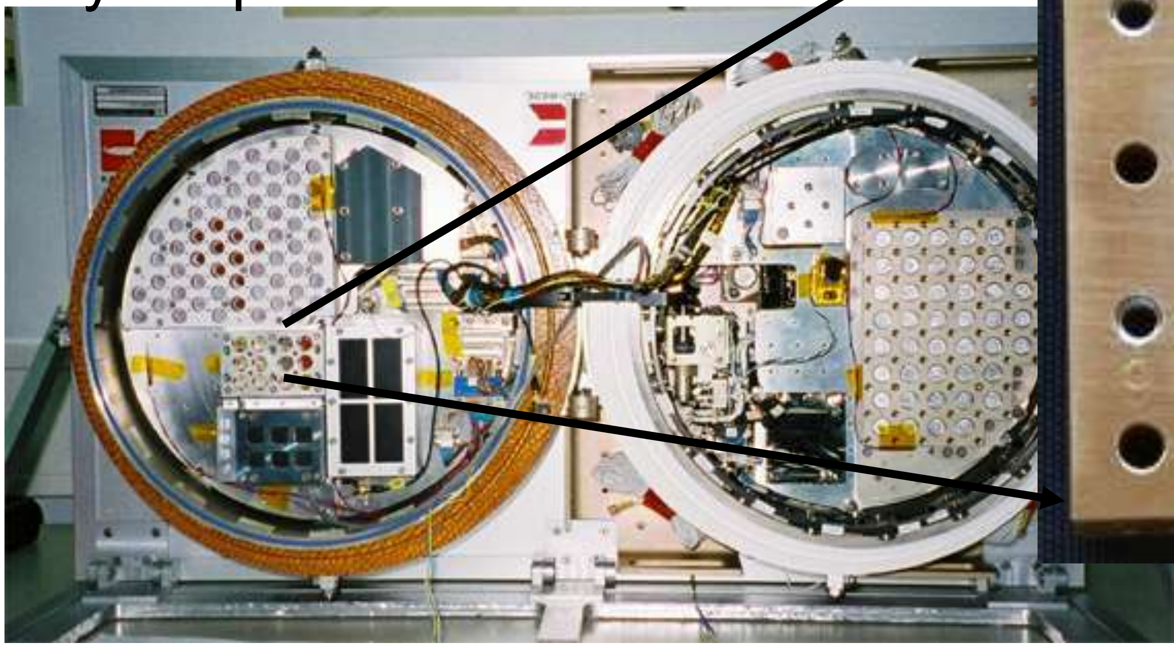
Symbiosis and symbiogenesis: outcome 2 – Lichens: fighting tumours and "Space Tourists"



Chemical structures of lichen compounds with **antiproliferative effects on tumour cells** (Burlando et al. 2008)

Touristic LICHEN samples

Soyuz spacecraft

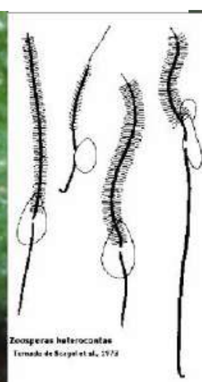


(Sancho et al. 2007, *Astrobiology*)

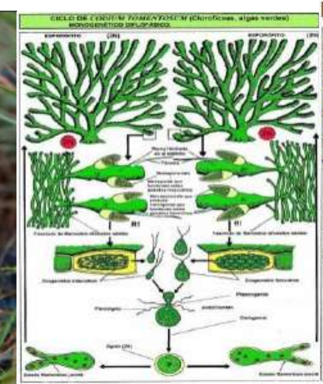
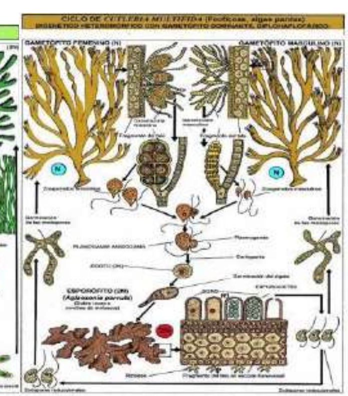
Lecture 02

part 3

Reproduction and life cycles in plants and fungi



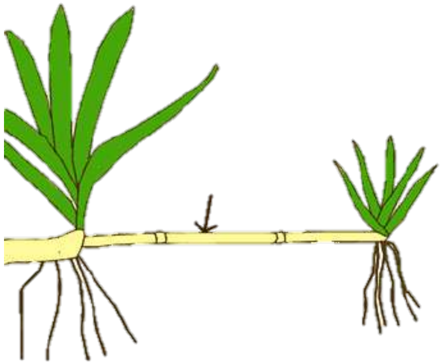



Reproduction in plants and fungi

One of the main traits of living beings is their ability to reproduce.

Types of reproduction

Asexual (vegetative propagation):

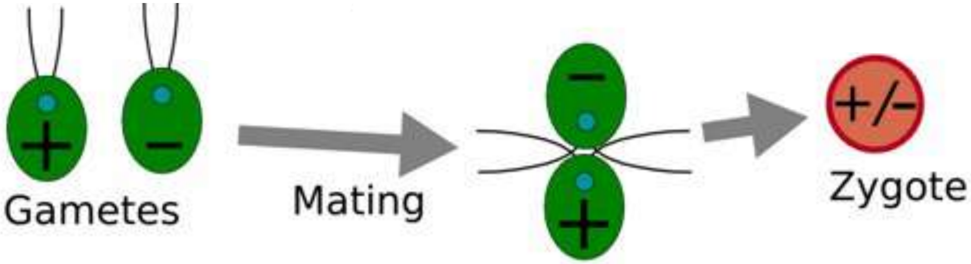


Only one individual is needed.

The individual’s genotype is conserved.

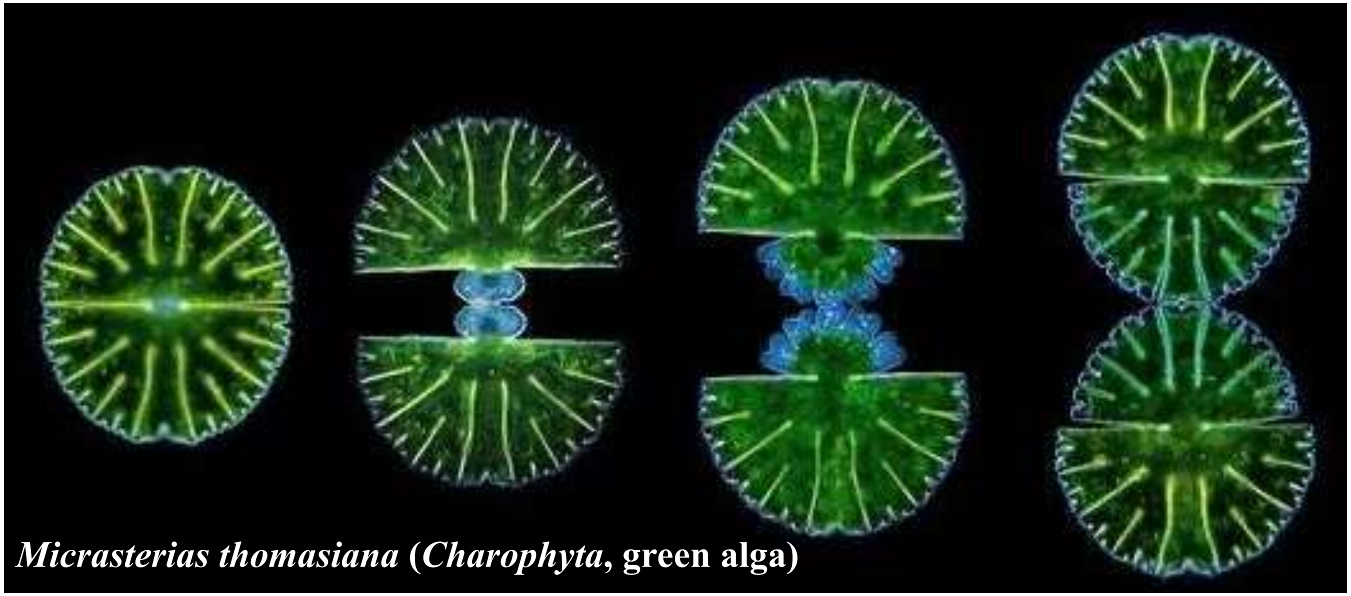
Each offspring is a clone of the initial organism.

Sexual: two reproductive cells give rise to a zygote whose genome is the sum of the genomes of the reproductive cells.

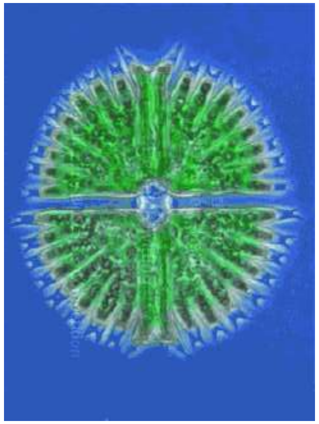


Asexual reproduction (vegetative propagation)

Cellular division (binary fission): this is the usual type of reproduction in single-celled organisms. Two cells are obtained that are identical to each other and identical to the individual from which they originated.



Micrasterias thomasiana (*Charophyta*, green alga)



Asexual reproduction (vegetative propagation)

- **Fragmentation**: in many plants and fungi (multicellular organisms), a fragment of the thallus or a poorly differentiated part of a woody plant can regenerate a whole individual.

- This form of reproduction is used in agriculture and gardening.

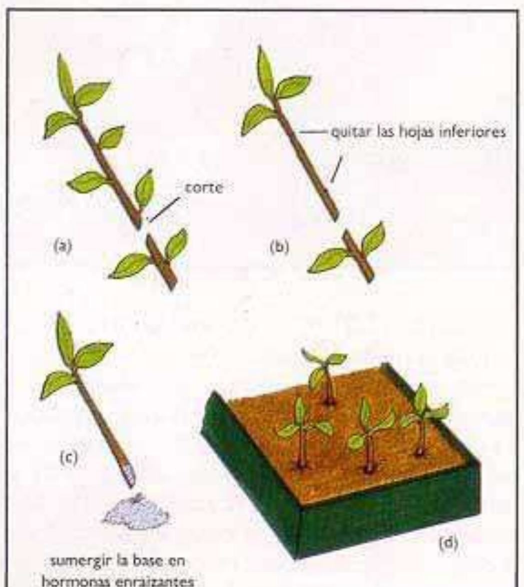


Fig. 10 No utilizar nunca retoños con flor como esquejes.

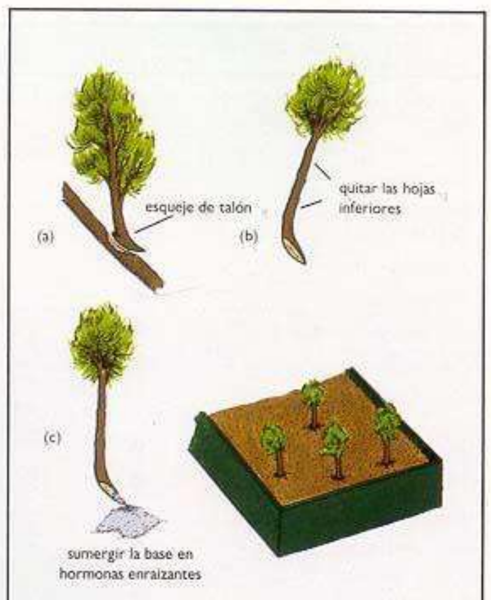


Fig. 11 La mayoría de los esquejes semimaduros enraizarán sin calefacción interior.

Asexual reproduction (vegetative propagation)

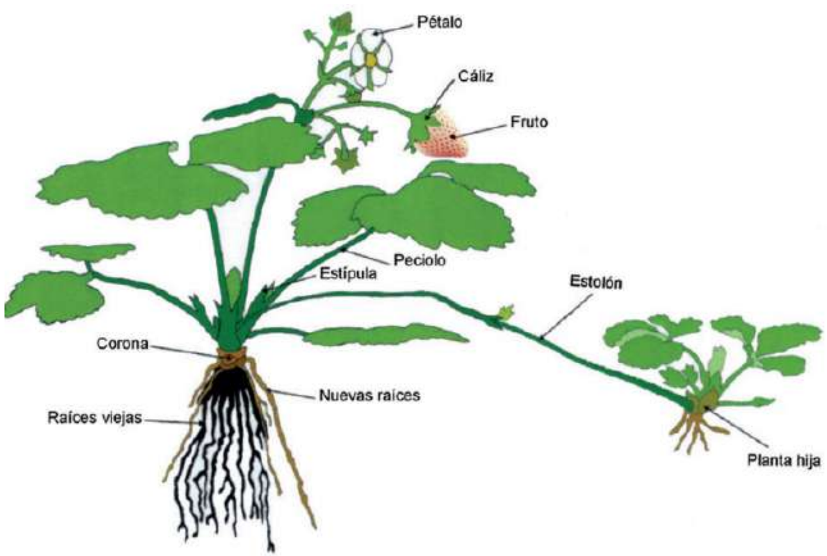
- Production of specialised structures
  Propagules **(sing. propagule)**

Lunularia cruciata
Bryophyte, liverwort

Marchantia polymorpha Bryophyte, liverwort

Asexual reproduction (vegetative propagation)

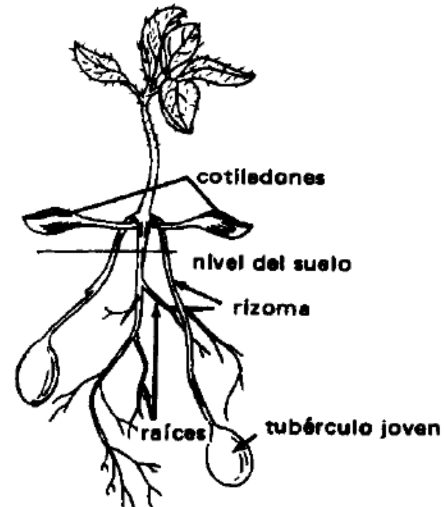
- **Runners or stolons**: these are long, slender stems that grow along the surface of the soil. In cultivated strawberry, leaves, flowers, and roots are produced at every other node on the runner. Just beyond the second node, the tip of the runner turns upwards and thickens. This thickened portion first produces adventitious roots and then a new shoot, which constitutes the runner.



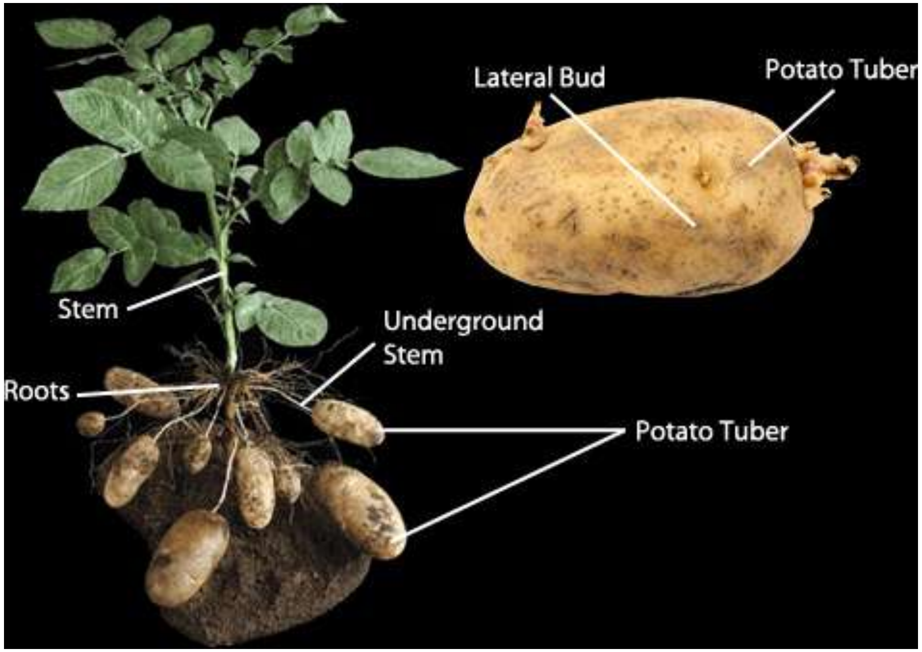
Fragaria vesca (*Rosaceae*) (strawberry)

Asexual reproduction (vegetative propagation)

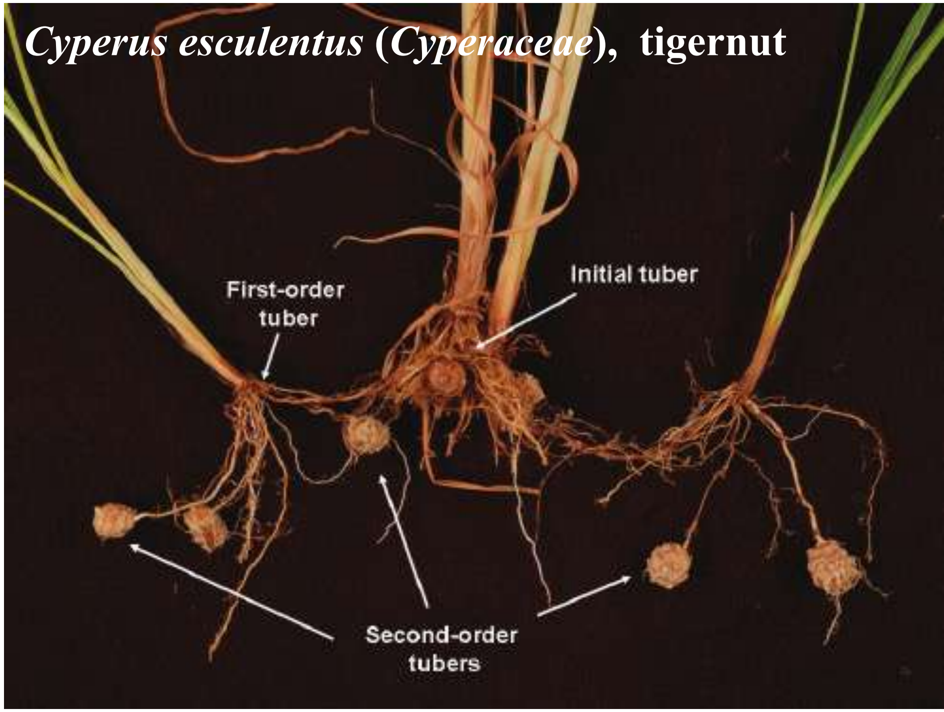
- **Tubers**: with some plants, long-lasting structures form underground. In the potato, this structure is the stem.



Patatera. Tomado de Rost et al., 1985



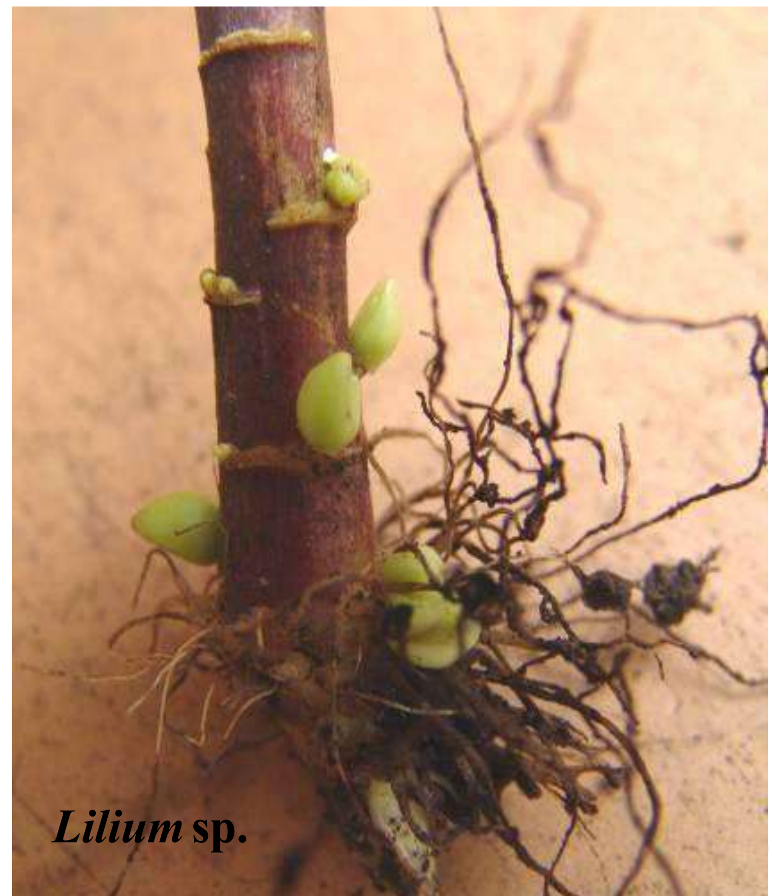
***Solanum tuberosum* (*Solanaceae*), potato**



Asexual reproduction (vegetative propagation)

- **Bulbils**: these are small buds that form in the axils of the phylidia of certain mosses and on the leaves or stems of certain vascular plants.

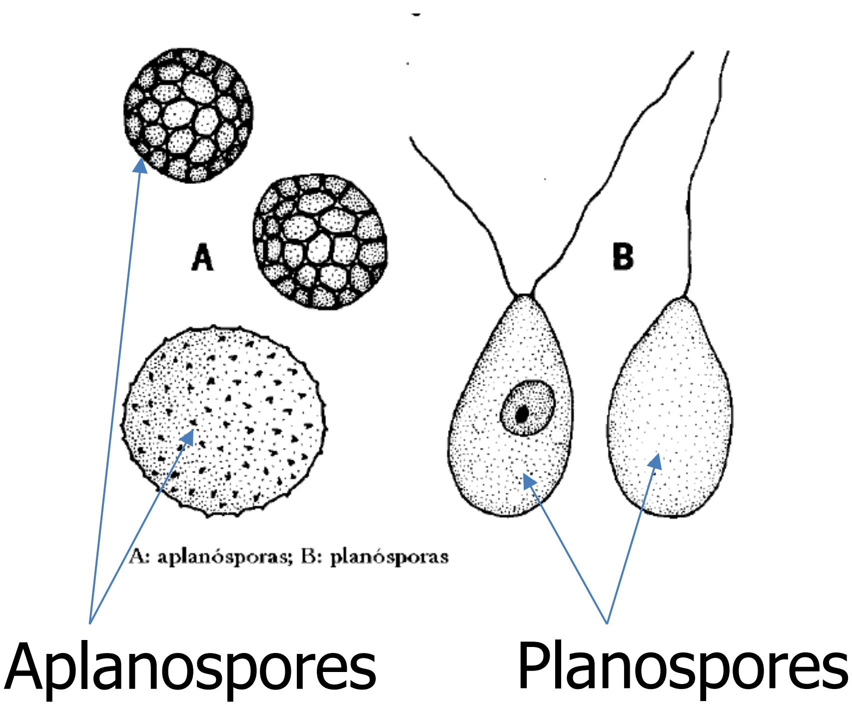
Kalanchoe daigremontiana

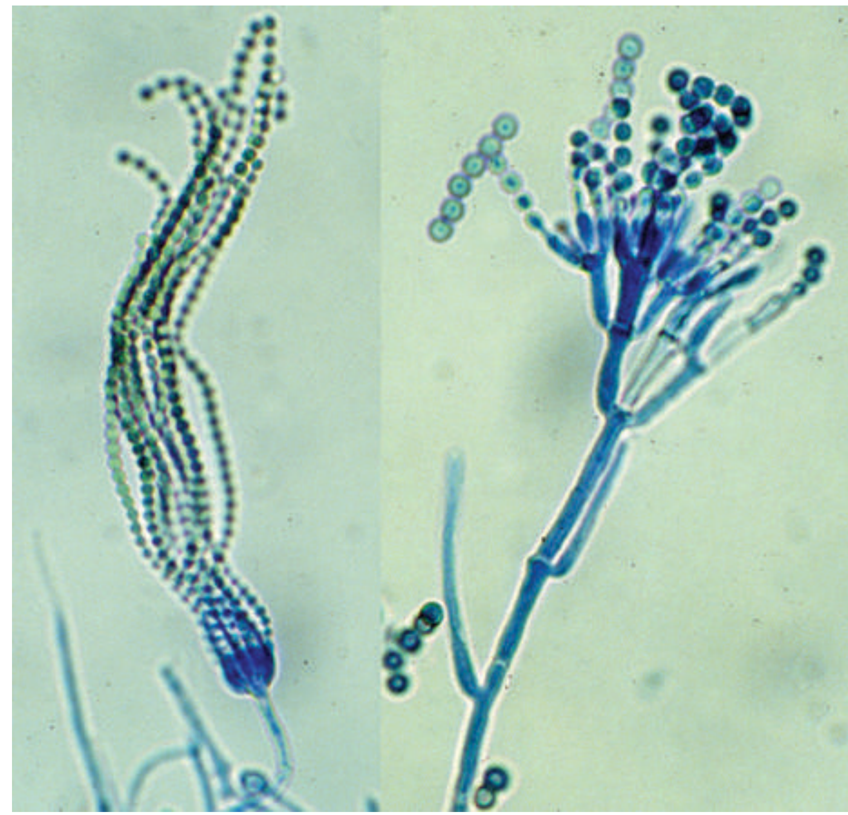


Lilium sp.

Asexual reproduction (vegetative propagation)

- **Sporulation:** a spore is a haploid or diploid cell that is able, on its own, to develop a new individual.





Conidiophores and conidiospores (asexual origin) of *Penicillium* sp. (fungus)

Asexual reproduction (vegetative propagation)

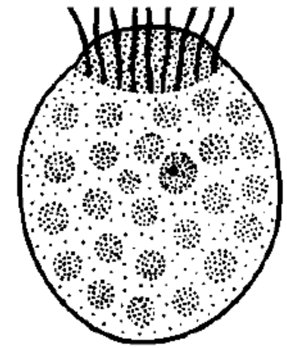
- Planospores may be:

Isokont

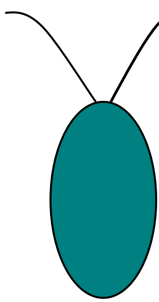
Heterokont

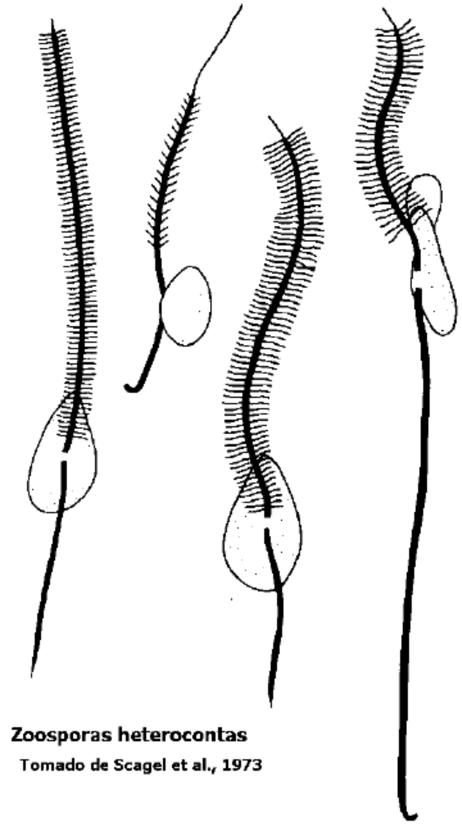
Stephanokont

Tomado de Scagel et al., 1973

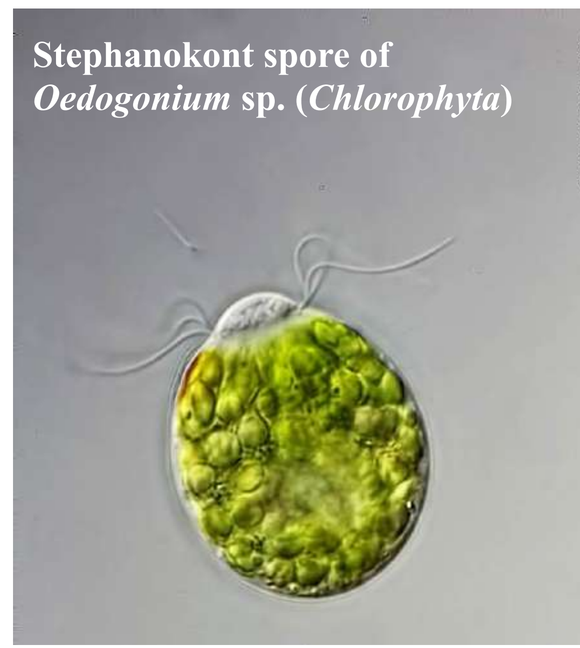


Stephanokont





Heterokont



Asexual reproduction (vegetative propagation)

- **Advantages of vegetative propagation**

- Maintenance of traits: genetically identical individuals.

- Rapid development.

- Sometimes there are dioecious organisms in which the exclusive presence of individuals of one sex makes it impossible to maintain the population.

- **Disadvantages of vegetative propagation**

- Genetically homogeneous individuals are generated, which creates populations with *little genetic variability.*

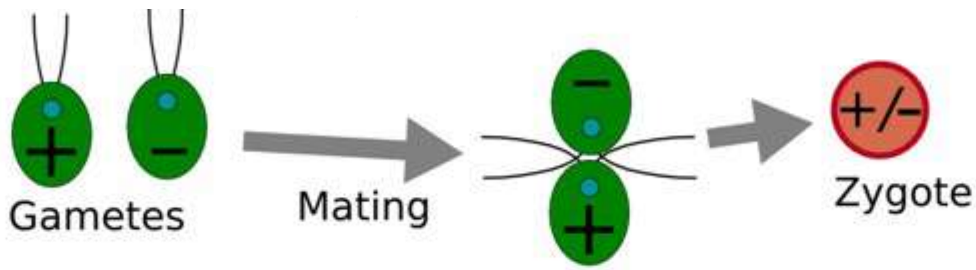
- Transmission of disease (viruses).

- Early senescence of individuals.

Sexual reproduction

- This is the formation of a new individual from the **union of two reproductive cells**; the resulting genome is the recombination of the parents' genomes.

- The result is always a **ZYGOTE**.

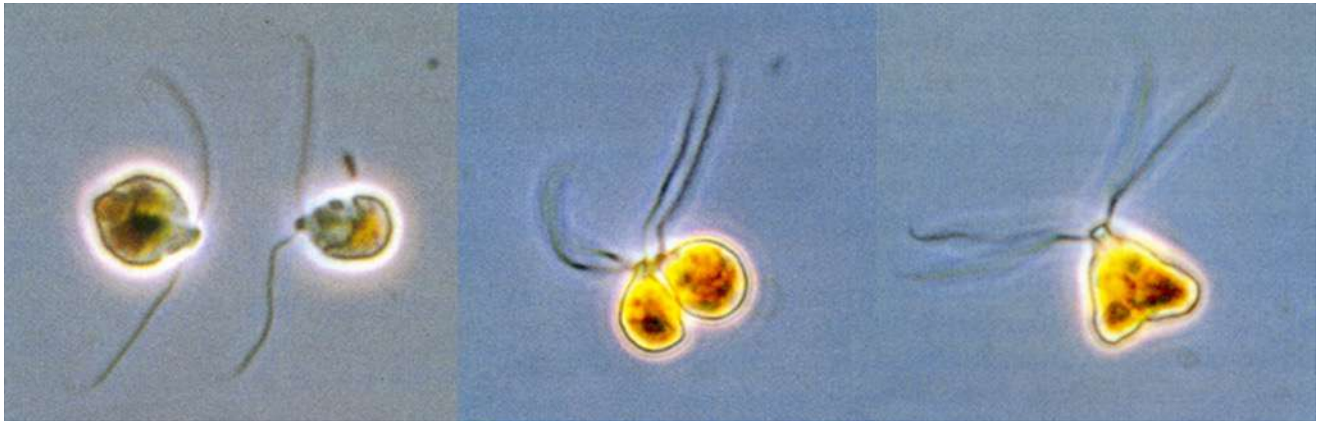


- This is characteristic of **eukaryotes.** The variability generated in individuals that originate from this process is the basis for the evolution of species.

Sexual reproduction

- **Hologamy**: when the entire individual (unicellular) acts as a gamete at the time of reproduction; e.g. some unicellular green algae.

Dunaliella salina
(*Chlorophyta*, green alga)



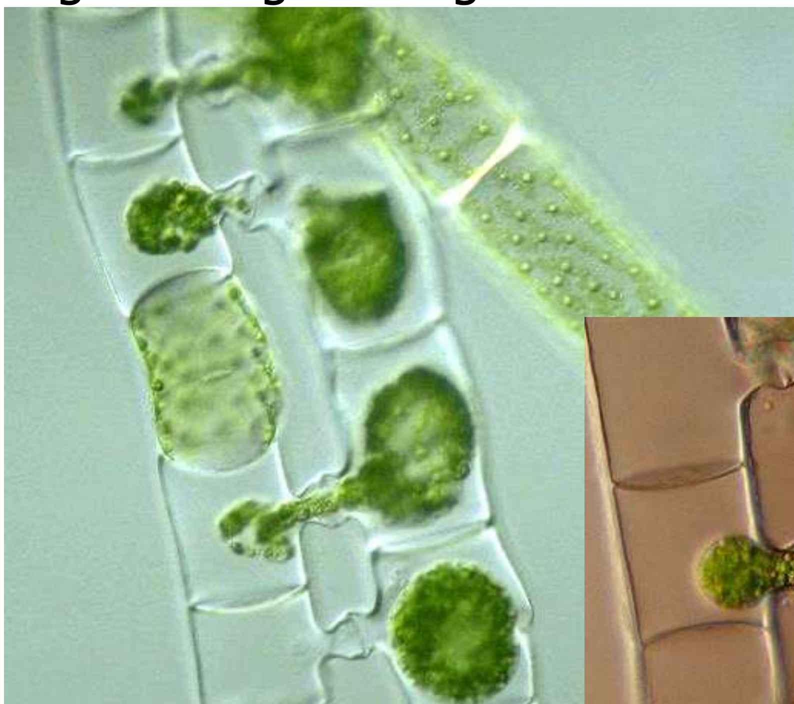
***Chlamydomonas* sp.** (*Chlorophyta*, green alga)

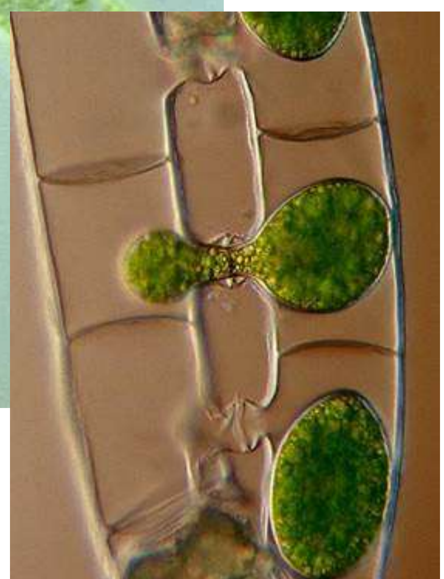
Sexual reproduction

- **Cystogamy (gametangial copulation, gametangiogamy):**

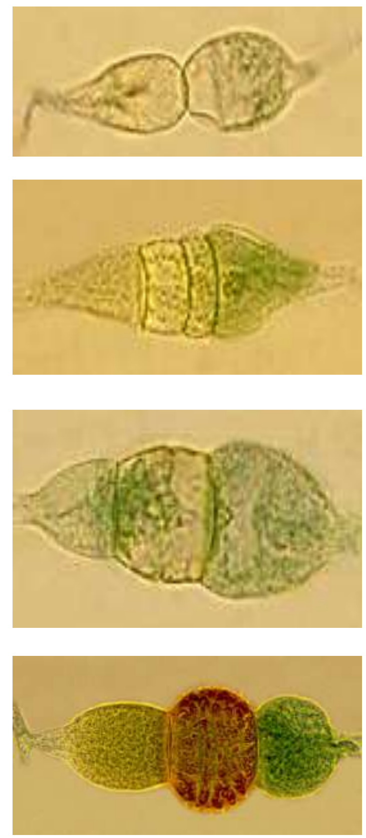
- no gamete formation

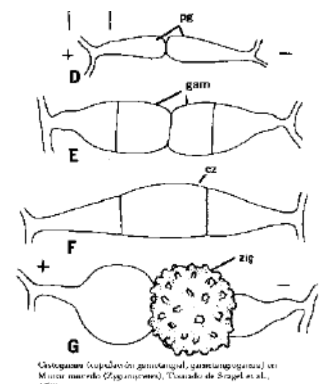
- vegetative cells that differentiate and transform into gametocysts and fuse; e.g. some green algae and mucoromycete fungi.





***Spirogyra* sp. (*Charophyta*, green alga)**



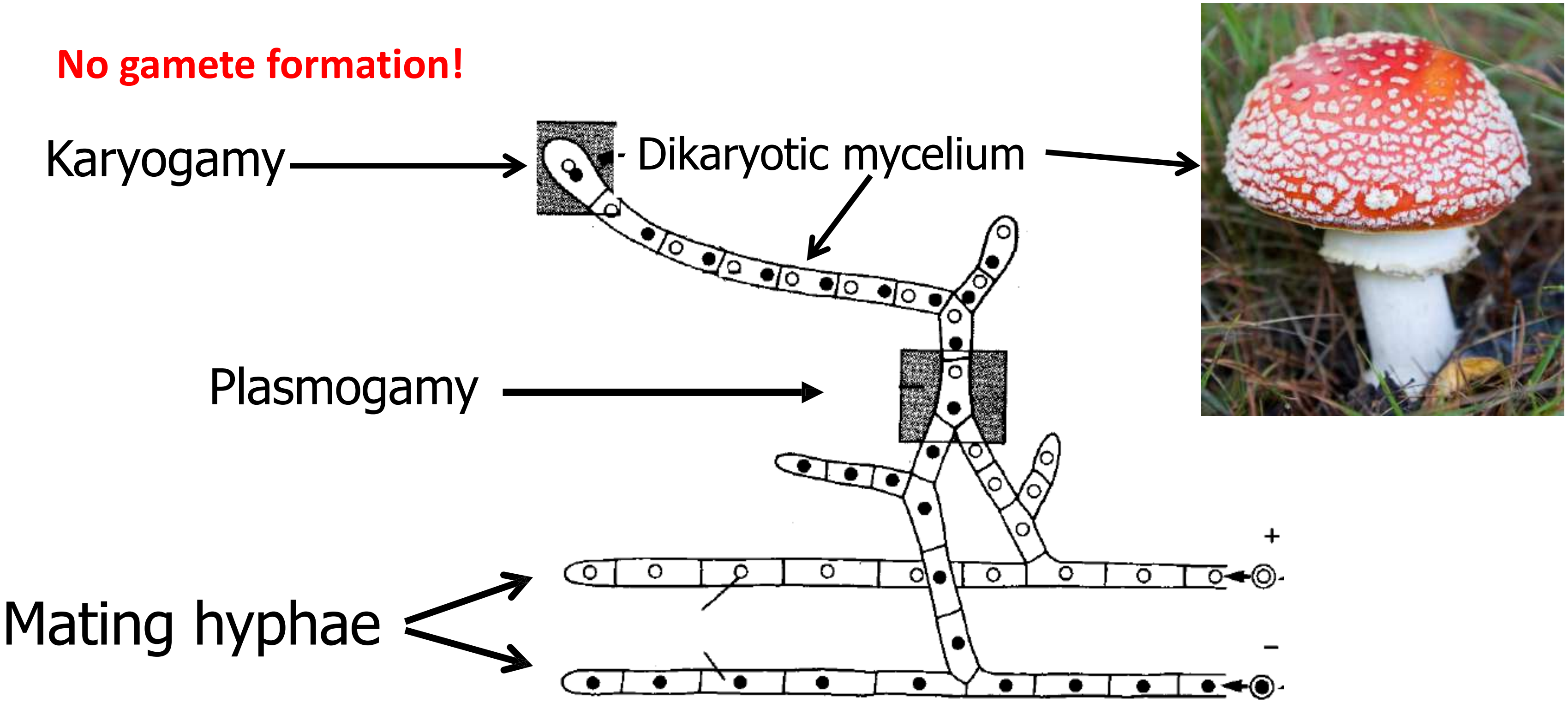


Gametangiogamy in a mucoromycete fungus

Sexual reproduction

- **Somatogamy**: this is characteristic of higher fungi: two compatible hyphae fuse (**plasmogamy**), leading to the **dikaryotic mycelium** (in which each cell of the mycelium has two nuclei); **karyogamy** and meiosis will occur later.

No gamete formation!



Sexual reproduction

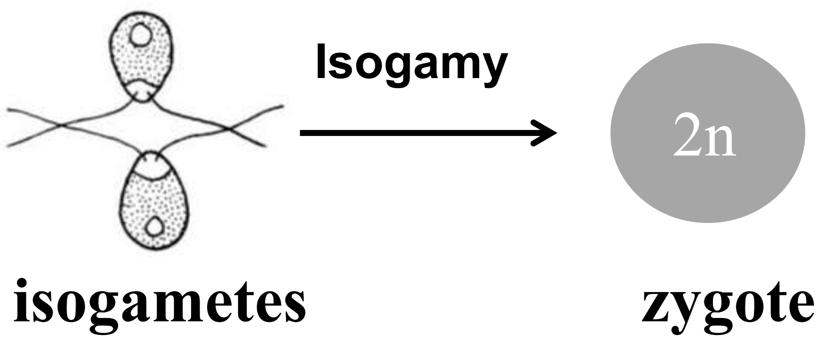
- **Merogamy**: with this type of reproduction, some cell(s) of an individual are transformed into gametes.

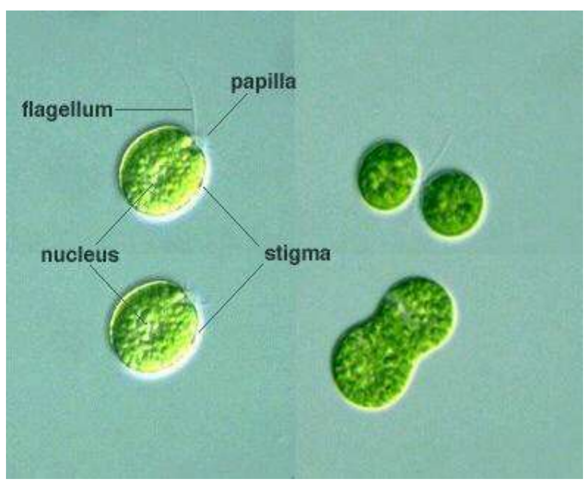
- Gametes are haploid cells whose purpose is to join together to form first a zygote and then a new individual.

- Types: **Isogamy**
  Anisogamy
  Oogamy

Sexual reproduction

Isogamy: this is considered the most primitive type of reproduction and occurs when the two gametes are equal and mobile.

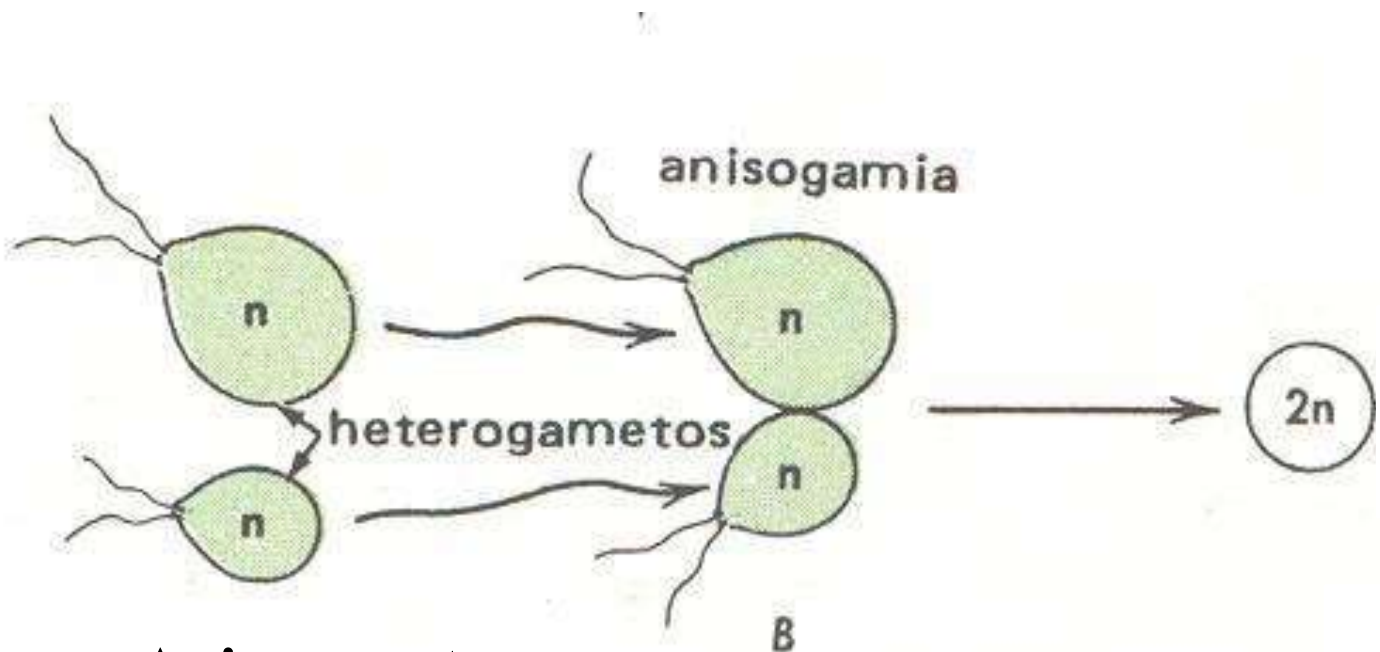




Ulva sp.

Sexual reproduction

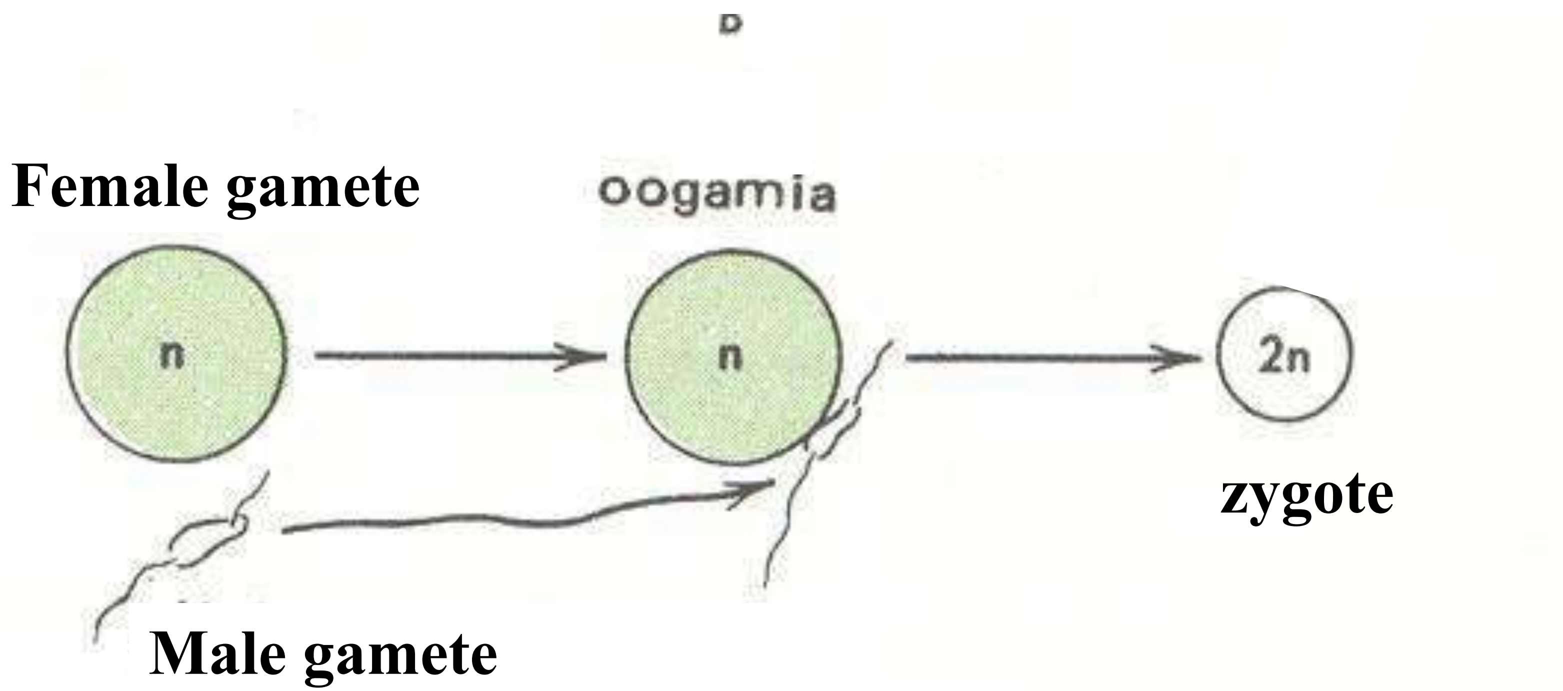
Anisogamy: this occurs when the two fusing gametes are functionally or morphologically different.



Anisogametes
Heterogametes

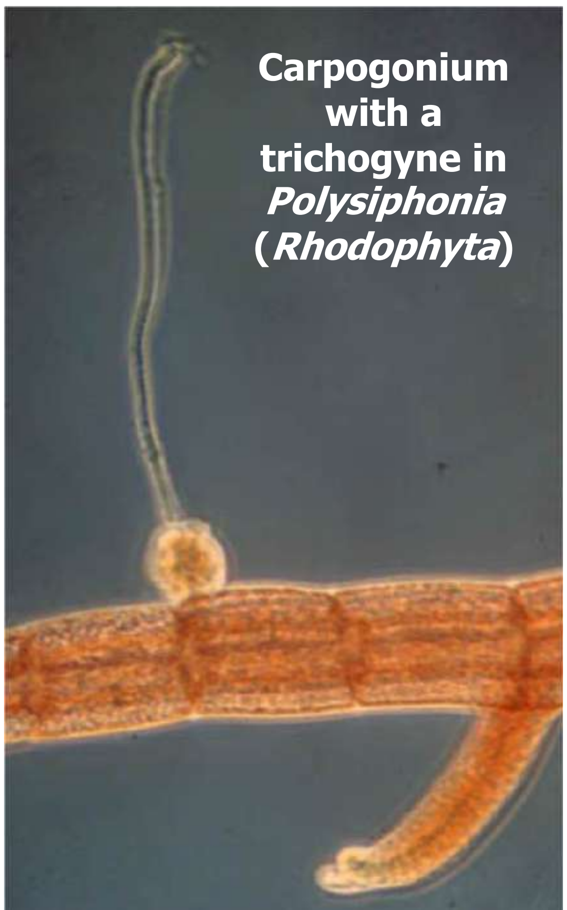
zygote

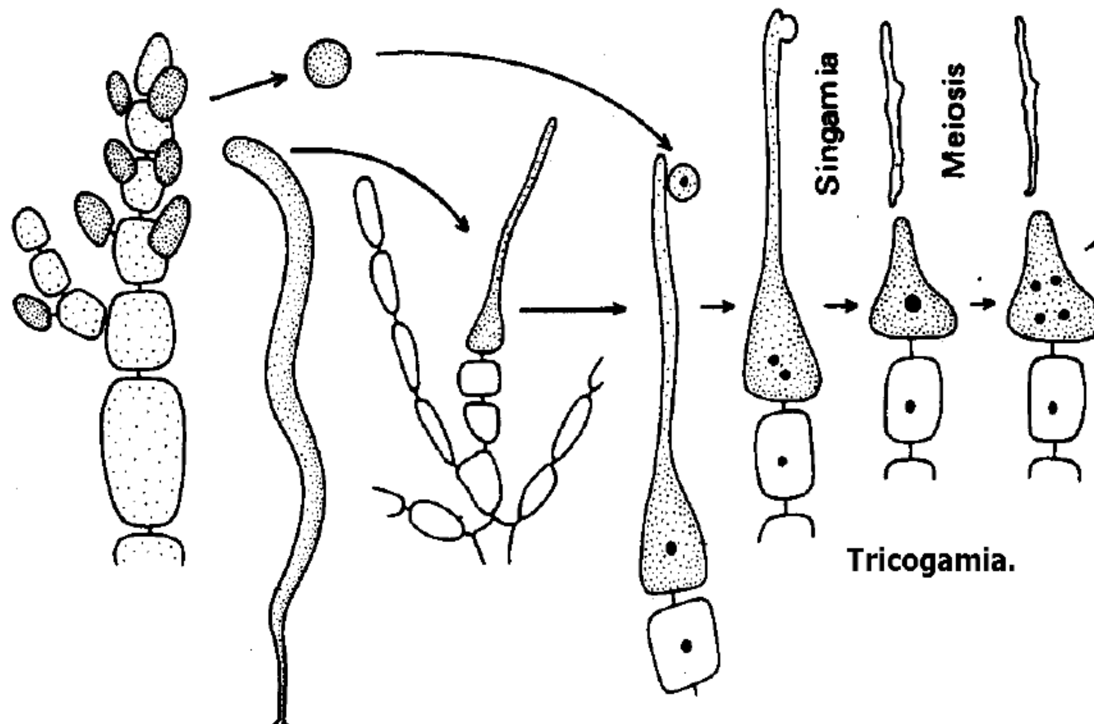
Oogamy: the female gamete (*oosphere*) is large and immobile; the male gamete (*sperm*) is mobile and much smaller.



Sexual reproduction

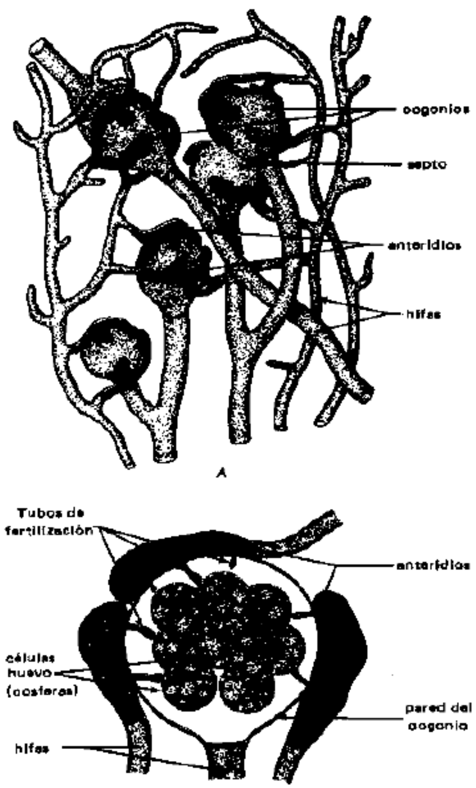
Trichogamy: male gametes (***spermatia***; singl. spermatium) are small and immobile. The female gamete (***carpogonium***) is enclosed in a structure with an extension called **trichogyne**. This form of reproduction occurs in some red algae and in fungi.





Sexual reproduction

Siphonogamy: male gametes are not released into the environment but are transported inside a tube or siphon to the female gamete. This form of reproduction is considered the most evolved and an adaptation to life on land.



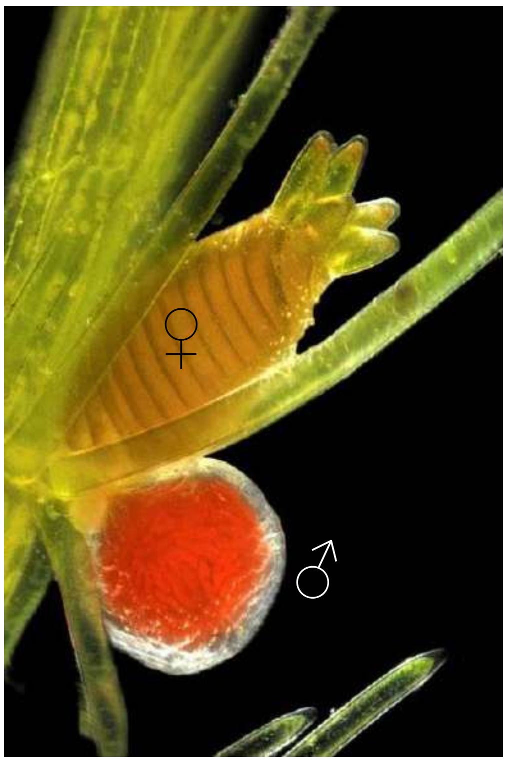
Saprolegnia sp.

Germination of a pollen grain; pollen tube

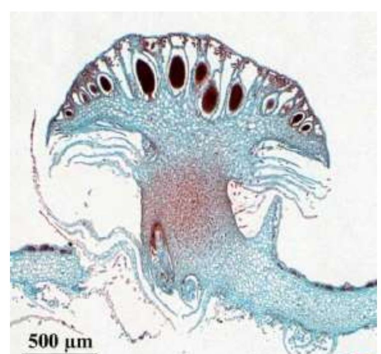
Sexual reproduction

Monoecy and dioecy

- Organisms in which male and female gametes are formed in the same individual are **monoecious**.
- **Dioecious** organisms are organisms that have two types of individuals, one of which produces male gametes and the other produces females.



Monoecious species in *Characeae* with an oogonium (nucule) and globules with anteridia.



Marchantia polymorpha, dioecious liverwort.

Life cycles: syngamy and meiosis

- In sexual reproduction there is one basic fact:

  - **syngamy**: the fusion of two reproductive cells.

  This union forms the **zygote**.

  To maintain the chromosome number of a species, **meiosis** occurs.

  Syngamy and meiosis are two complementary processes but they can occur at different times in the life of an organism.

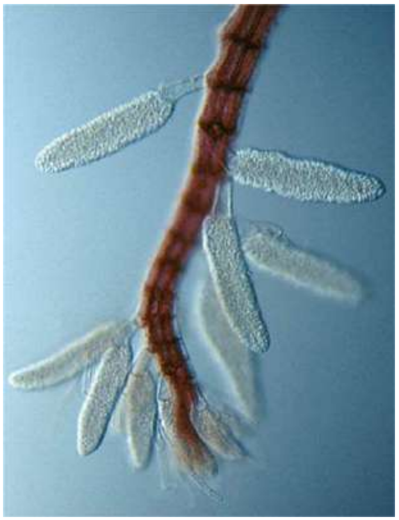
Reproductive structures

The various stages of an organism's biological cycle have structures that are responsible for producing the cells involved in reproduction.

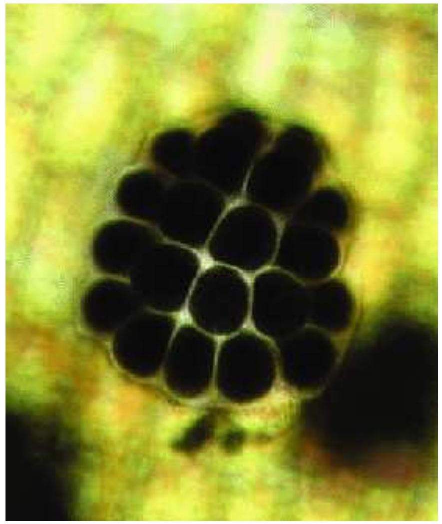
	Without an outer layer of sterile cells	**With an outer layer of sterile cells**
Gametophyte *Gametófito*	Gametocysts *Gametocistes* **Algae, fungi**	Gametangia *Gametangios* **Land plants**
Sporophyte *Esporófito*	Sporocysts *Esporocistes* **Algae, fungi**	Sporangia *Esporangios* **Land plants**

Reproductive structures

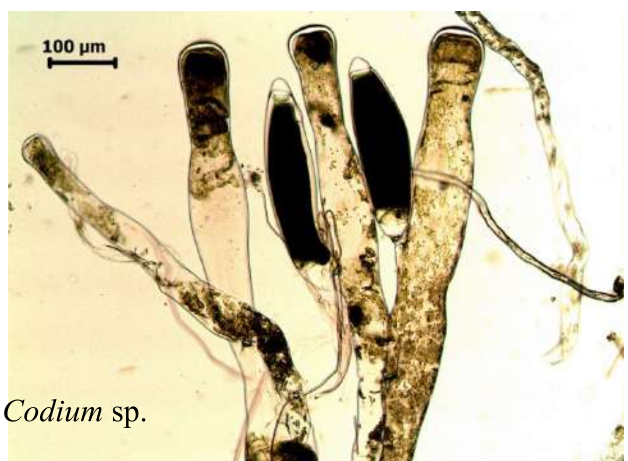
Gametocysts



Spermatangia with spermatia (male gametes) in *Polysiphonia* sp. (*Rhodophyta*, red alga)



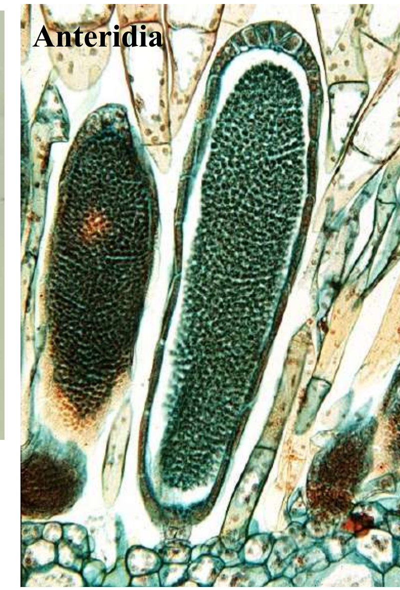
Female gametocysts of *Dictyota* sp. (*Phaeophyceae*, brown alga)

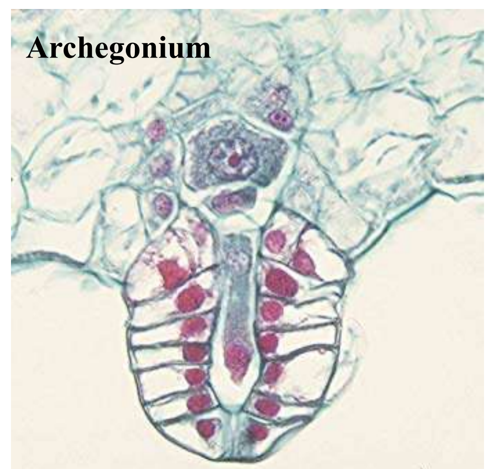


Gametocysts of *Codium* sp. (*Chlorophyta*)

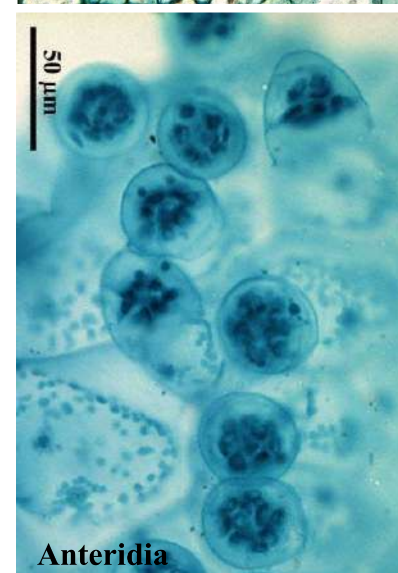
Gametangia

Gametangia of a moss (*Bryophyta*)





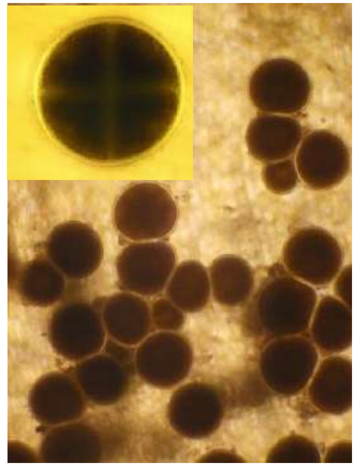
Gametangia of a fern (*Monilophyta*)



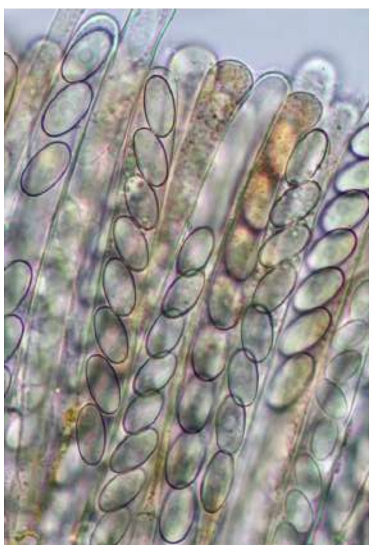
Reproductive structures

Sporocysts

Tetrasporocysts of *Antithamnion* sp. (*Rhodophyta*, red alga)



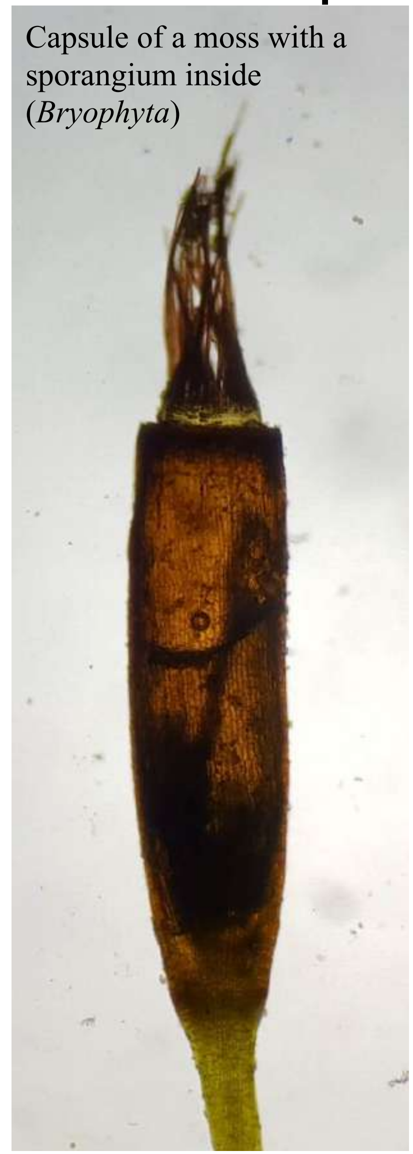
Tetrasporocysts of *Dictyota* sp. (*Phaeophyceae*, brown alga)



Asci of *Morchella* sp. (*Ascomycota*, fungi)

Basidium and basidiospores (*Basidiomycota*, fungi)

Sporangia



Capsule of a moss with a sporangium inside (*Bryophyta*)

Sporangium of a fern (*Monilophyta*)

Anther with microsporangia of an angiosperm (*Magnoliophyta*, land plant)

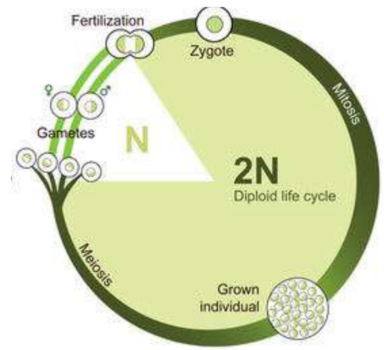
Life cycles

- In the life cycle of an organism, **haploid and diploid cells alternate**.
- Depending on when meiosis occurs, there may be:

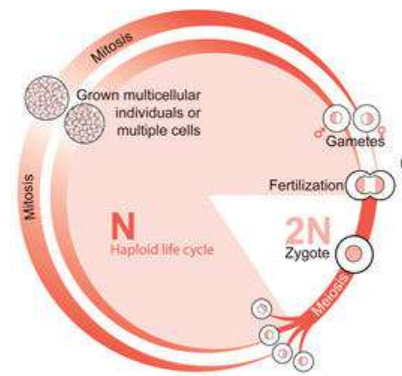
- **Gametic meiosis** is when meiosis occurs just before the formation of gametes. All cells are diploid except gametes, which are haploid.

- **Zygotic meiosis** is when meiosis occurs at the first division of the zygote. All cells are haploid except the zygote, which is diploid.

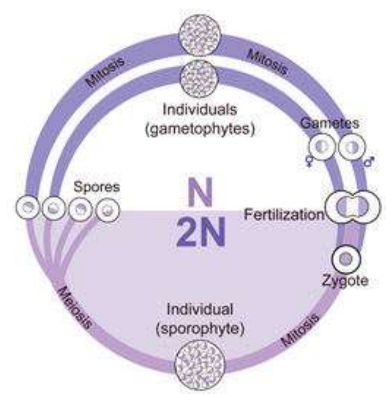
- **Sporic meiosis** is when meiosis occurs in the formation of spores that will give rise to the gametophyte. One haploid and one diploid are generated.



(b) Diploid Life Cycle



(a) Haploid Life Cycle



(c) Alternation of Generations

Life cycles: the concept of generation

A **generation** is the “stage in the development of a living being that begins with a reproductive cell (spore or zygote) and ends, after a marked vegetative activity, with the production of other reproductive cells (spores or gametes) different or not from those that have produced the considered stage of development”(from Curso de Botánica, Díaz et al. 2004).

Life cycles: the alternation of generations

- In animals, and more rarely in plants, the zygote gives rise to an individual that is capable of reaching sexual maturity and producing gametes.

- In plants and some fungi, there may be two or more generations that complete the life of an organism.

The two GENERATIONS that may be recognised in any LIFE CYCLE are:

- the **gametophyte**, i.e. the haploid generation that produces gametes.

- the **sporophyte**, i.e. the diploid generation that produces meiotic spores (= meiospores).

The alternation of generations occurs when the life of an organism is completed by two or more generations.

Life cycles: types

- Depending on the number of generations, life cycles may be:
- **Monophasic** (monogenetic): one generation.
- **Diphasic** (digenetic): two generations.
- **Triphasic** (trigenetic): three generations.

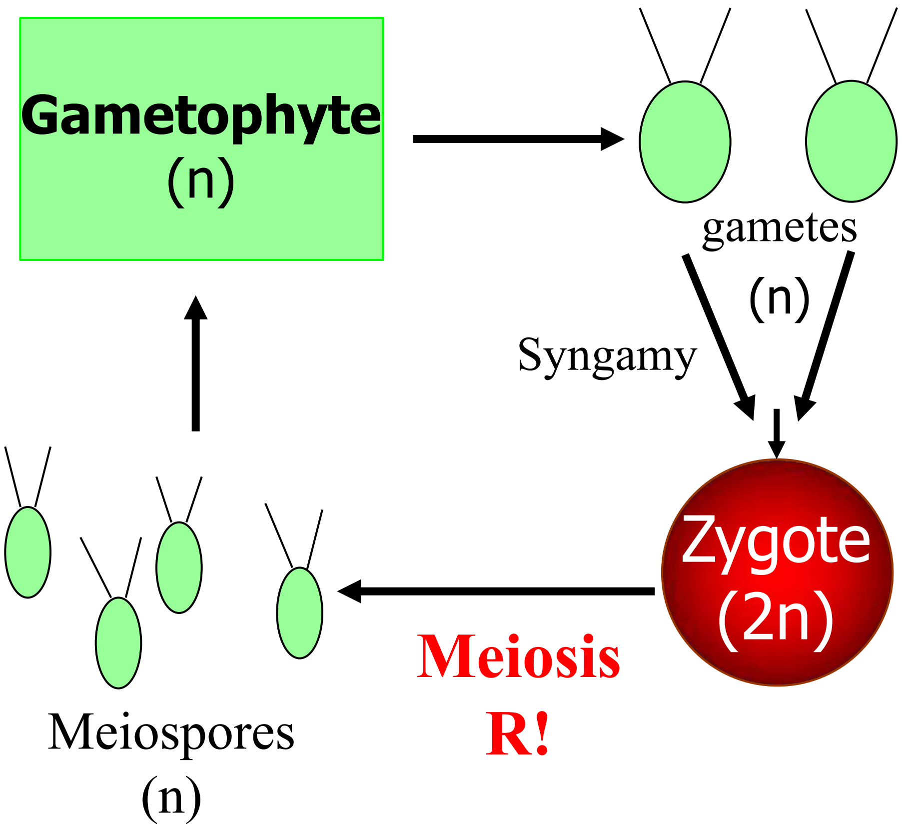
Monogenetic life cycles: description and types

The life cycle of the organism is completed in a **single generation**.

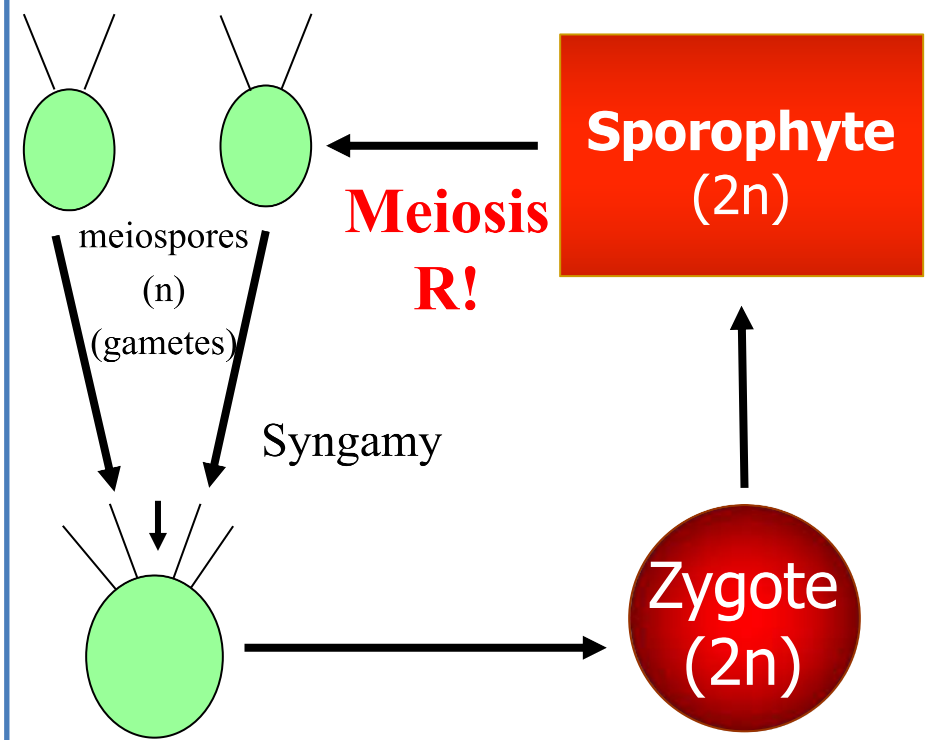
As this generation may involve a haploid or diploid individual, monogenetic cycles can be **haploid** or **diploid**.

Monogenetic life cycles: description and types

Monogenetic haploid cycle: zygotic meiosis



Monogenetic diploid cycle: gametic meiosis



Digenetic life cycles: description and types

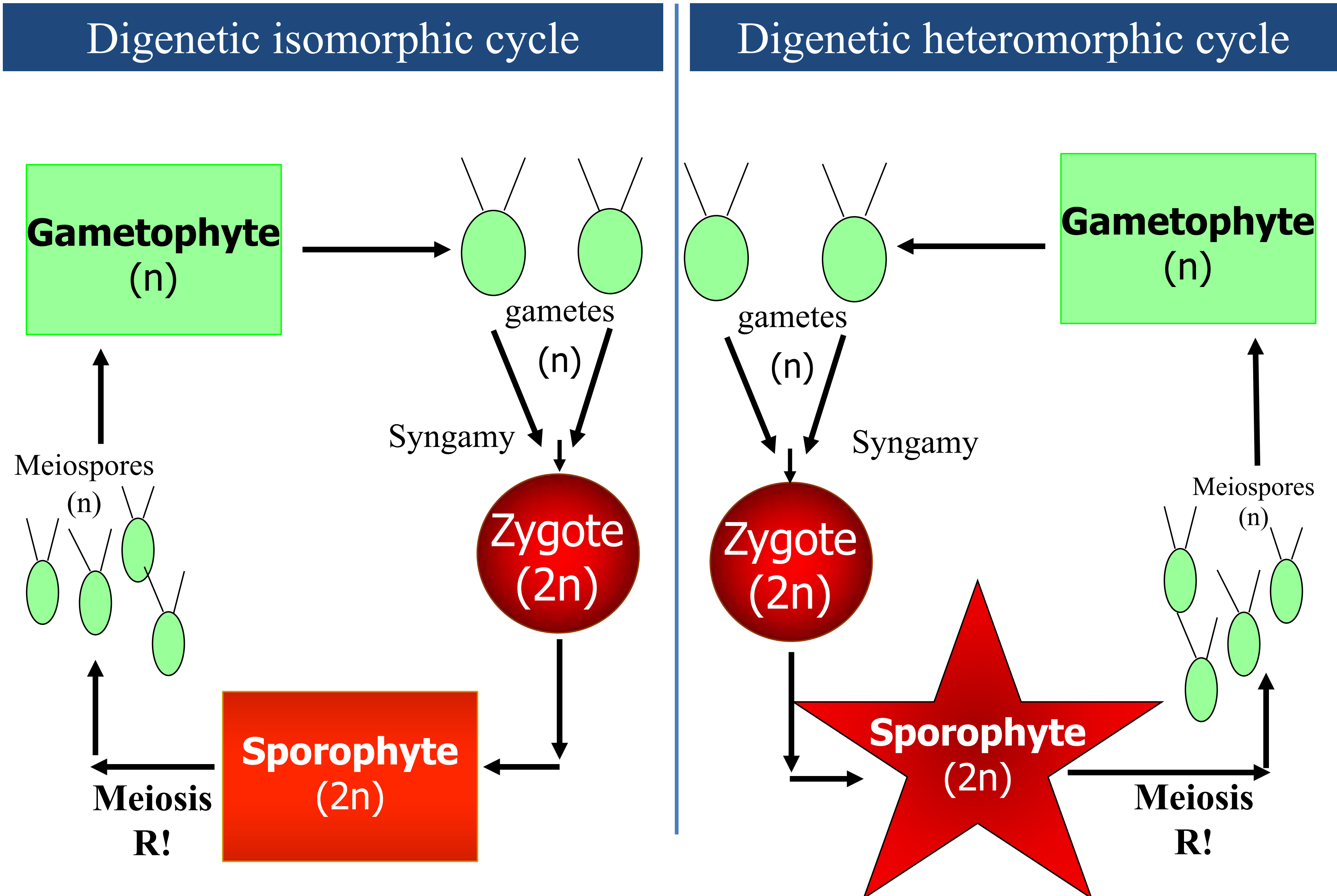
The life cycle of the organism is completed in two generations.

- Digenetic cycles show **sporic meiosis**.
- Digenetic cycles are **haplo-diploid**.
- Digenetic cycles may be:

Isomorphic: the gametophyte and sporophyte are morphologically identical.

Heteromorphic: the gametophyte and sporophyte are morphologically different.

Digenetic life cycles: description and types



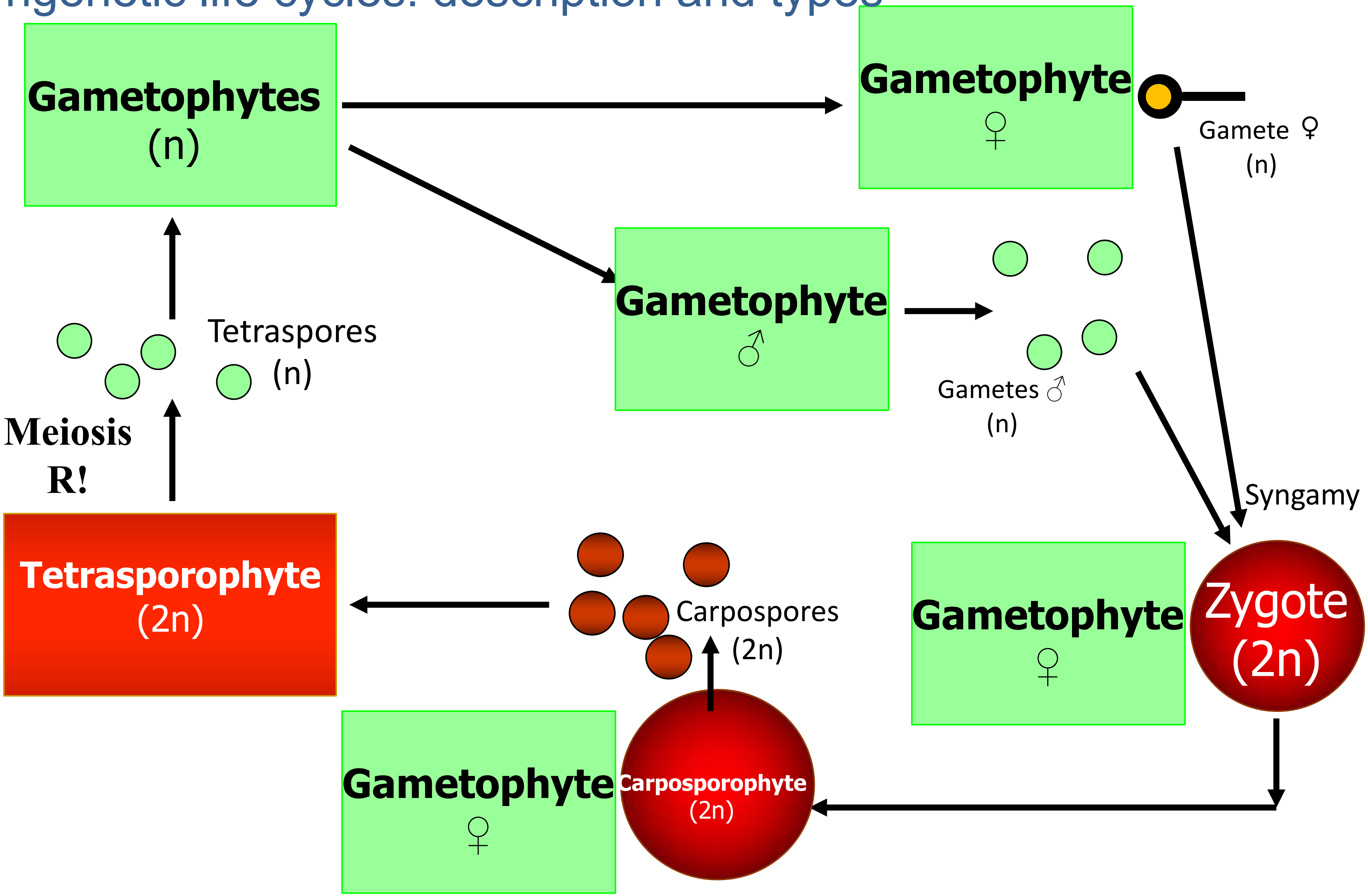
Trigenetic life cycles: description and types

- The life cycle of the organism is completed in three generations.

- **Two diploid (2n) generations**: the first generation, named **carposporophyte**, has no independent life and produces 2n spores named **carpospores**; the second generation, named **tetrasporophyte**, has independent life and produces meiospores named **tetraspores**.

- This type of cycle occurs in most **red algae**.

Trigenetic life cycles: description and types



Trigenetic haplodiplophasic cycle with sporic meiosis

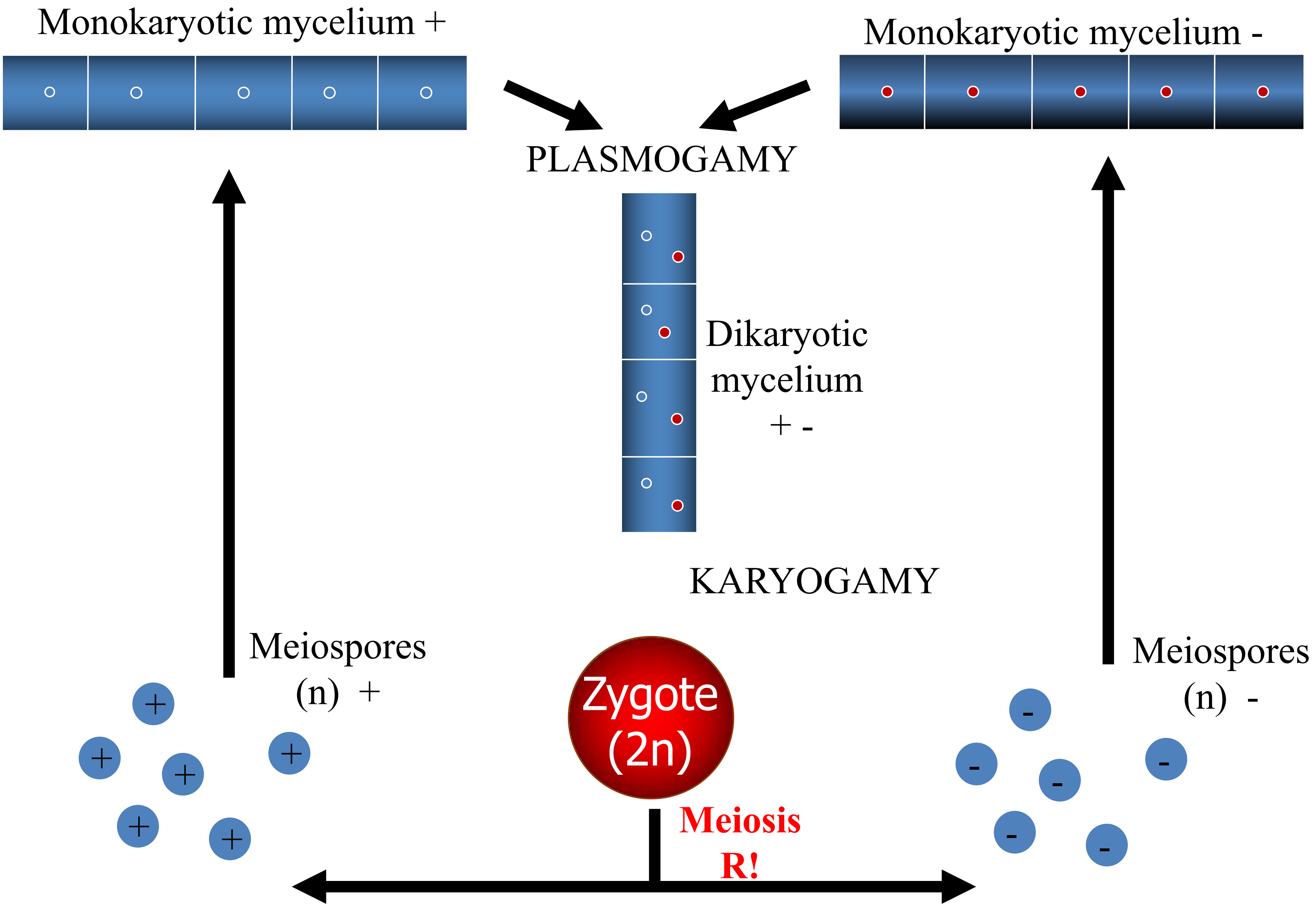
Haplo-dikaryotic **fungal** life cycle: description

- In most fungi, the process of syngamy separates **plasmogamy** and **karyogamy** in time and space.

- In this life cycle there is **no real alternation of generations**.

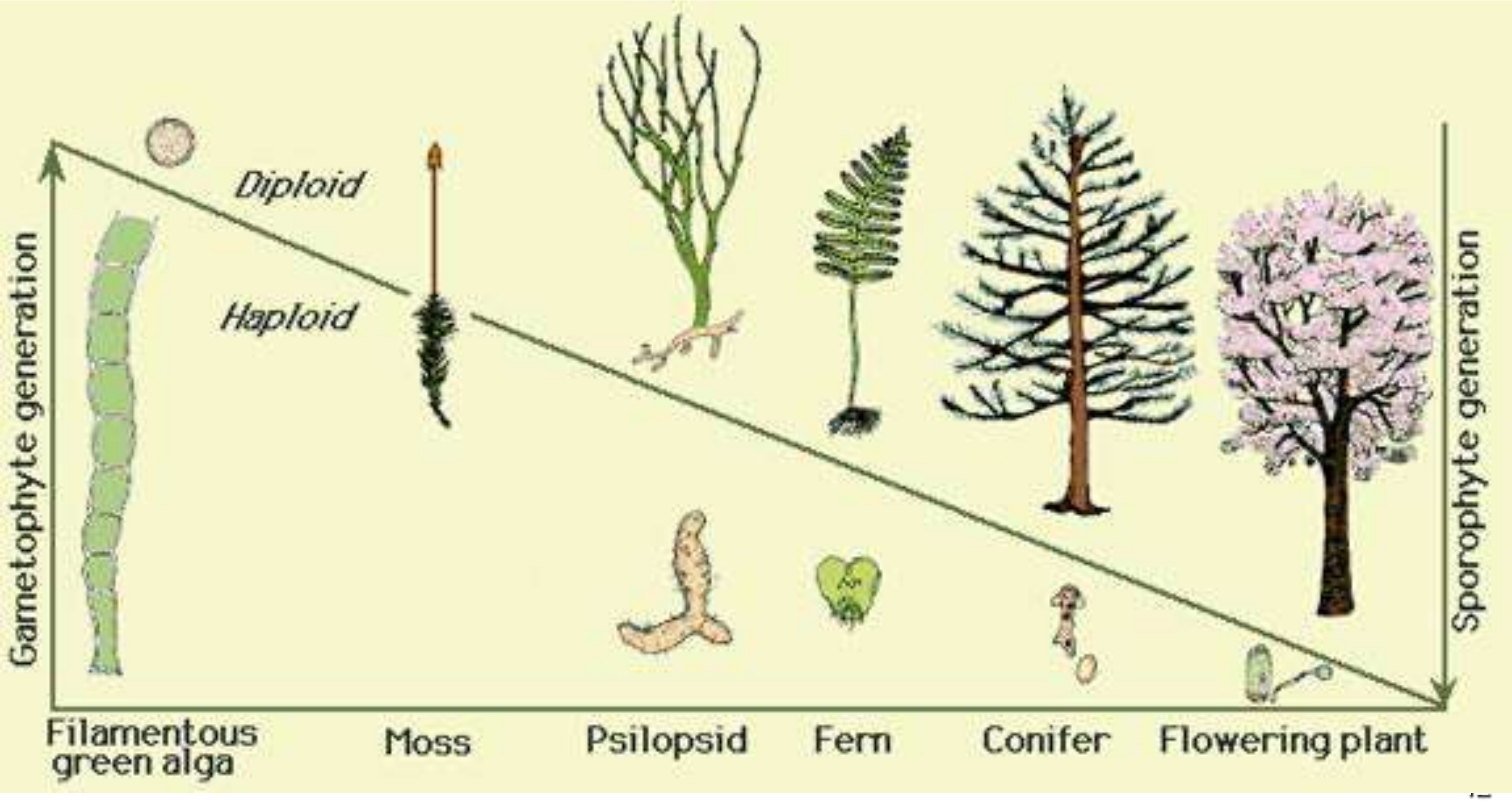
- A **monokaryotic** mycelium [each cell has a single nucleus (n)] **alternates** with a **dikaryotic** mycelium [each cell has two nuclei (n) (n)].

Haplo-dikaryotic **fungal** life cycle: description



Life cycles and their adaptive meaning

In plants and fungi in general, there is a **trend towards a reduction or even suppression of the haploid phase** and a **predominance of the diploid phase**.



Life cycles and their adaptive meaning

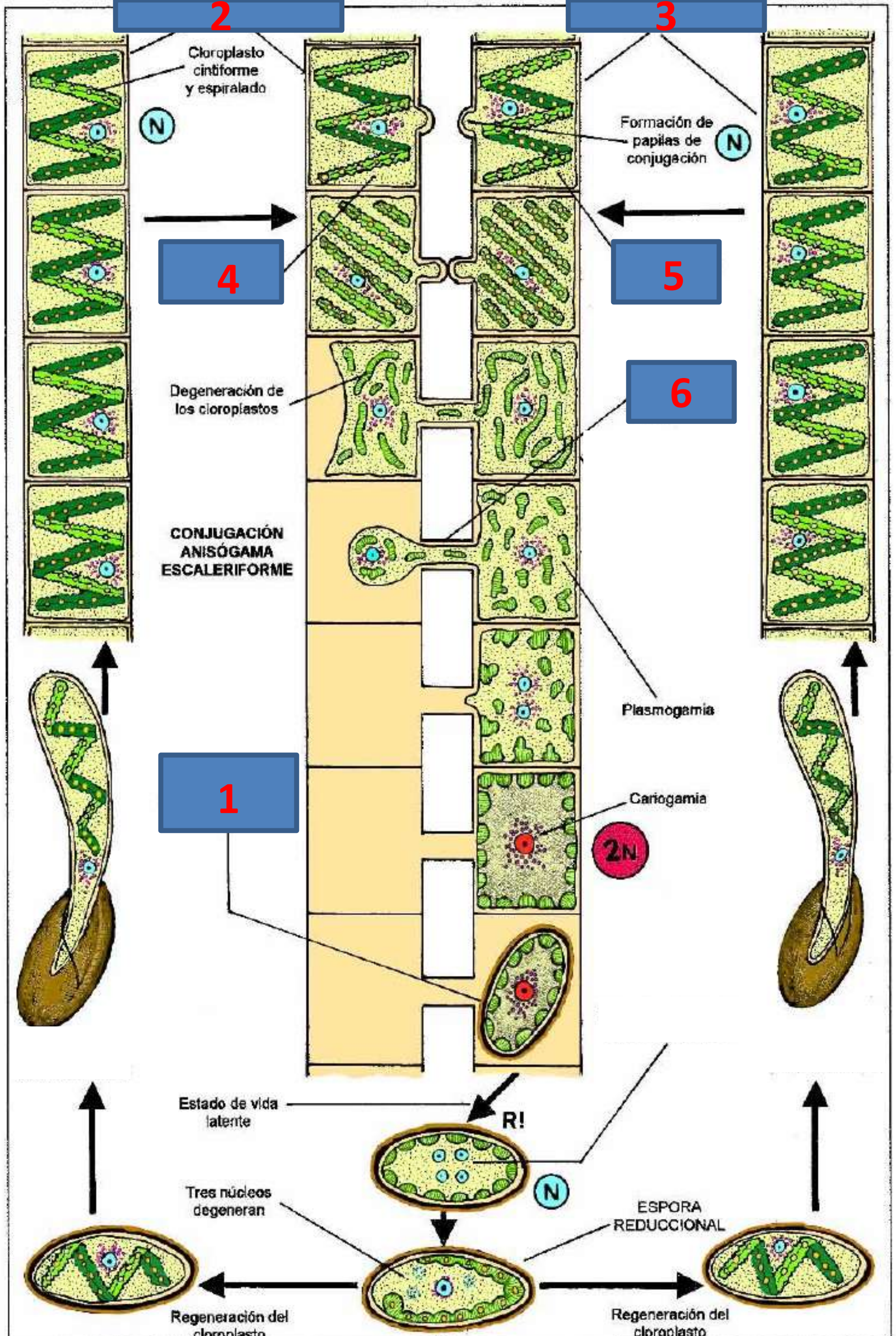
- In nature, diploid monogenetic cycles, or digenetic cycles, are observed in which **diploid individuals are the dominant phase**. In cormophytes, a progressive **reduction of the gametophyte** is observed.

Codium sp.
Green alga

Pteridophyte
(fern)

Spermatophyte

LIFE CYCLE EXAMPLES
(“blind” cycles)

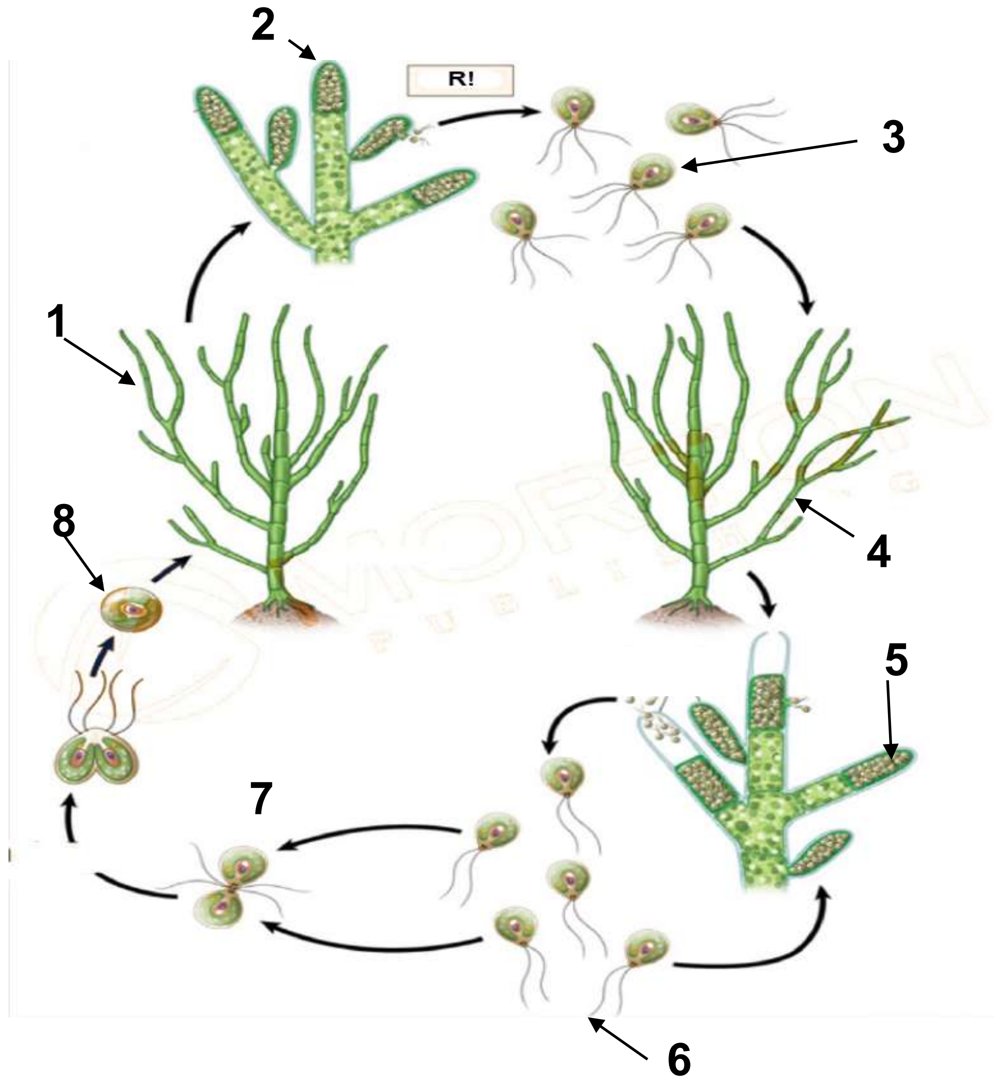


7 reproduction type?

8 meiosis type?

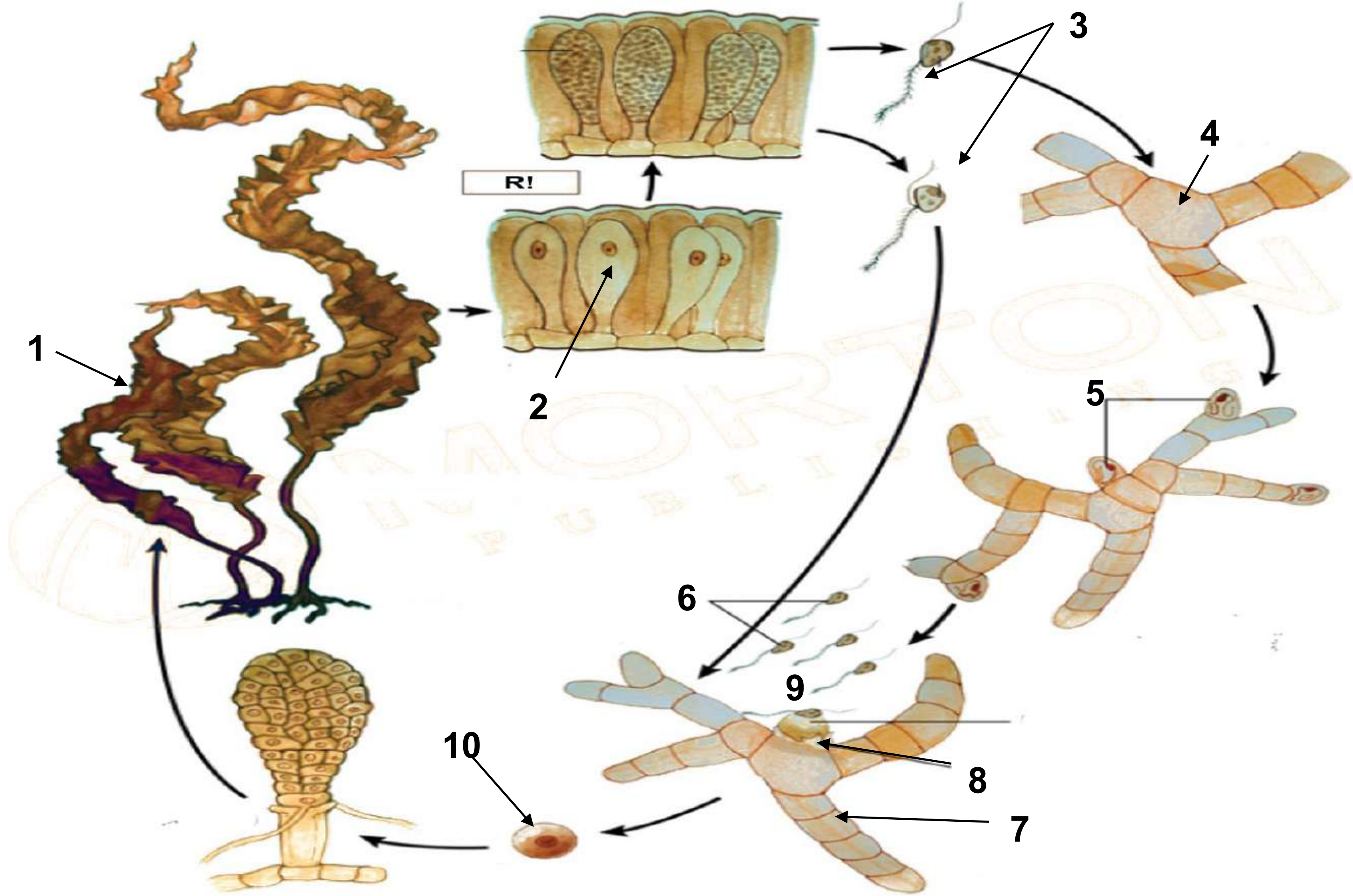
9 cycle type?

10 Organism?



9 Cycle type? **10 Meiosis type?**

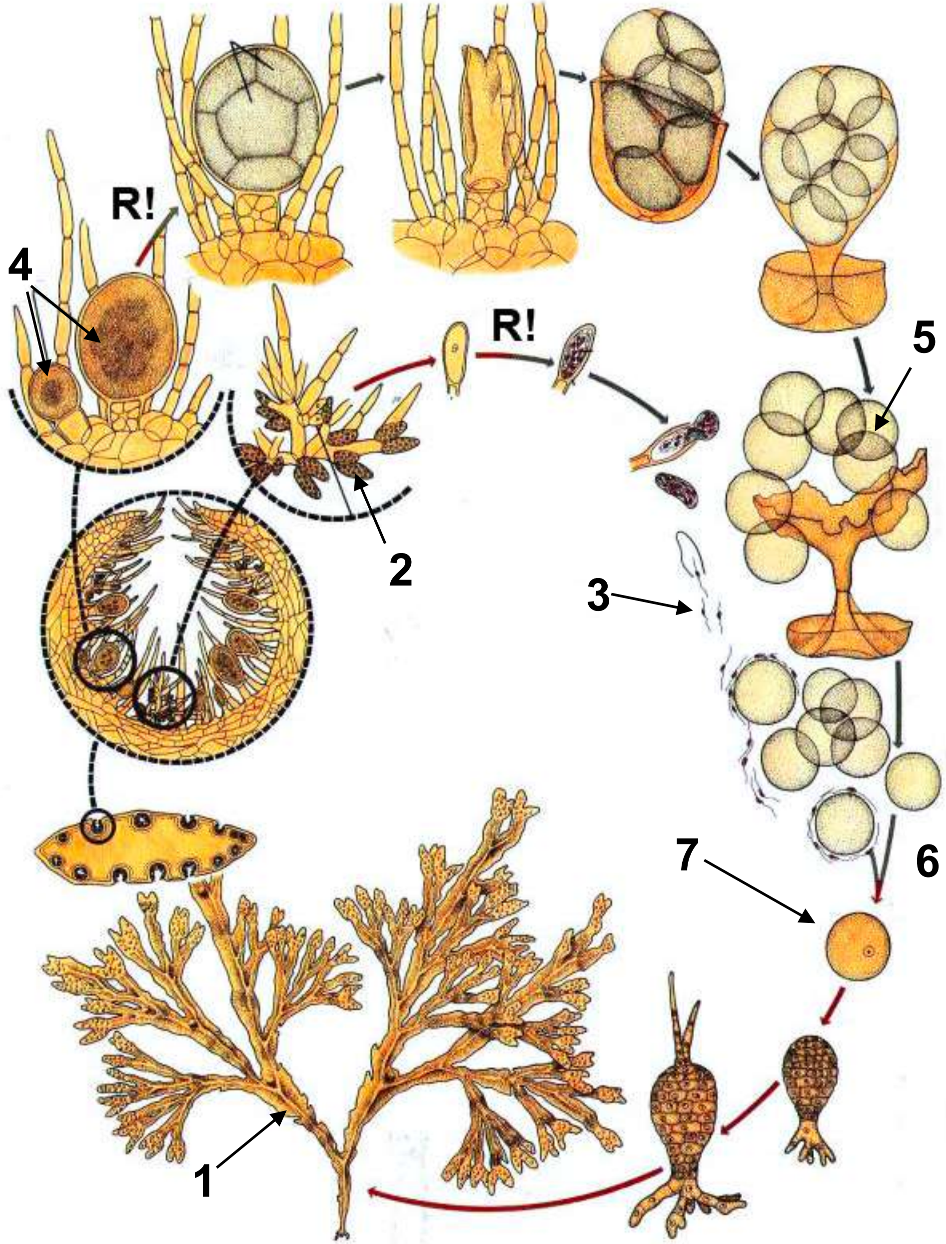
11 Organism?



9 Cycle type?

10 Meiosis type?

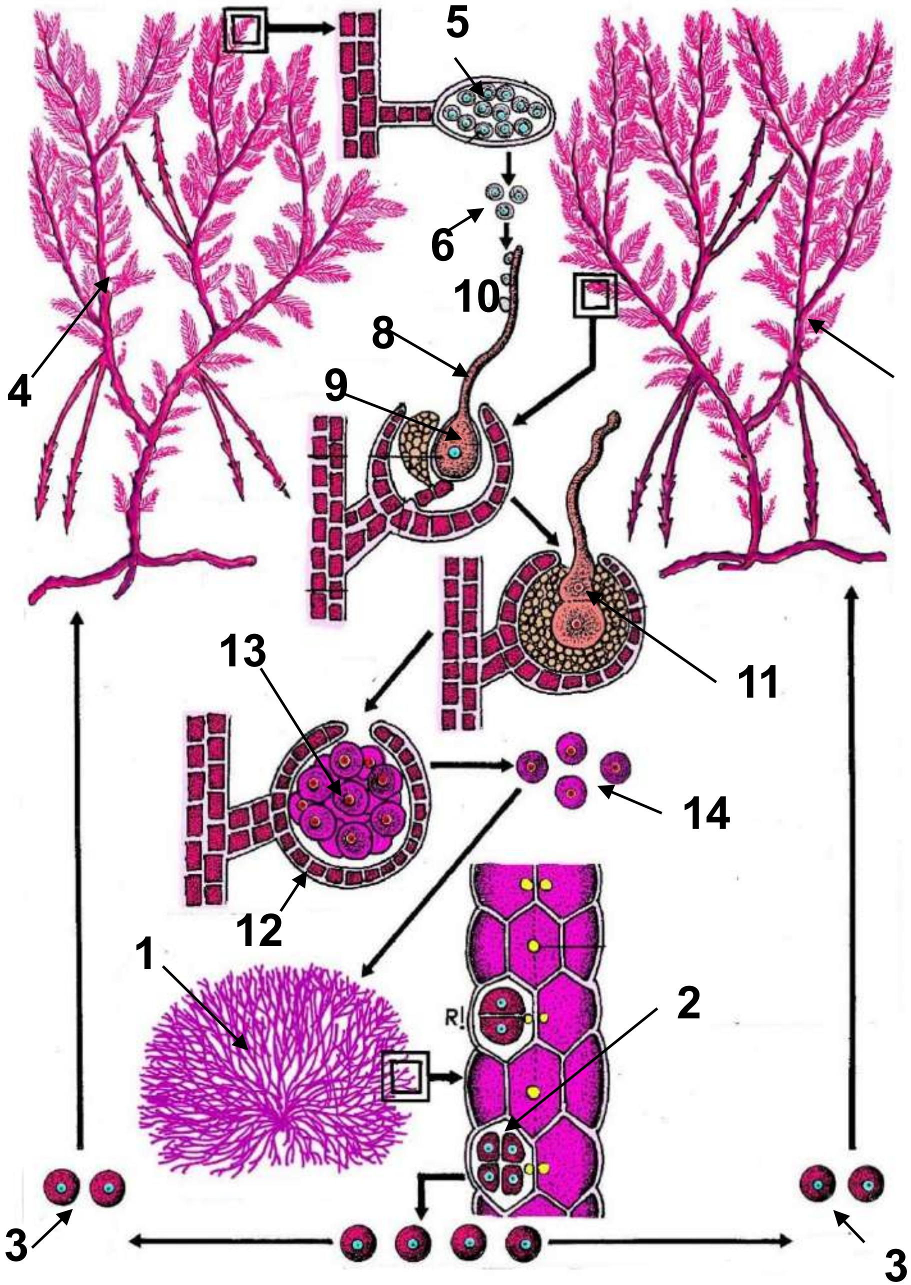
11 Organism?



9 Cycle type?

10 Meiosis type?

11 Organism?



9 Cycle type?

10 Meiosis type?

11 Organism?

Sexual reproduction in plants and fungi

Unicellular organisms

Hologamy — The whole individual becomes the gamete.

Multicellular organisms

Cystogamy — No gamete is formed.

Gametangial copulation (= gametangiogamy; also named conjugation).

Merogamy — Some cell(s) are transformed into gametes.

- Isogamy
- Anisogamy
- Oogamy

Involvement of flagellated gametes (at least one male or female).

- Trichogamy

Immobile gametes (the male gamete is dispersed, for example, by water).

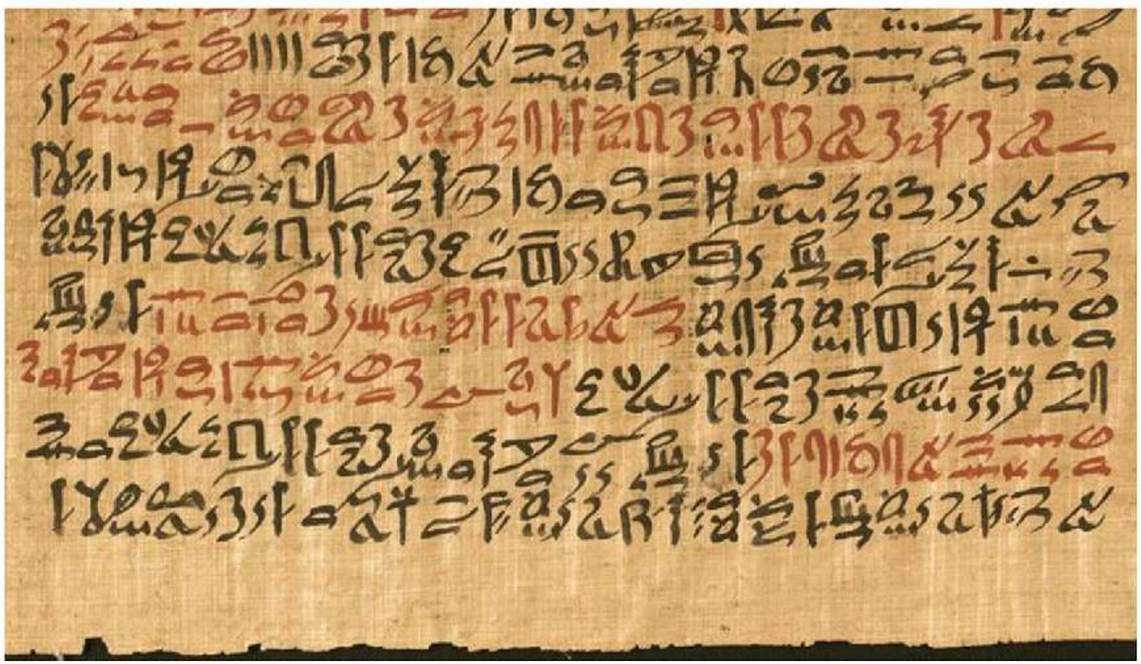
- Siphonogamy

The male gamete is transferred to the female gamete through a tube or siphon.

Somatogamy shares characteristics with cystogamy (because individualised gametes are not formed) and merogamy (since it is typical of multicellular organisms, only a few cells of which participate in reproduction). Typical of basidiomycetes and ascomycetes (fungi).

Lecture 03 part 1

Plant and fungal species Taxonomy and nomenclature



The Ebers Papyrus and the castor oil plant (*Ricinus communis*)

Species: the products of evolution?

In Latin, **species** simply means "kind", so species are, in the simplest sense, different kinds of organisms.

- **Morphological species concept** (e.g. Regan 1926): the distinction between species is based on anatomical and morphological criteria. Often, the judgment of a specialist in a particular plant or fungal group is used.

Layia discoidea

VS

Layia glandulosa

Species: the products of evolution?

In Latin, **species** simply means “kind”, so species are, in the simplest sense, different kinds of organisms.

- **Morphological species concept** (e.g. Regan 1926): the distinction between species is based on anatomical and morphological criteria. Often, the judgment of a specialist in a particular plant or fungus group is used.

HOWEVER:

- ❑ Certain characters may vary in extraordinary fashion within a single species (e.g. petal colour).
- ❑ Subjectivity may be incorporated by different systematicists or experts.

Layia glandulosa

Species: the products of evolution?

In Latin, **species** simply means "kind", so species are, in the simplest sense, different kinds of organisms.

- **Biological species concept** (Mayr 1969): species are groups of interbreeding, natural populations that are reproductively isolated from other such groups.

HOWEVER:

- ❑ The true extent of gene flow among natural populations is difficult to measure.
- ❑ Conducting experiments on reproduction in microscopic organisms such as most fungi is extremely complicated.
- ❑ What about species that mostly reproduce asexually?
- ❑ Interspecific hybridisation between species of flowering plants is common.
- ❑ What qualifies as reproductively isolated? 25%, 50%, 75% or 100%?

Layia discoidea

x

Layia glandulosa

= **Offspring of *L. discoidea* and *L. glandulosa* 100% fertile!**

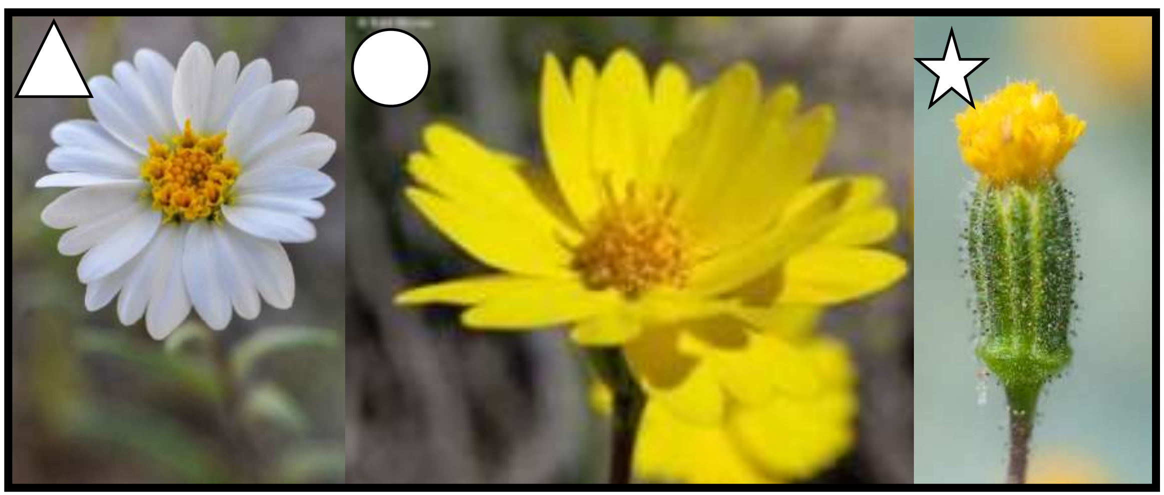
Species: the products of evolution?

In Latin, **species** simply means “kind”, so species are, in the simplest sense, different kinds of organisms.

- **Ecological species concept** (Van Valen 1976): a species is a lineage which occupies an adaptive zone that is minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range.

HOWEVER:

❑ not all species fit this model and it is difficult to confirm without extensive genetic study.

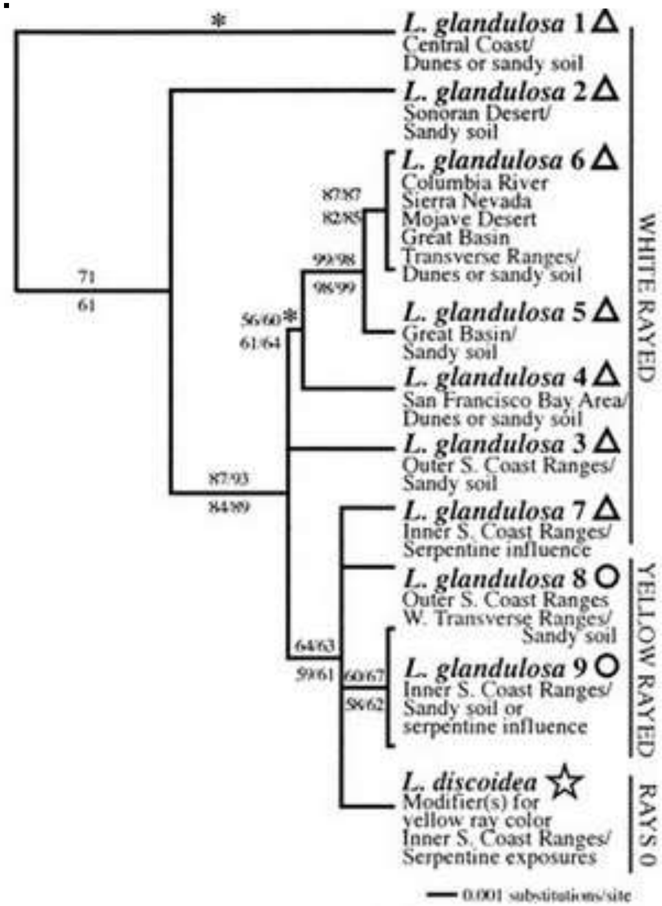


Species: the products of evolution?

In Latin, **species** simply means “kind”, so species are, in the simplest sense, different kinds of organisms.

- **Phylogenetic species concept**: species are the terminals in a phylogenetic tree (Davis & Goldman 1993), i.e. the smallest diagnosable monophyletic unit with a parenteral pattern of ancestry and descent (Rosselló-Mora & Amann 2001).

BUT:

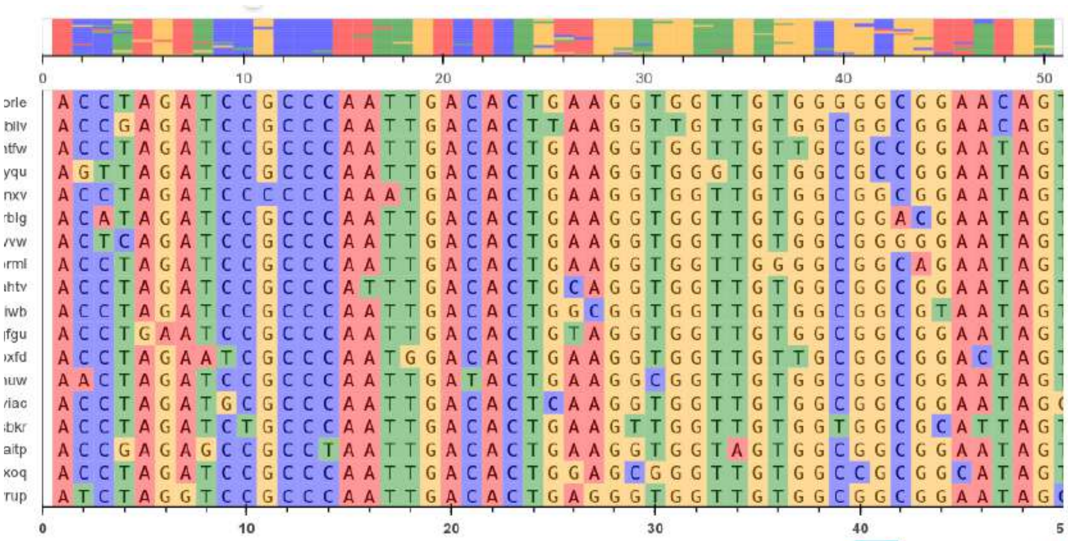


- ❑ Species are mosaics of genetic variation often with a reticulate origin.
- ❑ Some species are monophyletic while others are paraphyletic.
- ❑ it is unrealistic to assume that all species are bifurcating, completely evolved entities that form at the same evolutionary rates.

Species: the products of evolution?

In Latin, **species** simply means “kind”, so species are, in the simplest sense, different kinds of organisms.

- **Barcode species concept** (Hebert et al. 2003): the identification of species is based on comparing DNA sequences of specimens to sequences in databases.



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HOWEVER:

- ❑ Many sequences in databases are based on misidentifications.
- ❑ Interspecific and intraspecific variation exhibited by common gene markers vary between plant taxa.
- ❑ Genetic variation considered intraspecific by some researchers is treated as interspecific by others.

Species: the products of evolution?

In Latin, **species** simply means "kind", so species are, in the simplest sense, different kinds of organisms, **However, in view of the discrepancies between the various concepts of species, we can conclude that:**

- ❖ Species are not "real" or "static" through time, since they are formed by one or multiple **populations** of "real" individuals that are continuously **evolving**.
- ❖ A **population** is an interbreeding group of organisms that is defined and united by its gene pool (the sum of all the alleles of all the genes of all the individuals in the population).
- ❖ **Evolution** is the result of accumulated changes in the composition of the gene pool.
- ❖ For **speciation** (the formation of new species) to occur, populations that formerly shared a common gene pool must be reproductively isolated from one another and subsequently subjected to different selection pressures.

<u>CONSEQUENCES</u> (from a pharmaceutical botanical perspective):

- **different populations of a species may be genetically distinct as well as distinct in terms of their chemical properties, and**
- **products of interest obtained from plants and fungi are continuously evolving, but over thousands or millions of years.**

Evolution through natural selection

***Solanaceae* family**

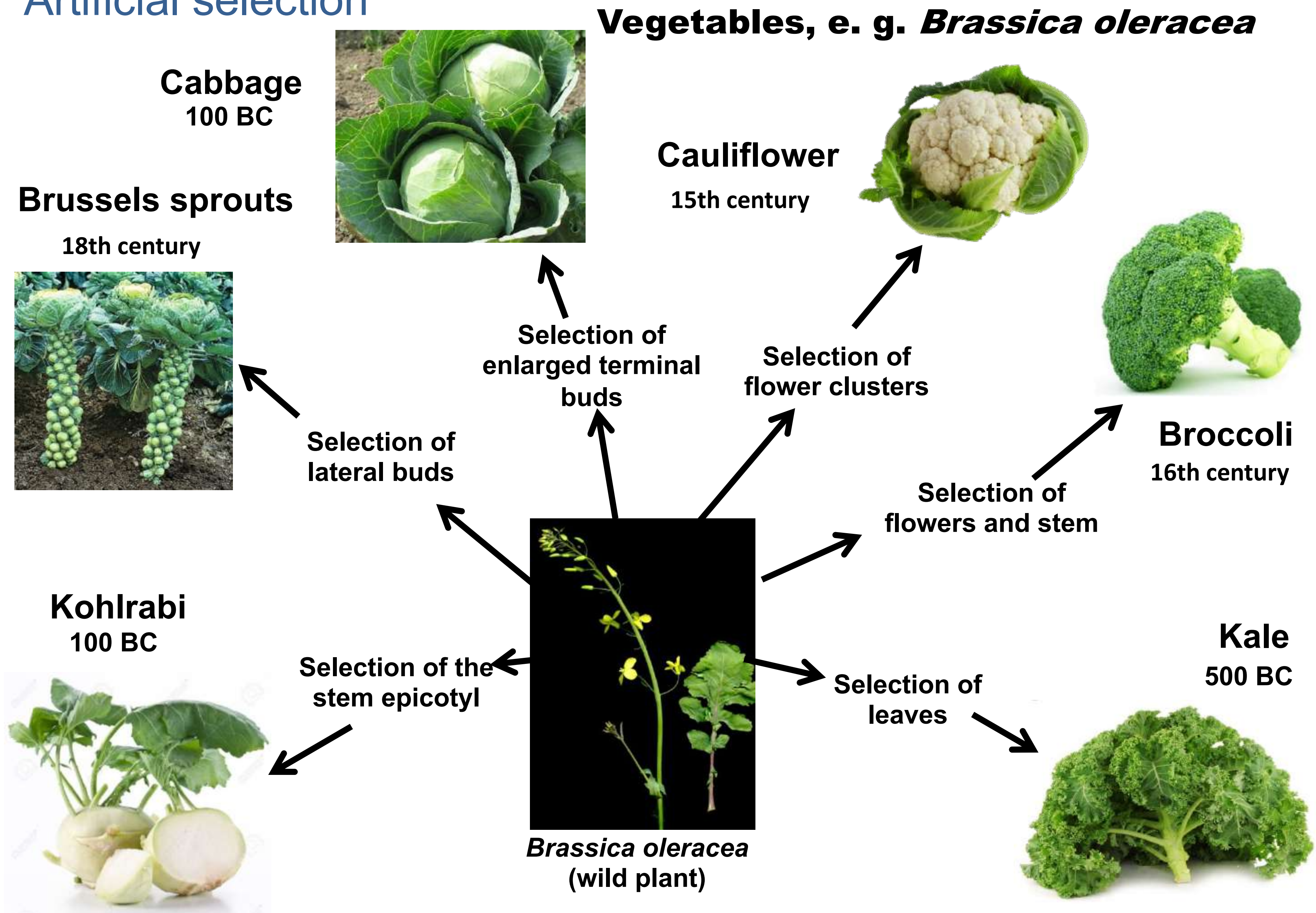
Atropa belladonna

Solanum dulcamara

Solanum melongena

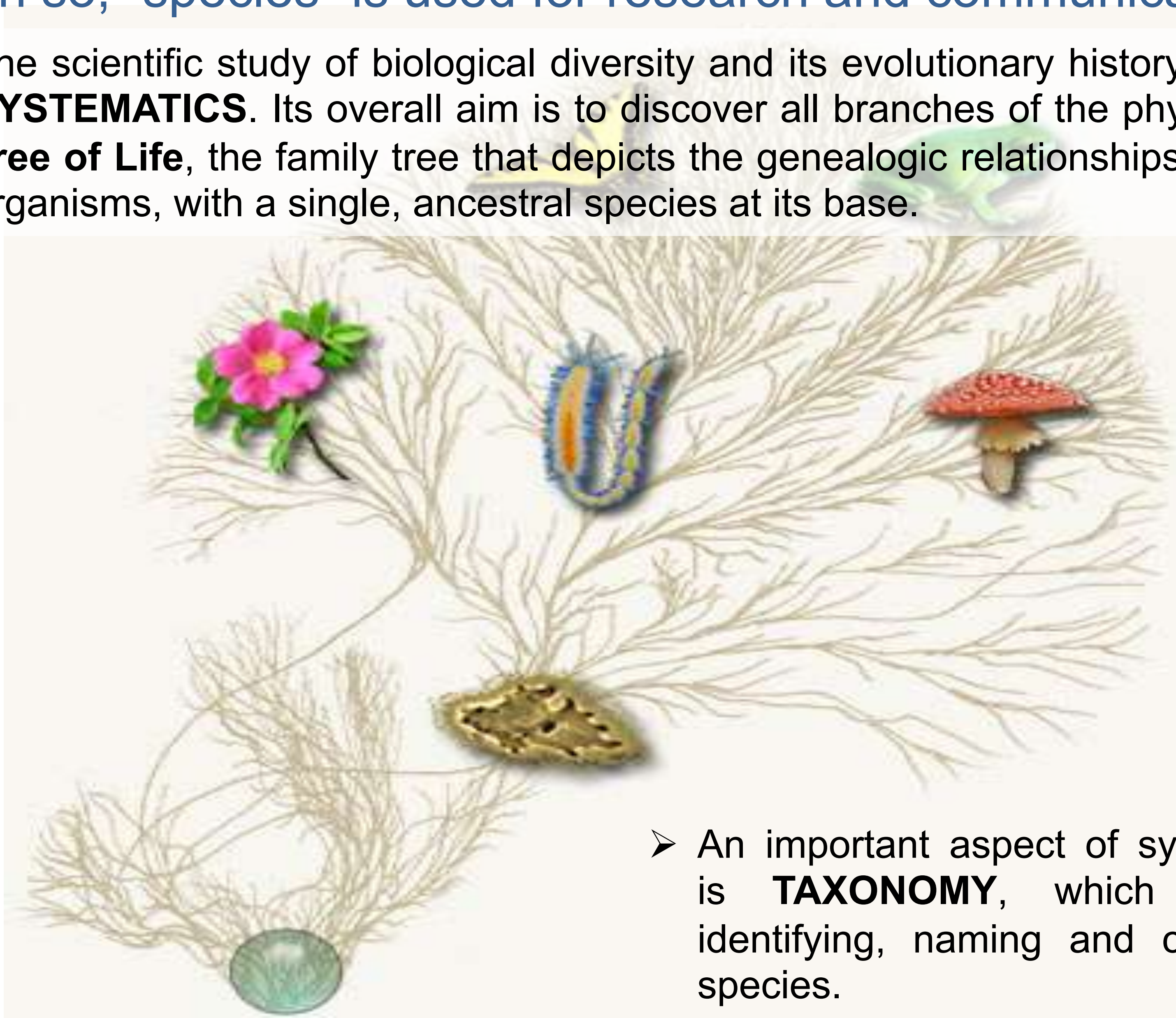
Solanum tuberosum

Artificial selection



Even so, “species” is used for research and communication

- The scientific study of biological diversity and its evolutionary history is called **SYSTEMATICS**. Its overall aim is to discover all branches of the phylogenetic **Tree of Life**, the family tree that depicts the genealogic relationships between organisms, with a single, ancestral species at its base.

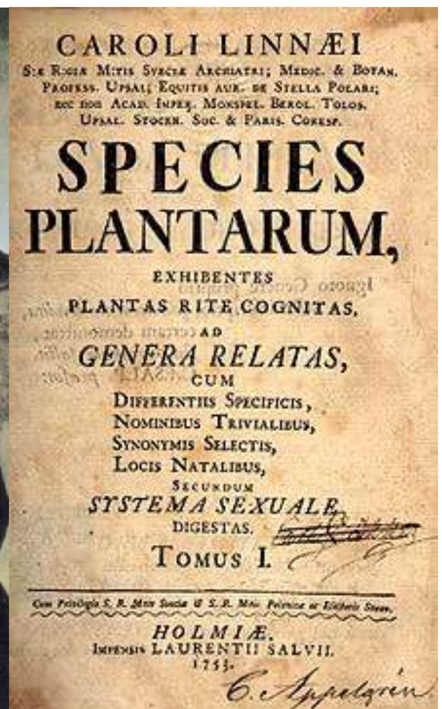


- An important aspect of systematics is **TAXONOMY**, which involves identifying, naming and classifying species.

Even so, "species" is used for research and communication

The system for naming living things began with the eighteenth-century Swedish naturalist **Carl Linnaeus** and his two-volume work ***Species Plantarum*** (The "*Kinds*" of Plants).

- It introduced a **binomial system of nomenclature** whereby the name of a species consists of two parts: the first part is the name of the **genus** (also called the generic name); and the second part is the **specific epithet**. For rosemary, the generic name is *Salvia* and the specific epithet is *rosmarinus*, so the species name is *Salvia rosmarinus* (see photograph below).



CAROLI LINNÆI

S:æ R:GÆ M:TIS SVECIÆ ARCHIATRI; MEDIC. & BOTAN. PROFESS. UPSAL; EQUITIS AUR. DE STELLA POLARI; nec non ACAD. IMPER. MONSPEL. BEROL. TOLOS. UPSAL. STOCKH. SOC. & PARIS. CORESP.

SPECIES PLANTARUM,

EXHIBENTES PLANTAS RITE COGNITAS, AD GENERA RELATAS, CUM DIFFERENTIIS SPECIFICIS, NOMINIBUS TRIVIALIBUS, SYNONYMIS SELECTIS, LOCIS NATALIBUS, SECUNDUM SYSTEMA SEXUALE DIGESTAS.

TOMUS I.

HOLMIÆ, IMPENSIS LAURENTII SALVII. 1753.

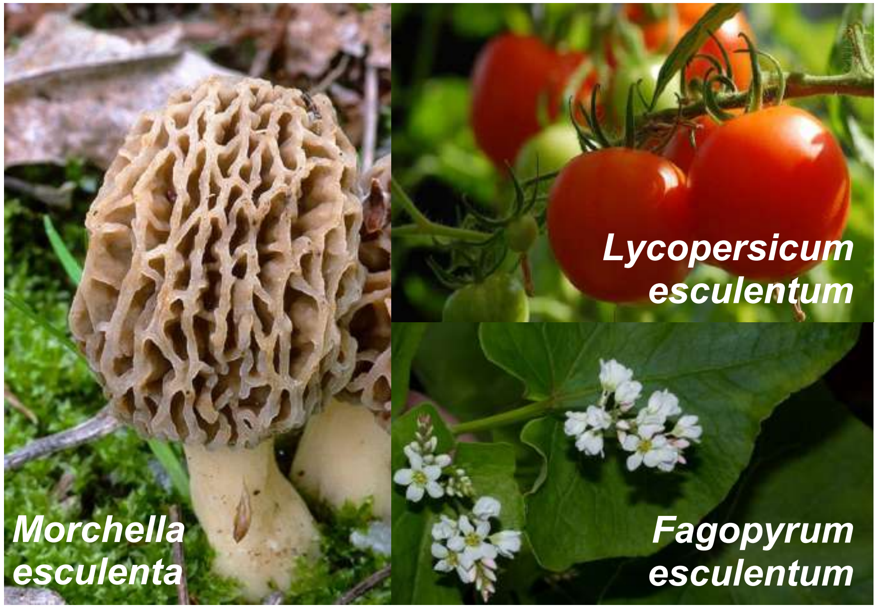
Even so, “species” is used for research and communication

The system of naming living things began with the eighteenth-century Swedish naturalist **Carl Linnaeus** and his two-volume work ***Species Plantarum*** (The “*Kinds*” of Plants).

- According to the **binomial system of nomenclature**, a generic name can be written alone when one is referring to the entire group of species that makes up that genus (the genus *Solanum*, which appears on a previous slide). A specific epithet is meaningless, however, when it is written alone. Moreover, specific epithets may be used in conjunction with dozens of different generic names but the same species name cannot be applied to different organisms.

The genus *Salvia*

The specific epithet “*esculentum*”



Even so, "species" are used for research and communication

The system of naming living things began with the eighteenth-century Swedish naturalist **Carl Linnaeus** and his two-volume work ***Species Plantarum*** (The "*Kinds*" of Plants).

- **According to the binomial system of nomenclature,** the genus name must be capitalised but the specific epithet must not. The species name should be italicised. When species names are handwritten and therefore cannot be italicised, they must be underlined.

CORRECT

- ***Lycopersicum esculentum***
- ***Fagopyrum esculentum***
- ***Morchella esculenta***
- ***Salvia rosmarinus***
- ***Boletus edulis***
- ***Bryum argenteum***

INCORRECT

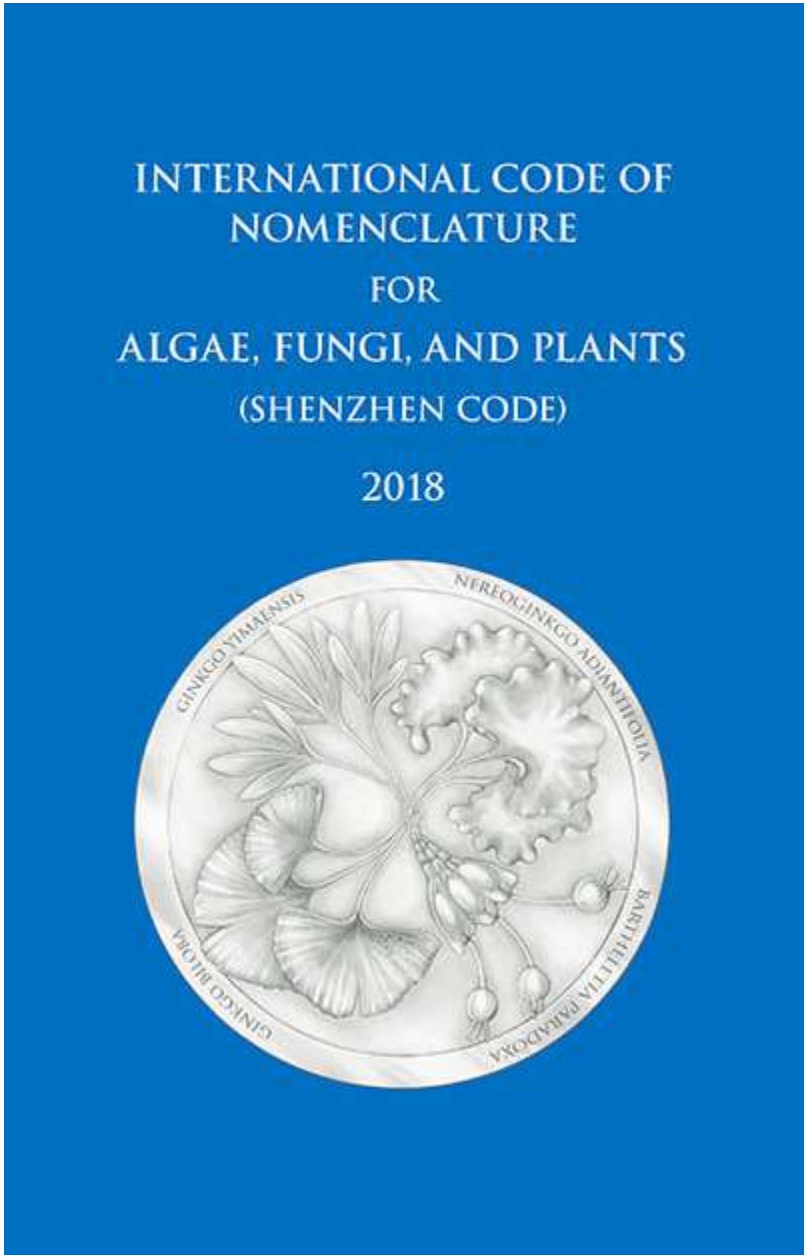
- ***Lycopersicum Esculentum***
- **Fagopyrum esculentum**
- ***morchella esculenta***
- ***salvia Rosmarinus***
- ***Boletus* edulis**
- **Bryum Argenteum**

Even so, “species” is used for research and communication

- **The priority principle**: the earliest binomial name given to a particular species has priority over other names later applied to the same species.

- The rules governing the scientific names of plants, photosynthetic protists, and fungi are embodied in the *International Code of Botanical Nomenclature.*

- Since scientific names are largely derived from Latin (or Greek), it helps to develop a basic understanding of the linguistic elements involved in formulating scientific names. Two kinds of words are used: nouns and adjectives. These words are inflected, i.e. **the terminations (endings) change, depending on the gender, number, and case**. Used in scientific names are three genders (masculine, feminine, and neuter), two numbers (singular and plural), and two cases (nominative and genitive).



Even so, “species” is used for research and communication

- Certain general trends are worth remembering. Names ending in -*us* (e.g. *Agaricus*, *Astragalus*) tend to be masculine unless they are names of trees, which tend to be feminine (*Aesculus*, *Prunus*, *Quercus*, *Ulmus*). Names ending in -*a* and -*is* are nearly always feminine (*Rosa*, *Yucca*; *Cannabis*, *Orchis*) unless they end in -*ma*, in which case they tend to be neuter (*Alisma*, *Melastoma*). Names ending in -*um* are always neuter (*Allium*, *Lilium*).

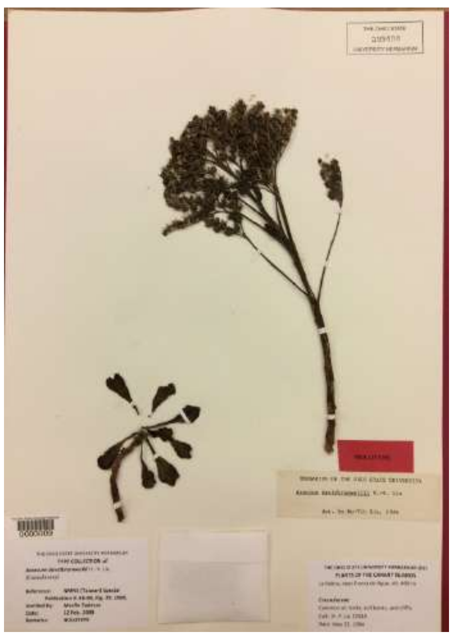
Quercus rotundifolia
(holm oak, encina)

Agaricus xanthodermus

Even so, “species” is used for research and communication

- Because of the danger of confusing names, **a specific epithet is always preceded by the name or the initial letter of the genus** that includes it: for example, *Quercus rotundifolia* or *Q. rotundifolia.*

- Each species has a **type specimen,** usually a dried plant specimen housed in a museum or **herbarium**, which is designated either by the person who originally named that species or by a subsequent author if the original author failed to do so. The type specimen serves as a basis for comparison with other specimens for determining whether they are members of the same species.




Plant species types

Fungal species type

Even so, “species” is used for research and communication

- A species name (genus name plus specific epithet) is usually followed by the **authorship** or **name of the person who first described** and named the species. <u>The authorship should NOT be written in italics</u>.

- This rule also applies to other taxa, so that the names of genera, families, etc. must also be followed by their authorship.

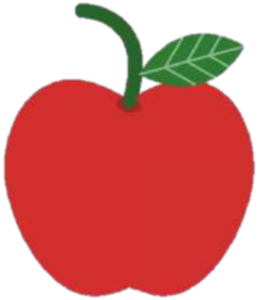
- Frequently, standardised abbreviations are used for authors’ names. Thus, LINNEO is abbreviated as L., CAVANILLES is abbreviated as Cav., and DE CANDOLLE is abbreviated as DC.

- When it comes to detailed studies, the citation of the **protologue** and the date and place of publication of the taxon are also indicated following standardised abbreviation.

- For **example**, the full, correct citation of the scientific name of the apple tree is:

  Malus sylvestris Miller, Gard. Dict. ed. 8, 1 (1768)

  This means that Miller described this species in the eighth edition of the work entitled "The Gardeners Dictionary", which was published in 1768.



Taxonomic ranks or categories

Living beings are identified from the following:
✓ Morphological characteristics (phenotypic, whether adaptive, etc.)
✓ Metabolic (biochemical) characteristics
✓ Biological characteristics (ontogeny, reproduction, life cycles, etc.)
✓ Molecular characteristics (DNA sequences)

"*Tillandsia* (plant) similar to *Usnea* (lichen)"

Taxonomic ranks or categories

Living beings are identified based on the following:

- ✓ Morphological characteristics (phenotypic, whether adaptive, etc.)
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- ✓ Molecular characteristics (DNA sequences)

Once the organisms have been accurately identified, they are arranged into Classification Systems (the result of research on systematics and taxonomy)

- ✓ Scientific classification focuses on placing organisms within hierarchical groups that indicate their relationships to other organisms. It is the method by which biologists group and categorise organisms by biological type.
- ✓ The rank (= "taxonomic category") is the level (relative position) in a hierarchy.

Current classification systems arrange entities in a hierarchical series of nested classes in which similar or related classes at one hierarchical level are combined comprehensively into more inclusive classes at the next higher level.

- ✓ A class is defined as **"a collection of similar entities",** whereby **similarity** involves the entities **having attributes or traits in common**.
- ✓ The classes are called **'taxa'** (singular **'taxon'**).

Taxonomic ranks or categories

There are seven main ranks defined by **international nomenclature codes.**

Rank		Plants	Fungi
DOMAIN			
KINGDOM			
SUBKINGDOM			
PHYLUM	= Division:	-phyta	(-mycota)
SUBPHYLUM	=Subdivision:	-phytina	(-mycotina)
CLASS	=Class:	-opsida, -phyceae	(-mycetes)
SUBCLASS	=Subclass:	-idea	(-mycetidae)
ORDER	=Order:	-ales	(-ales)
SUBORDER			
FAMILY	=Family:	-aceae	(-aceae)
SUBFAMILY			
GENUS			
SUBGENUS			
SPECIES			
SUBSPECIES			

GENUS + SPECIES → BINOMEN

SPECIES are the most fundamental units of taxonomy

Similarity means that the entities have attributes or traits in common.

The similarity between organisms in the same taxon is not arbitrary **but the result of shared descent from their nearest common ancestor.**

Taxonomic ranks or categories

How much can you tell about an organism when you know its place in the classification system? Below is an **example for plants.** Note that the descriptions here do not define the categories but tell you something about their characteristics.

Category	Taxon	Description
Maize		
Kingdom	Plantae	Organisms that are primarily terrestrial, with chlorophylls *a* and *b* contained in chloroplasts, spores enclosed in sporopollenin (a tough wall substance), and nutritionally dependent multicellular embryos
Phylum	Anthophyta	Vascular plants with seeds and flowers; ovules enclosed in an ovary, pollination indirect; the angiosperms
Class	Monocotyledoneae	Embryo with one cotyledon; flower parts usually in threes; many scattered vascular bundles in the stem; the monocots
Order	Poales	Monocots with fibrous leaves; reduction and fusion in flower parts
Family	Poaceae	Hollow-stemmed monocots with reduced greenish flowers; fruit a specialized achene (caryopsis); the grasses
Genus	*Zea*	Robust grasses with separate staminate and carpellate flower clusters; caryopsis fleshy
Species	*Zea mays*	Maize, or corn

Adapted from Eckert & Everhart (2013)

Taxonomic ranks or categories

How much can you tell about an organism when you know its place in the classification system? Below is an **example for plants.** Note that the descriptions here do not define the categories but tell you something about their characteristics.

Edible Mushroom

Kingdom	Fungi	Nonmotile, multinucleate, heterotrophic, absorptive organisms in which chitin predominates in the cell walls
Phylum	Basidiomycota	Dikaryotic fungi that form a basidium bearing four spores (basidiospores); subphyla Agaricomycotina, Pucciniomycotina, and Ustilaginomycotina
Class	Agaricomycetes	Fungi that produce basidiomata, or "fruiting bodies," and club-shaped, aseptate basidia that line gills or pores; the hymenomycetes
Order	Agaricales	Fleshy fungi with radiating gills or pores
Family	Agaricaceae	Agaricales with gills
Genus	*Agaricus*	Dark-spored soft fungi with a central stalk and gills free from the stalk
Species	*Agaricus bisporus*	The common edible mushroom

Adapted from Eckert & Everhart (2013)

Online resources for PLANTS

I·P·N·I

IPNI provides nomenclatural information (spelling, author, types and first place and date of publication) for the scientific names of Vascular Plants from Family down to infraspecific ranks. New records are added daily, and the IPNI team are continuously working to improve data standardisation.

https://www.ipni.org/

World Flora Online

DESCRIPTIONS OF
38%
OF 350,510 ACCEPTED
SPECIES INCLUDED

World Flora Online is an international initiative to achieve Target 1 of the Global Strategy for Plant Conservation and provides a global overview of the diversity of plant species. It is the essential tool for conservation planners, policymakers and practitioners at all levels.

http://www.worldfloraonline.org/

Tropicos®

connecting the world to botanical data since 1982

The Tropicos database links over 1.37M scientific names with over 5.01M specimens and over 971K digital images. The data include over 159K references from over 54.2K publications offered as a free service to the world's scientific community.

https://www.tropicos.org/home

EURO+MED PlantBase

The Euro+Med PlantBase provides an on-line database and information system for the vascular plants of Europe and the Mediterranean region against an up-to-date and critically evaluated consensus taxonomic core of the species concerned.

https://www.emplantbase.org/home.html

Online resources for ALGAE

algaeBASE

AlgaeBase is a global algal database of taxonomic, nomenclatural and distributional information.

https://www.algaebase.org/

Online resources for FUNGI

Index Fungorum

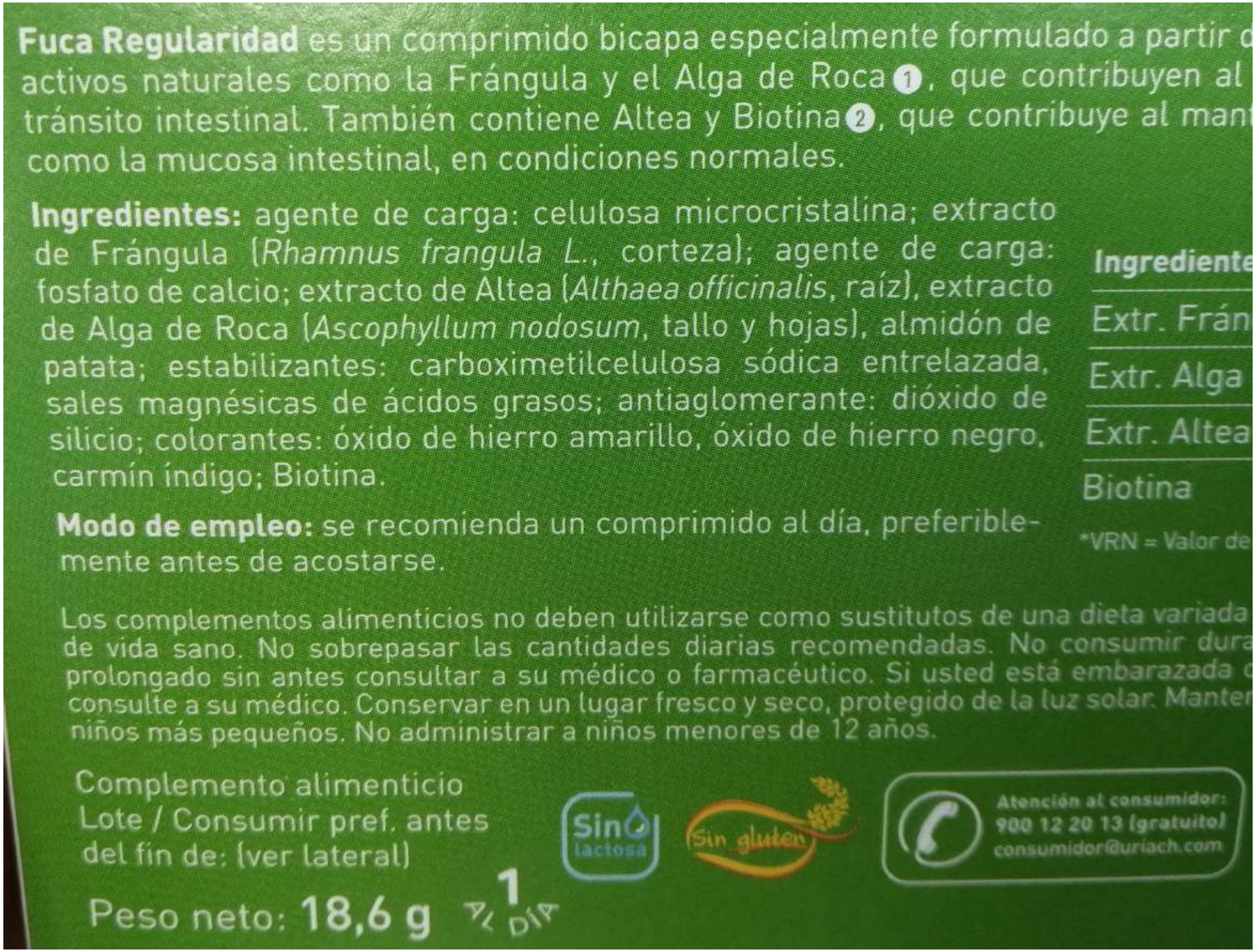
The Index Fungorum, the global fungal nomenclator coordinated and supported by the Index Fungorum Partnership, contains names of fungi (including yeasts, lichens, chromistan fungal analogues, protozoan fungal analogues and fossil forms) at all ranks.

http://www.indexfungorum.org/

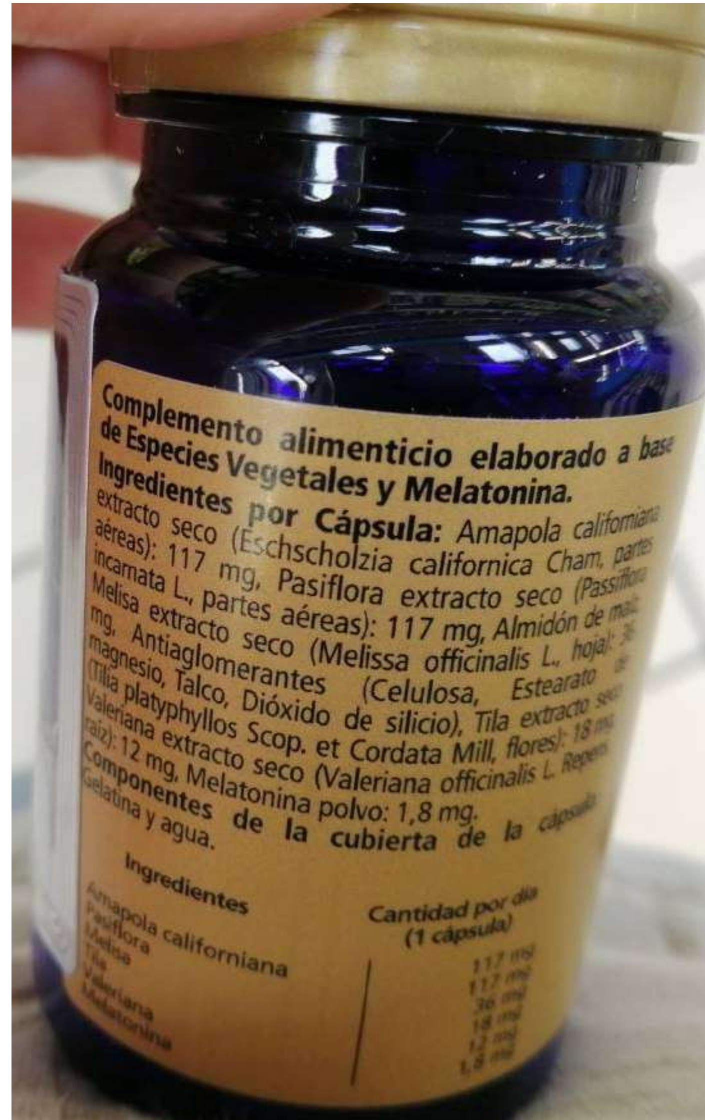
MycoBank is an online database aimed as a service to the mycological and scientific community by documenting mycological nomenclatural novelties (new names and combinations) and associated data such as descriptions and illustrations. Pairwise sequence alignments and polyphasic identifications of fungi and yeasts against curated references databases are proposed.

https://www.mycobank.org/

Right or wrong?

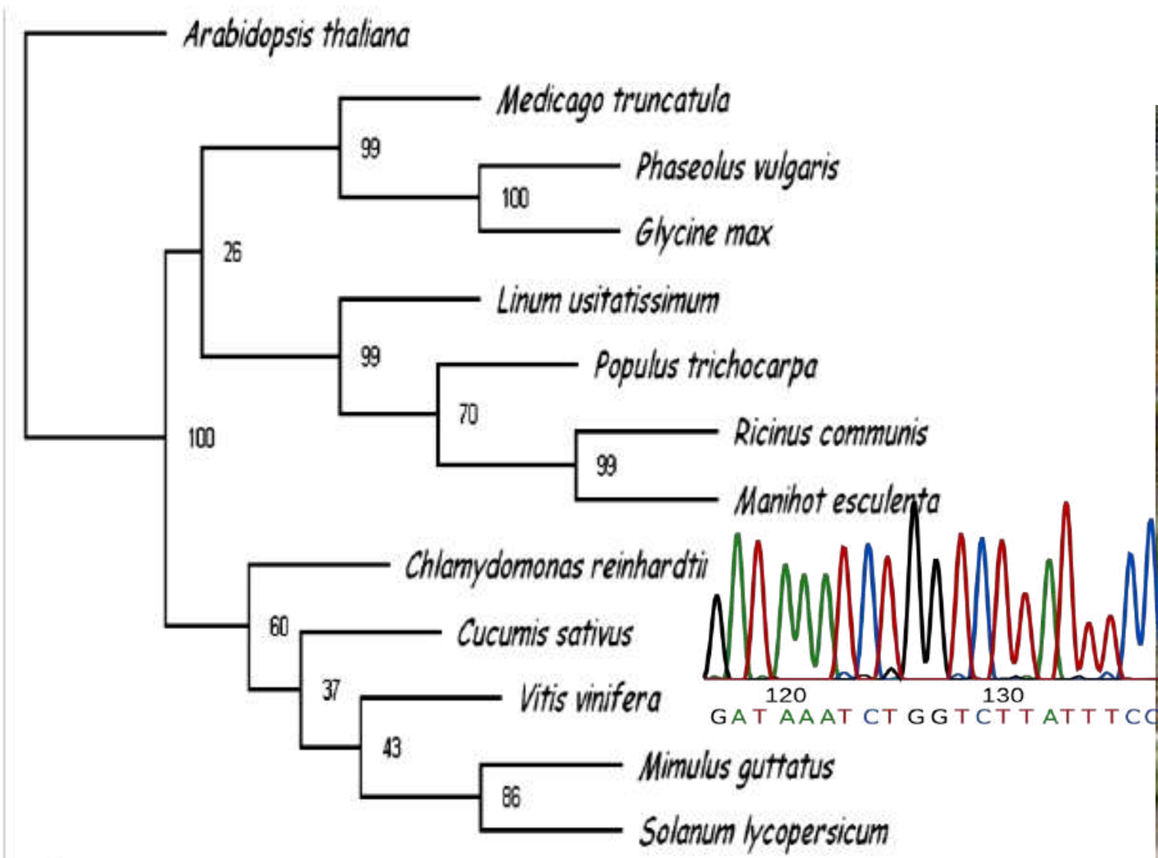


Right or wrong?



Lecture 03 part 2

Plant and fungal phylogenetics



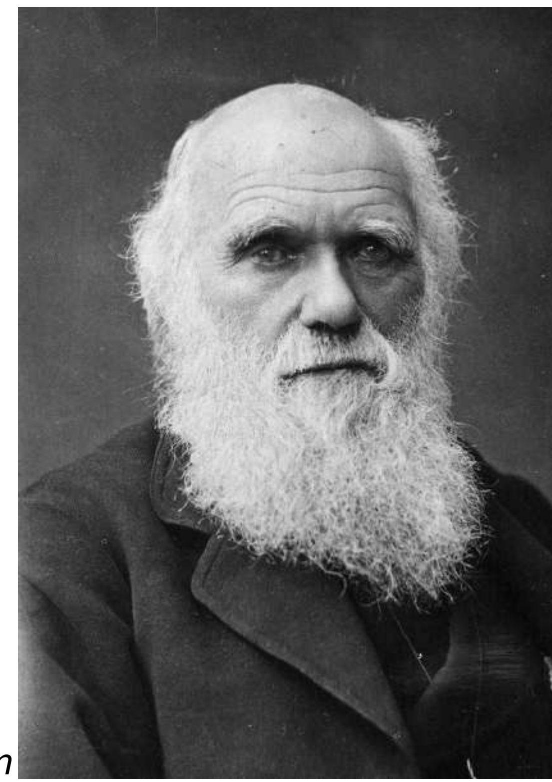
The castor oil plant (*Ricinus communis*)

What is a phylogeny?

"For Linnaeus and his immediate successors, the goal of taxonomy was the revelation of the grand, unchanging design of creation. After publication of Darwin's *On the Origin of Species* in 1859, however, differences and similarities among organisms came to be seen as products of their evolutionary history, or **phylogeny**." (Raven et al. 2013)

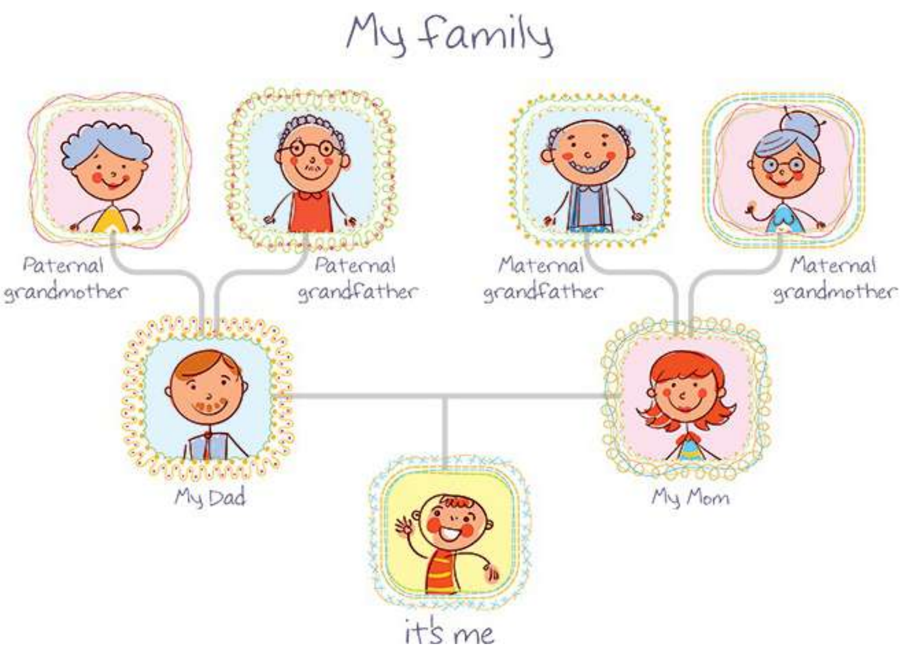
Linnaeus

VS



Darwin

What is a phylogeny?

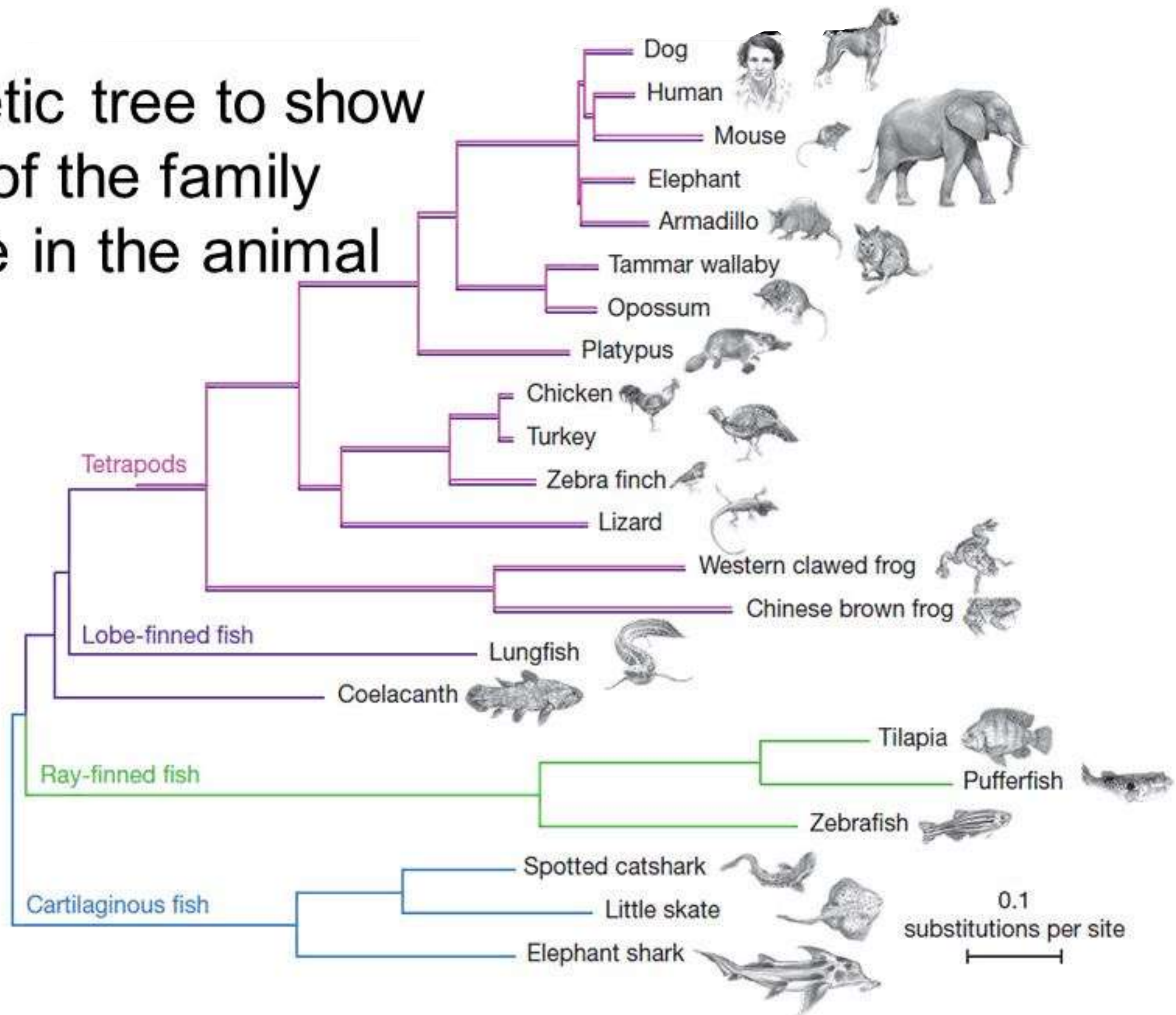


Biologists want classifications to be not only informative and useful but also an accurate reflection of the evolutionary relationships among organisms. Such classifications are referred to as **natural classifications**. The evolutionary relationships among organisms have often been diagrammed as **phylogenetic trees**, which depict the genealogic relationships between taxa as *hypothesized* by a particular investigator or group of investigators (Raven et al. 2013).

Example of a phylogeny

The hominid evolution

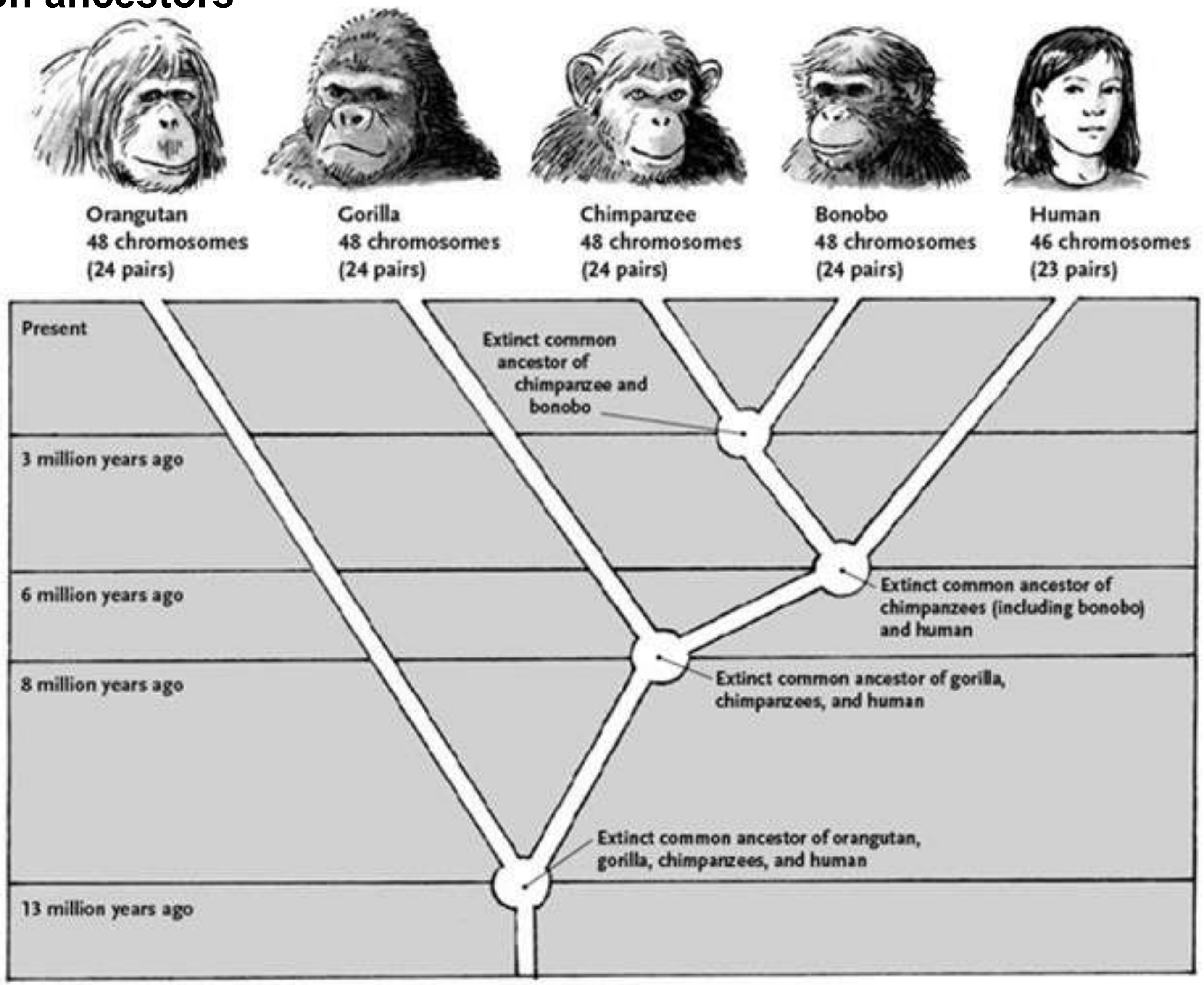
Phylogenetic tree to show the place of the family Hominidae in the animal kingdom.



https://slideplayer.com/slide/7848541/

Example of a phylogeny

Common ancestors



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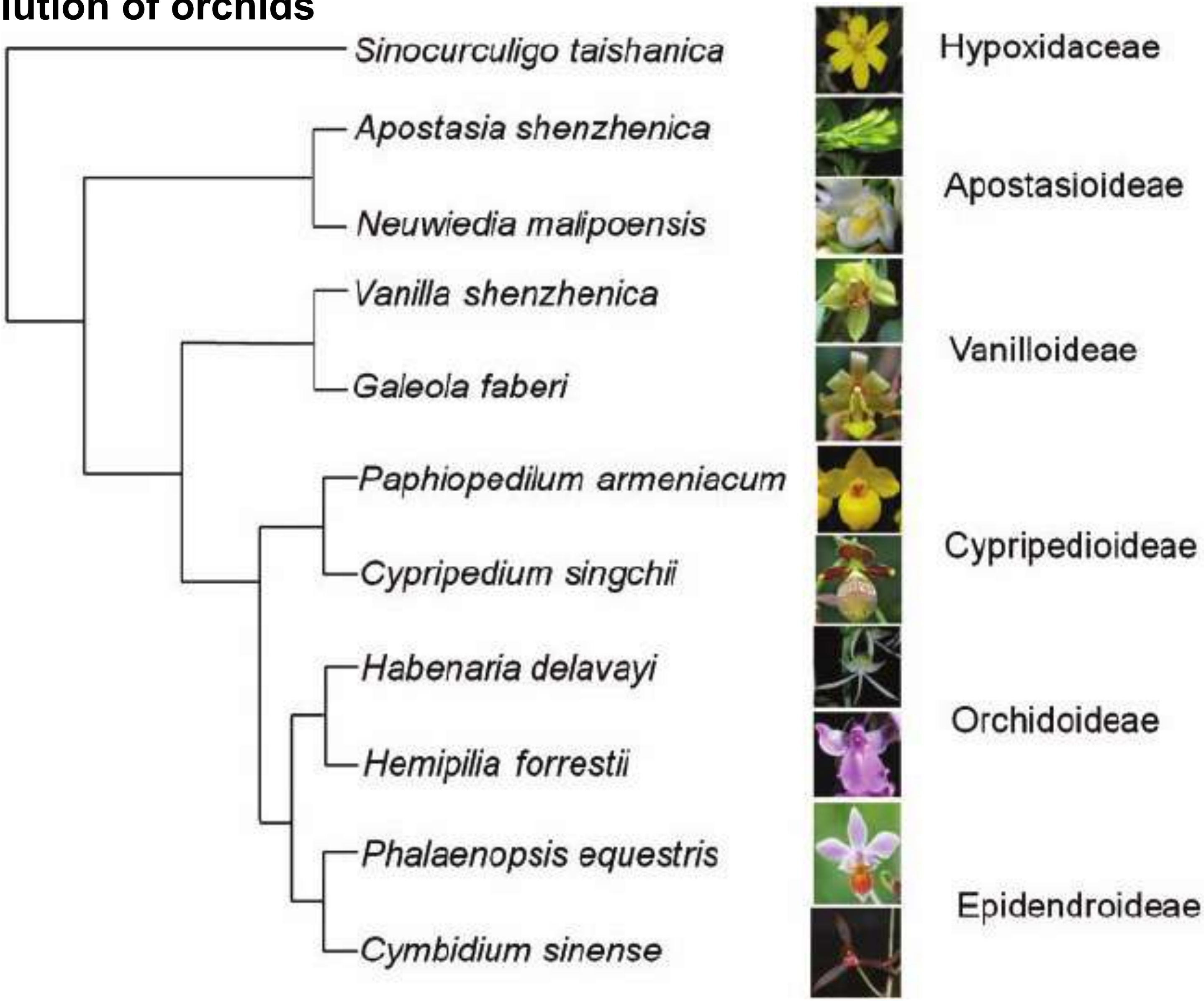
Example of a phylogeny

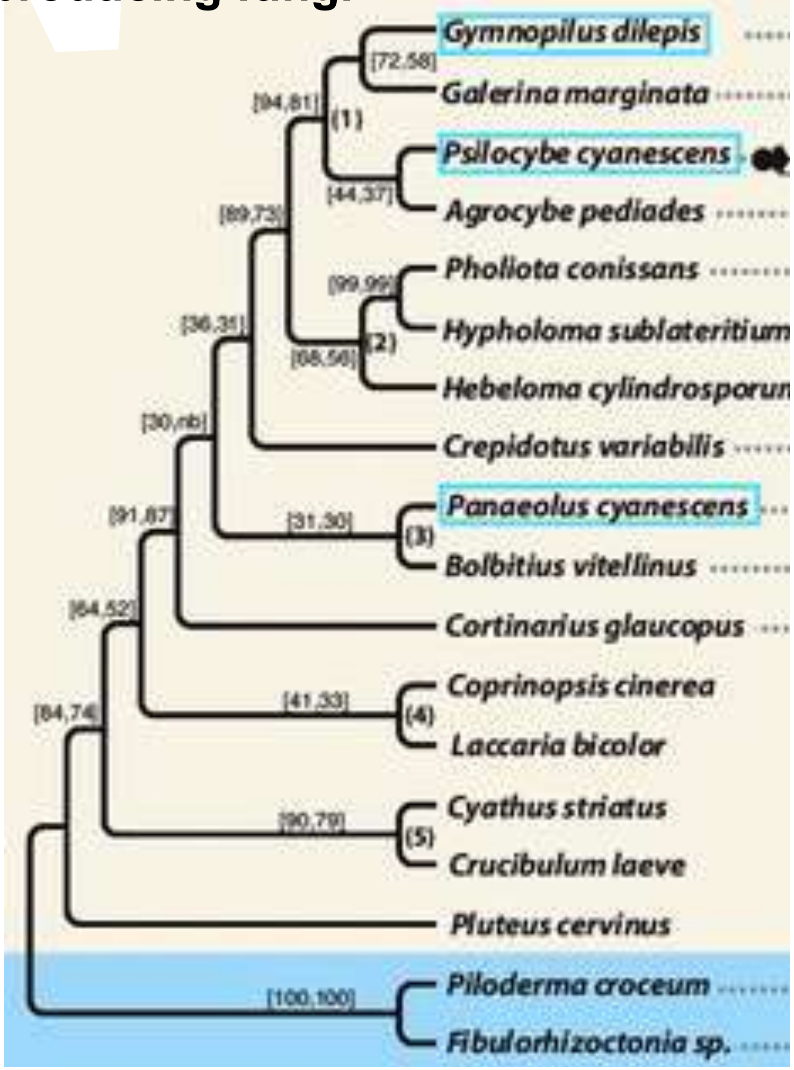
The evolution of orchids



Tsai et al. (2013) OrchidBase 2.0.

Example of a phylogeny: psilocybin-producing fungi

The evolution of psilocybin-producing fungi



Gymnopilus dilepis

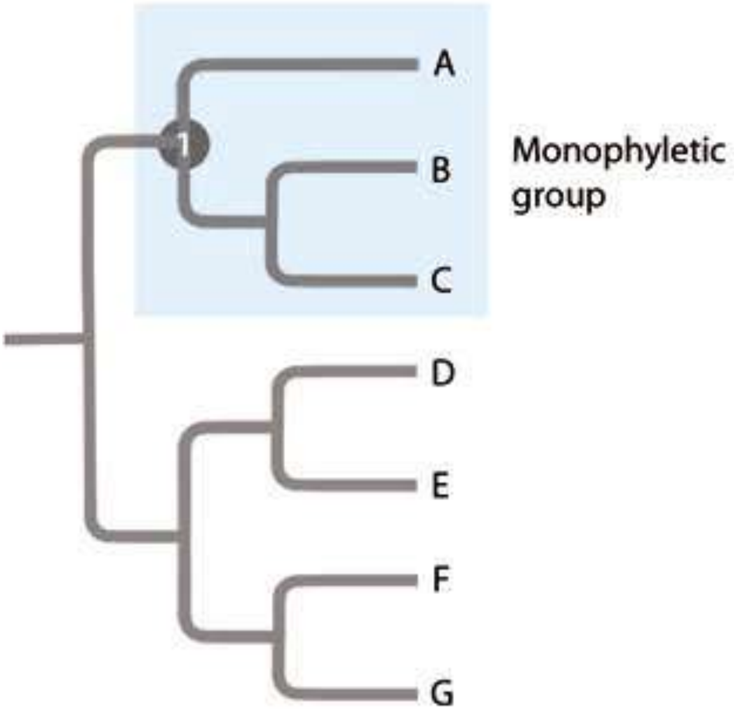
Psilocybe cyanescens

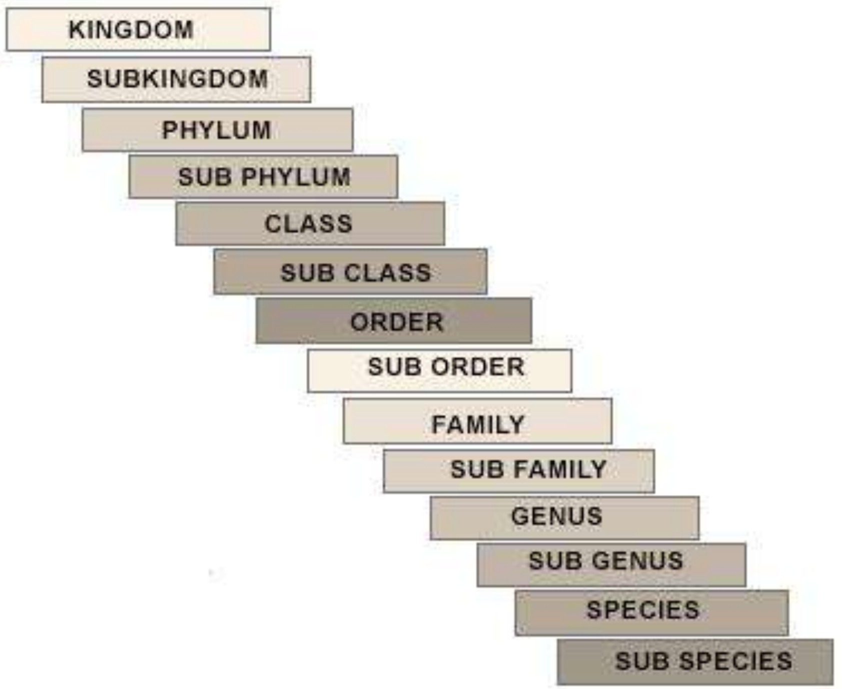
Panaeolus cyanescens

Reynolds et al. (2018)

Monophyly

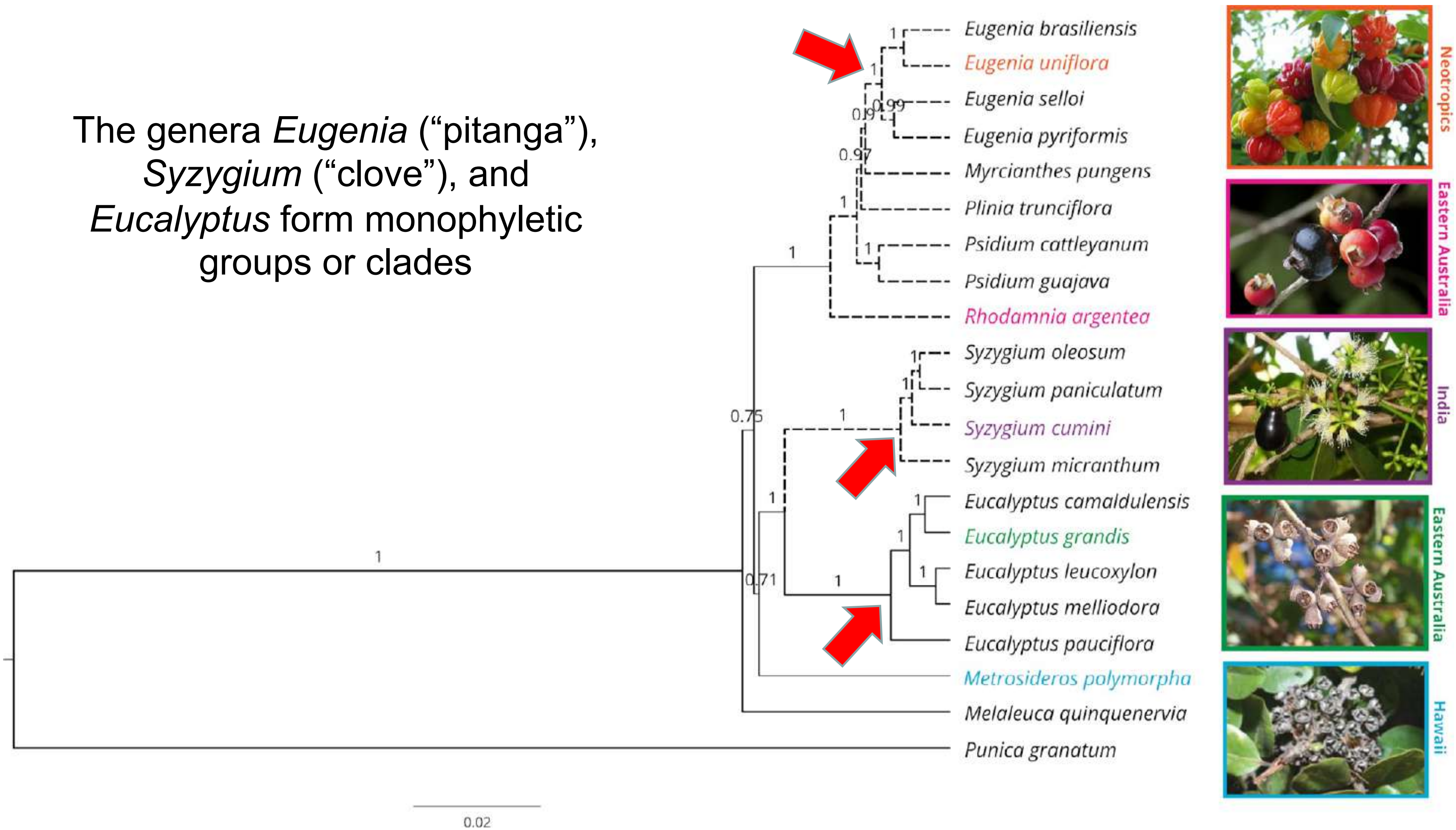
In a classification scheme that accurately reflects phylogeny, every taxon should be monophyletic. A **monophyletic group** (also called a **clade**) is composed of an ancestor and *all* its descendants; none of its descendants are excluded. Thus, a genus should consist of all species descended from the most recent common ancestor – and only of species descended from that ancestor. Simply stated, a monophyletic group is one that can be removed from a phylogenetic tree by one "cut" of the tree. A phylogenetic classification attempts to give formal taxonomic names only to groups that are monophyletic, although <u>not every monophyletic group may need a name</u> (Raven et al. 2013).





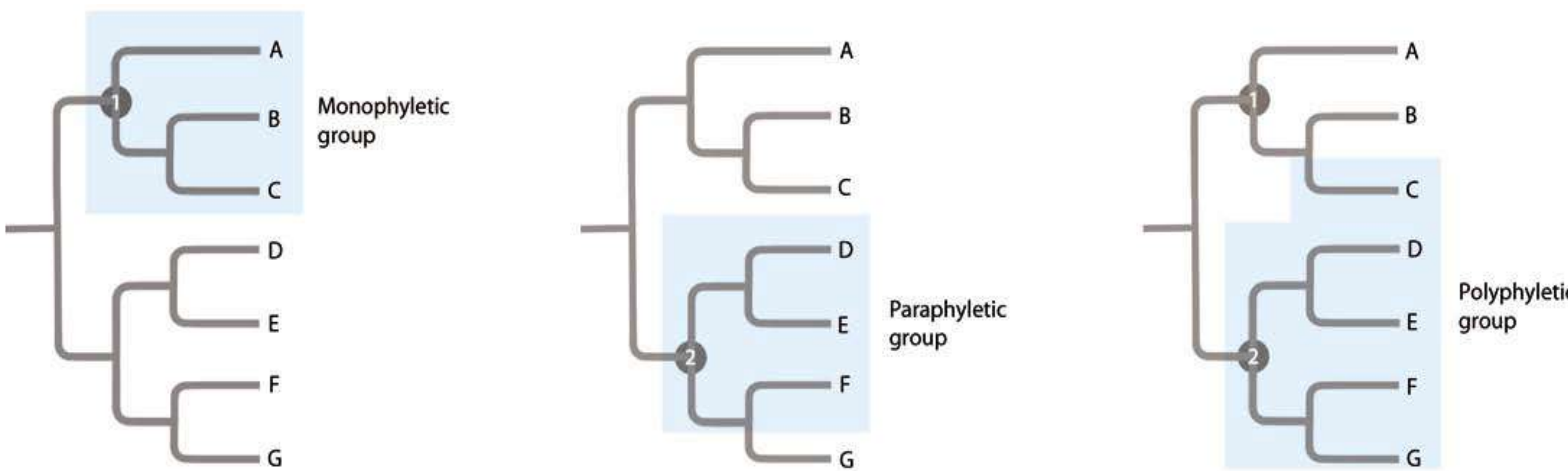
Monophyletic groups in the family Myrtaceae

The genera *Eugenia* ("pitanga"), *Syzygium* ("clove"), and *Eucalyptus* form monophyletic groups or clades

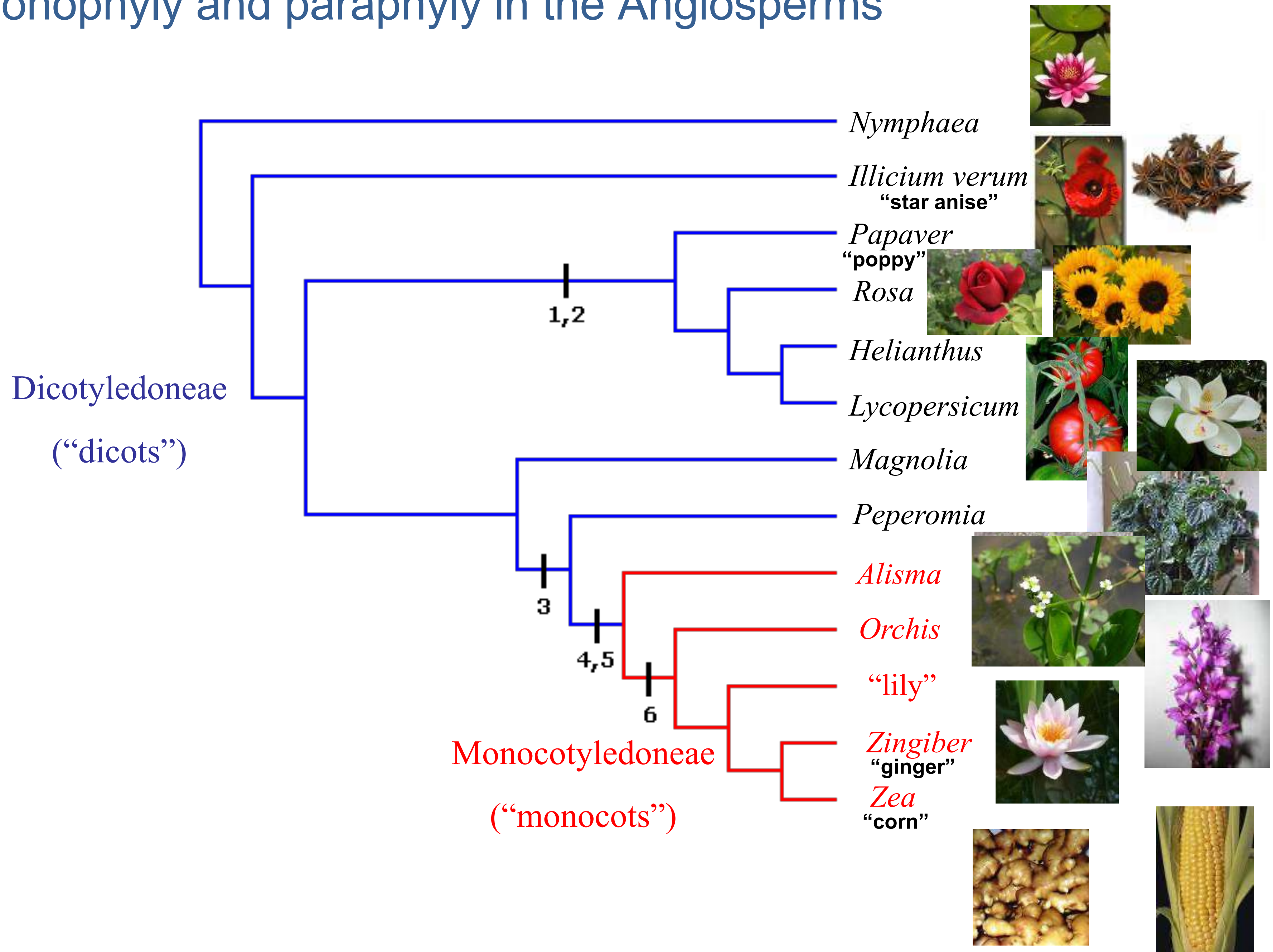


Paraphyly and polyphyly

As new information becomes available, researchers sometimes find that current taxonomic groups are not monophyletic. There are two such groups: **paraphyletic** and **polyphyletic**. A paraphyletic group is one consisting of a common ancestor, but not all descendants of that ancestor. In phylogenetic classification, paraphyletic groups are not given formal names. A polyphyletic group is a group with two or more ancestors, but not including the true common ancestor of its members (Raven et al. 2013).



Monophyly and paraphyly in the Angiosperms



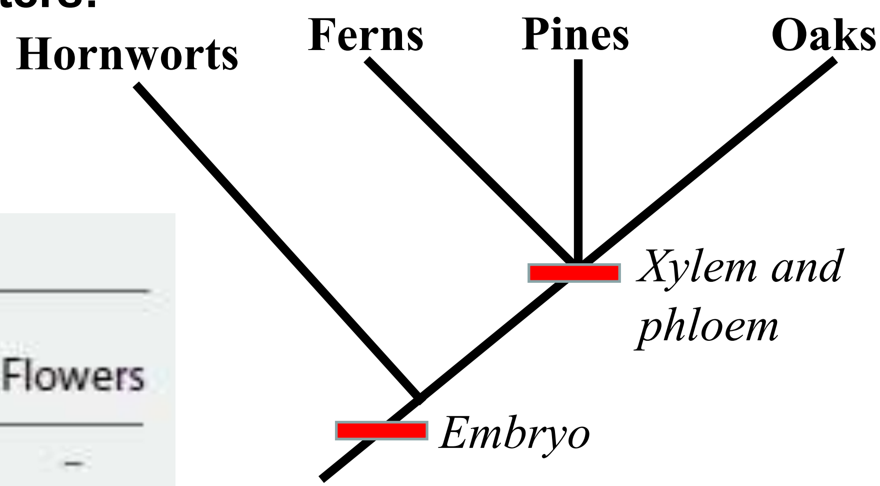
Cladograms and how to construct them

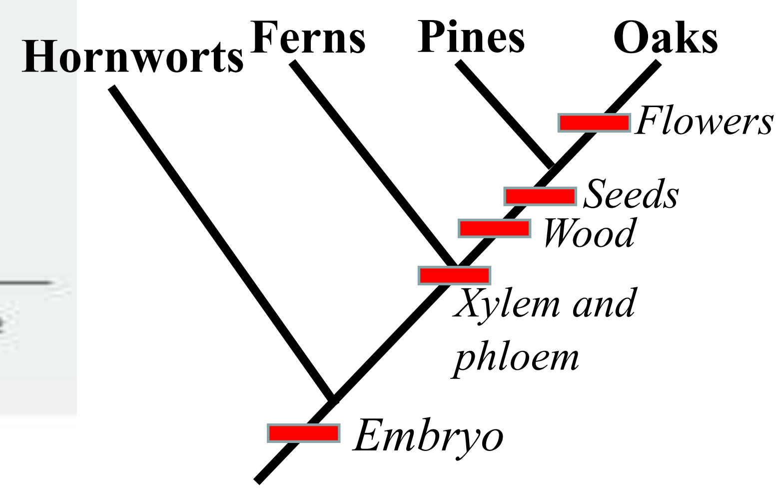
A cladogram is a **graphical representation** of a working model, or hypothesis, of the <u>phylogenetic relationships among a group of organisms</u>.

1. Based on a set of morphological characters:

	Characters*			
Taxon	Xylem and Phloem	Wood	Seeds	Flowers
Hornworts	–	–	–	–
Ferns	+	–	–	–
Pines	+	+	+	–
Oaks	+	+	+	+

*The character state "present" (+) is the derived condition; the character state "absent" (–) is the ancestral condition.





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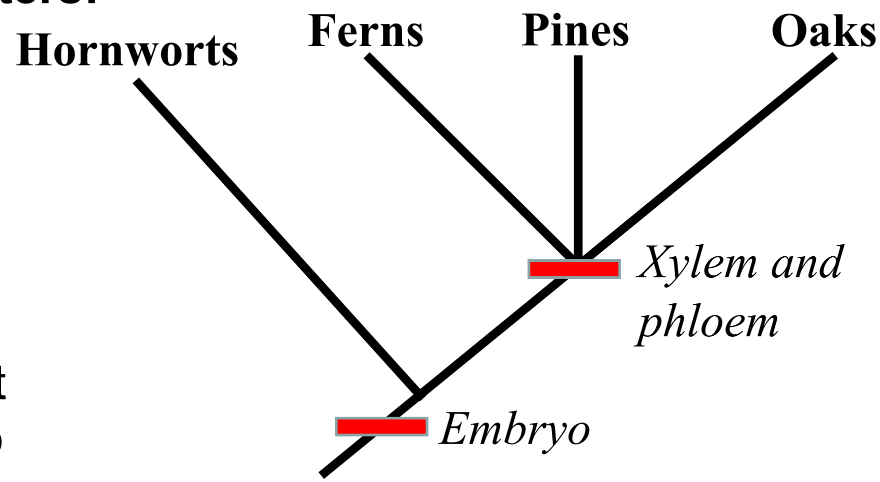
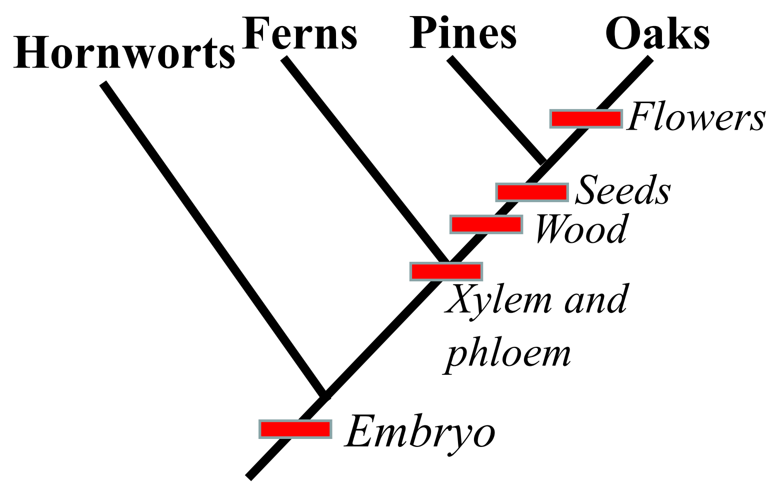


Synapomorphies are <u>character</u> states that arose in the common ancestor of the group and are present in all its members. Character states are two or more forms of a particular feature, such as the presence or absence of wood or flowers.



Cladograms and how to construct them

A cladogram is a **graphical representation** of a working model, or hypothesis, of the phylogenetic relationships among a group of organisms.

2. Based on a set of molecular characters:

DNA nucleotides

A= adenine

C= cytosine

T= thymine

G= guanine

Each position is a character and each possibility (A, C, T, G) is a character state.

Example of a phylogenetic study in fungi

Lab work

Starting from a piece of the fruiting body of a mushroom

Example of a phylogenetic study in fungi

Lab work

Fungal sample

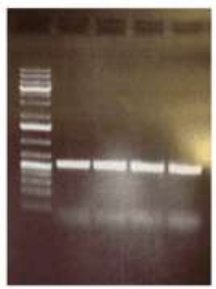
⇩

DNA extraction

⇩

PCR amplification using universal primers for ITS (e.g. ITS1F-ITS4)

⇩



Gel electrophoresis of the PCR amplicons

⇩

PCR purification, electrophoresis checking, and preparation for DNA sequencing by SANGER technology

Obtention of a raw DNA sequence (electropherogram)

⇩

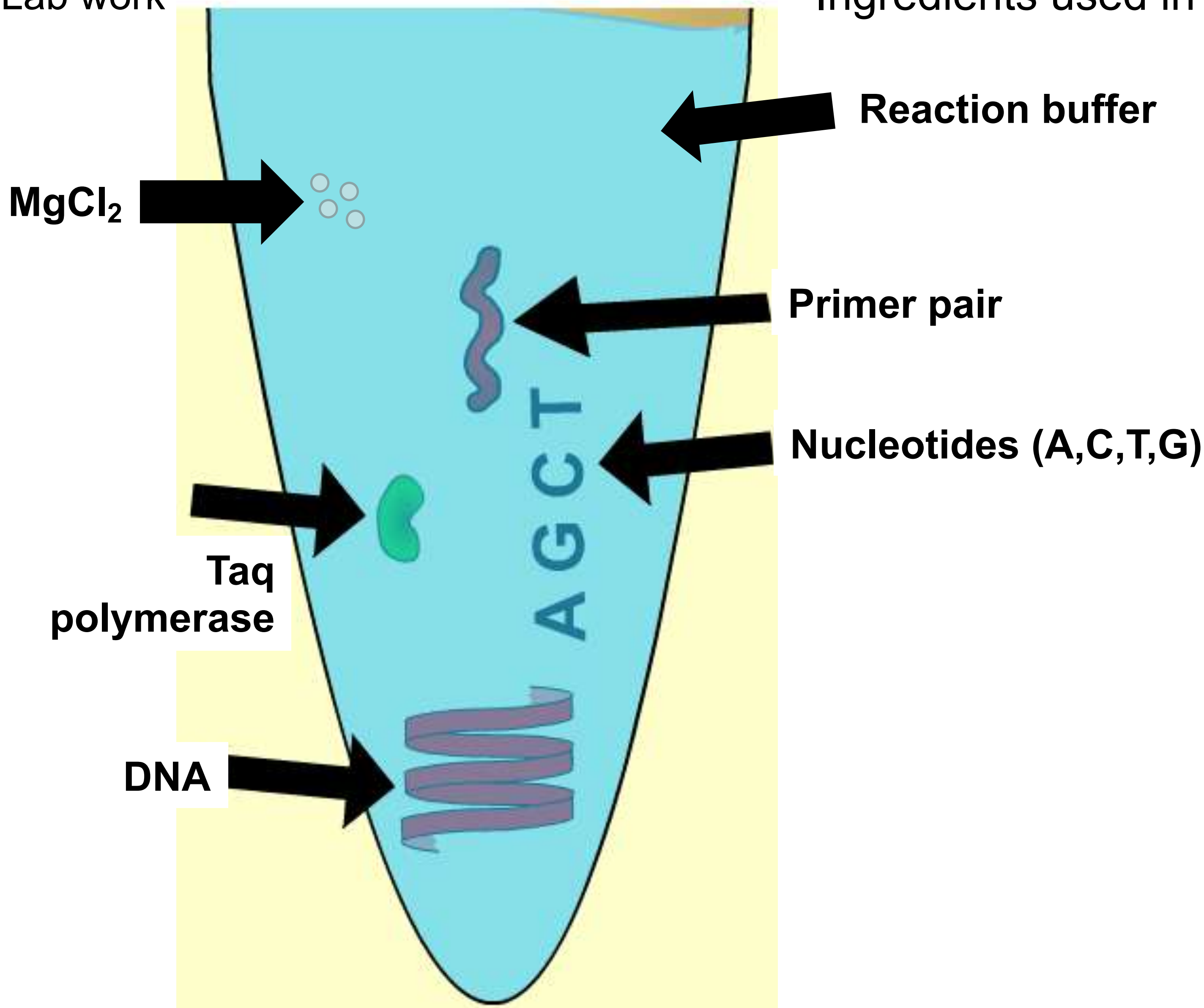
Bioinformatic analysis of the sequence

Adapted from https://studylib.net/doc/9563516/lesson-on-molecular-biology-produced-in-collaboration

Example of a phylogenetic study in fungi

Lab work

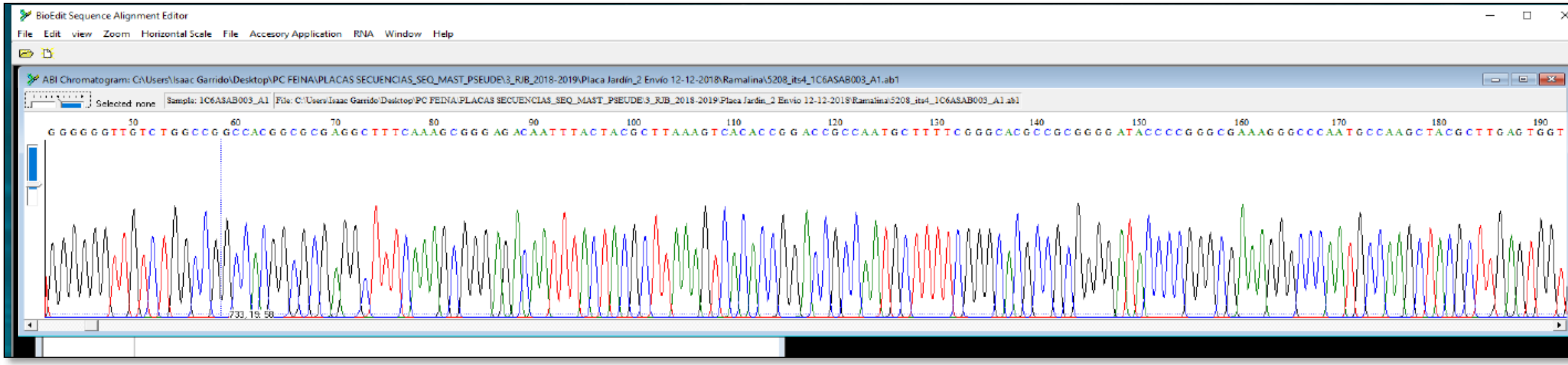
Ingredients used in a standard PCR



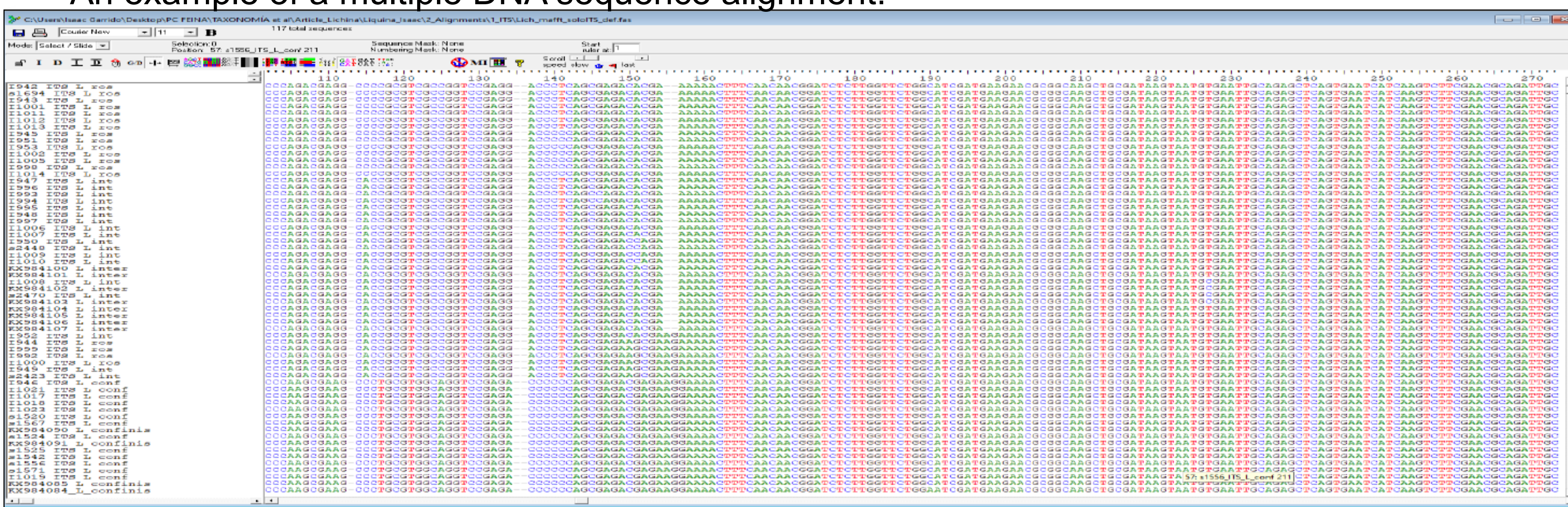
Example of a phylogenetic study in fungi

Boinformatic work

- Example of a fungal raw DNA sequence:



- An example of a multiple DNA sequence alignment:

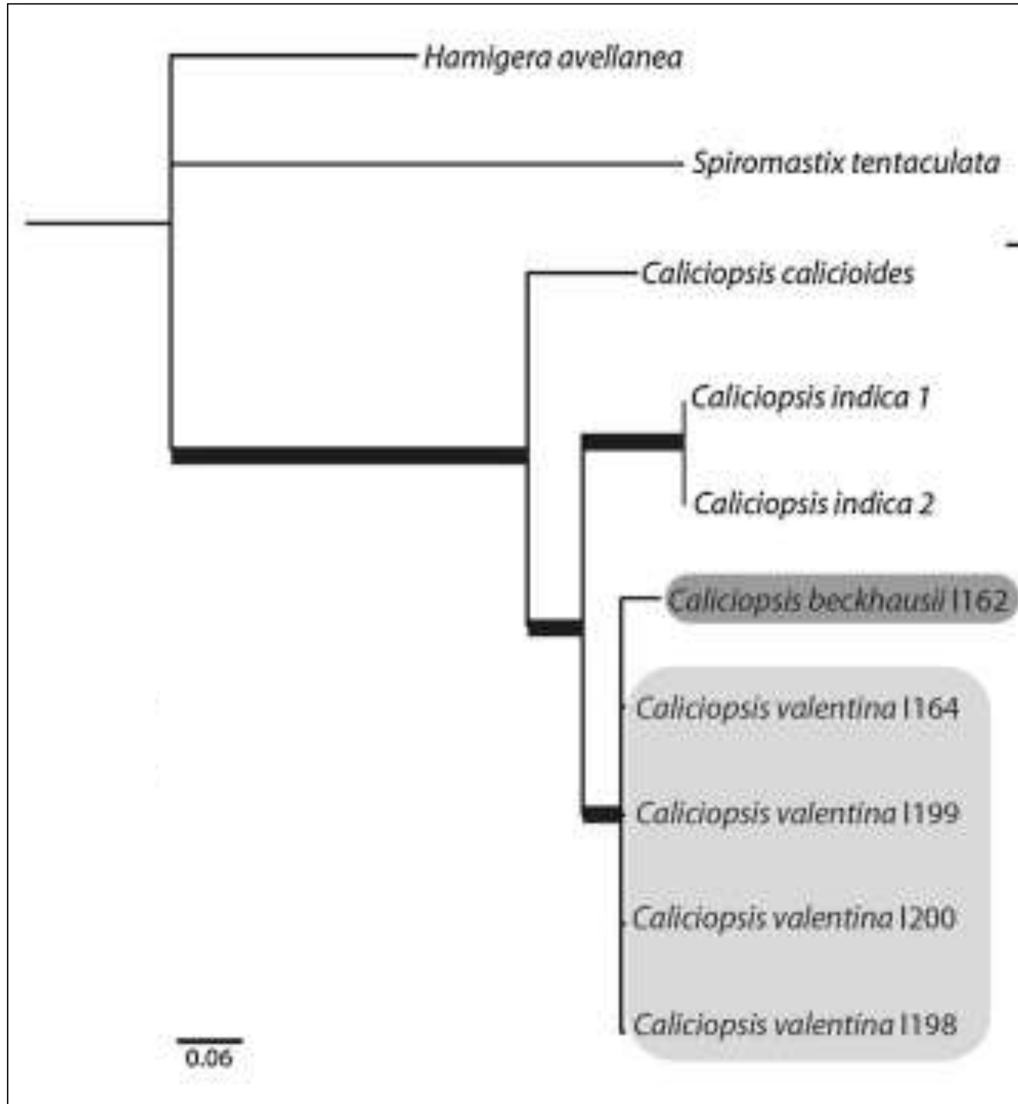


Example of a phylogenetic study in fungi

Boinformatic work

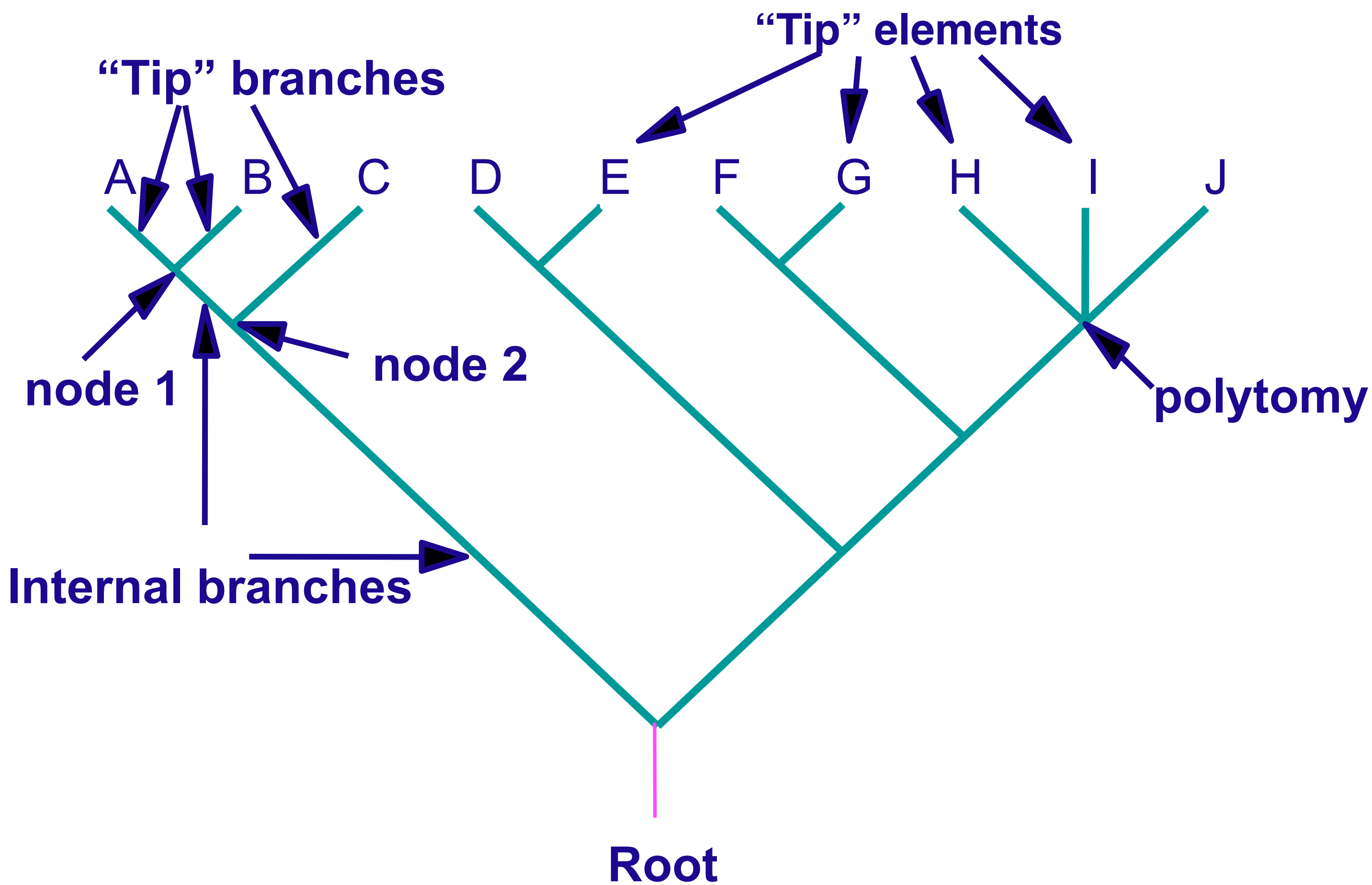
- The resulting phylogenetic tree:

Caliciopsis valentina
(Garrido-Benavent & Pérez-Ortega 2015)



Further interpretation of phylogenetic trees

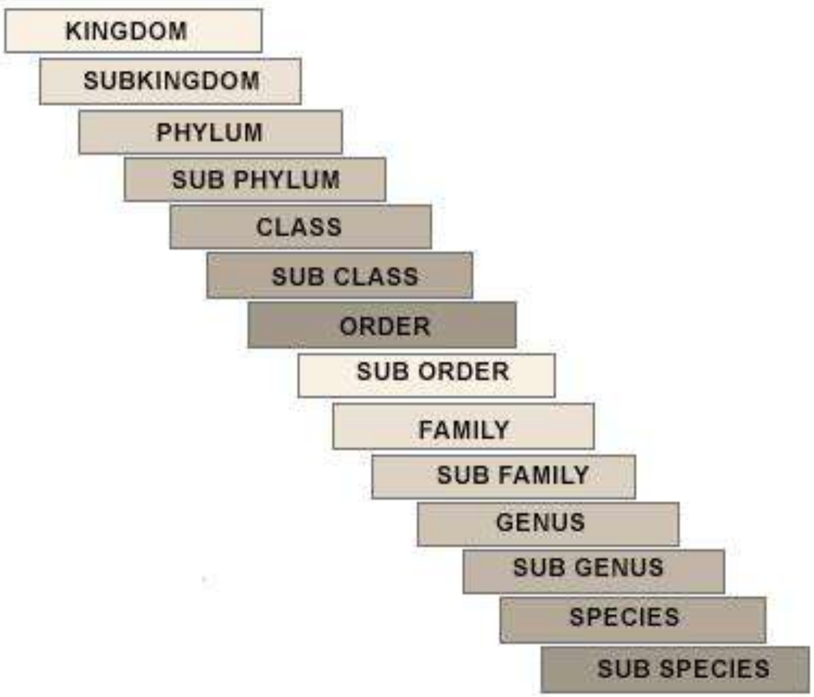
A ***SPECIES*** is often a "tip" on a phylogeny (or cladogram, as shown in the figure below), i.e. the smallest set of organisms that share an ancestor and can be distinguished from other such sets.

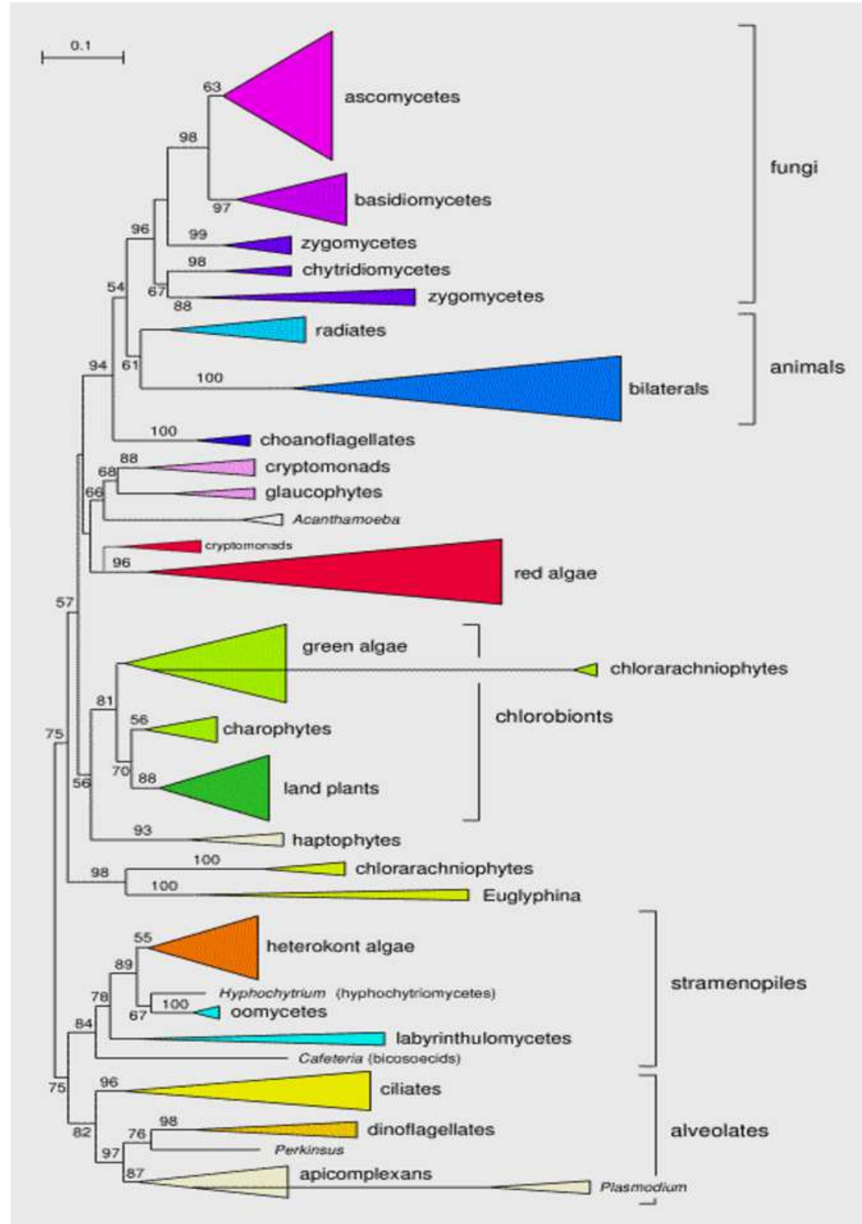


Further interpretation of phylogenetic trees

In a large tree that includes all the organisms (see the image on the right):

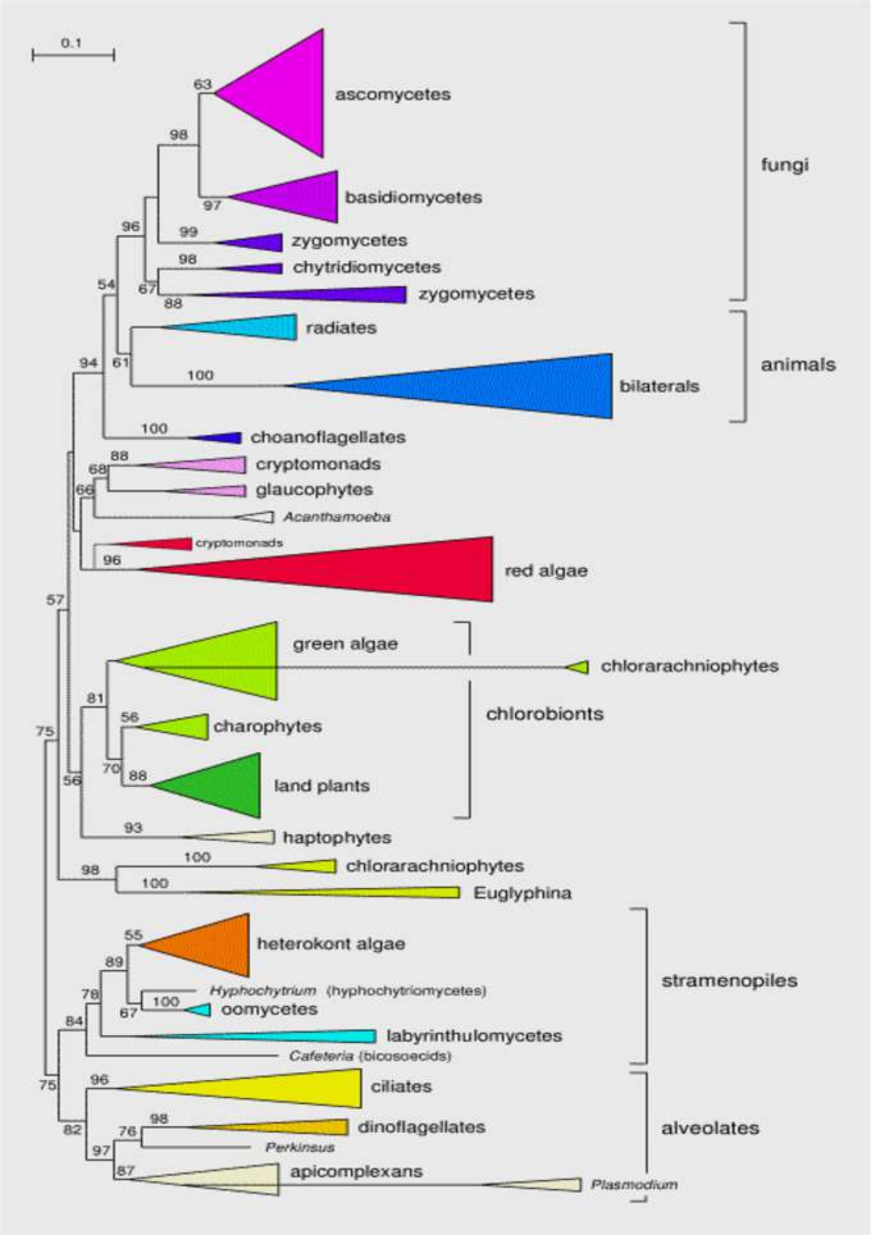
- the "tip" branches often represent the ***species***.
- the most internal branches often represent high taxonomic ranks (from ***genera*** to families and orders, or even to ***kingdoms***).





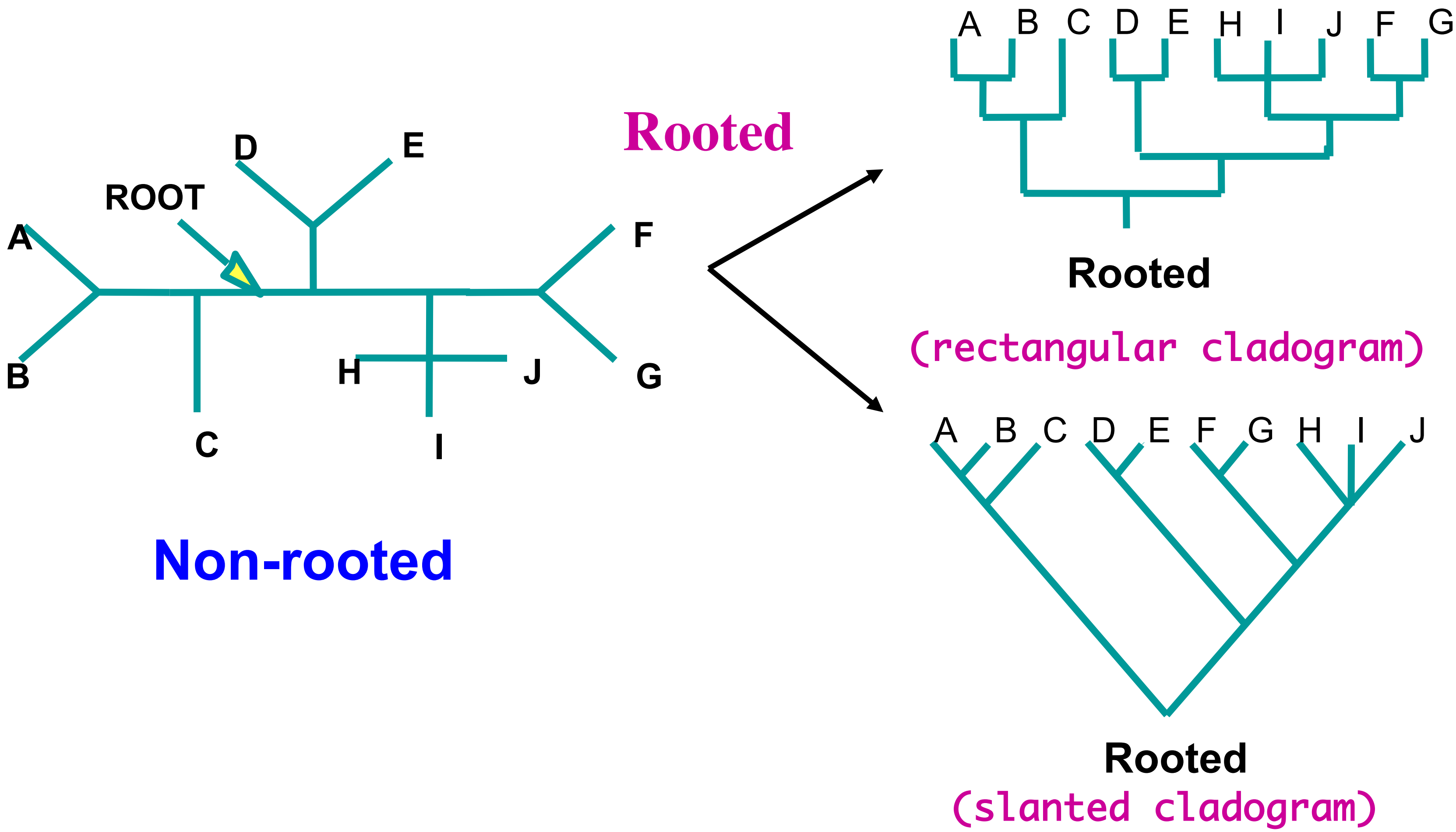
Further interpretation of phylogenetic trees

Organisms with the largest number of **identical molecular and/or morphological characters** will tend **to get closer in a phylogenetic tree** and, therefore, in any natural classification system.



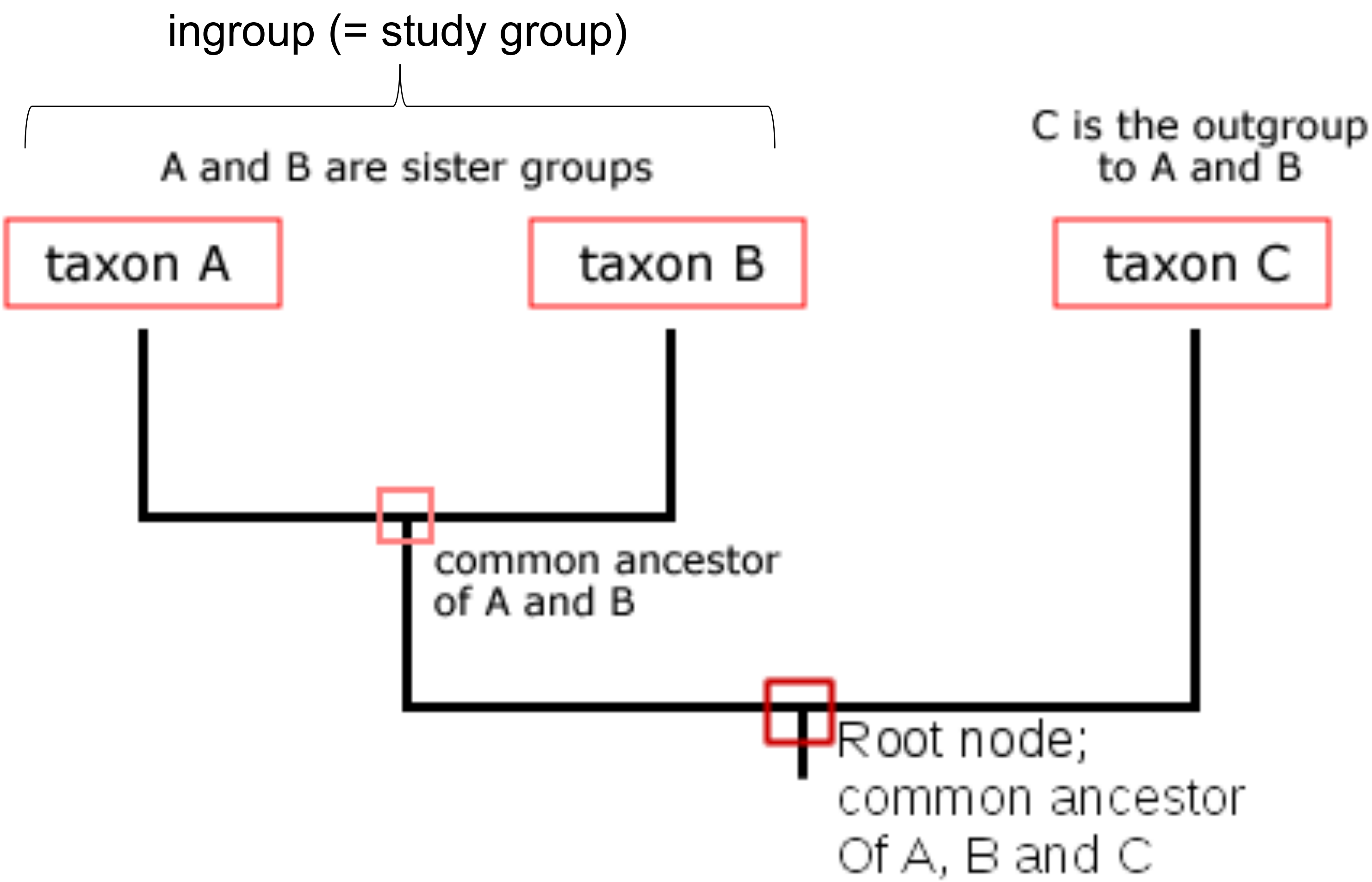
Further interpretation of phylogenetic trees

To develop an evolutionary tree, we must determine which changes are more recent and which occurred farther back in the past; i.e. the tree must have direction – it must be **rooted**. By arranging the characters in a specific direction, rooting makes it possible to recognise *shared derived character states* that define monophyletic taxa.

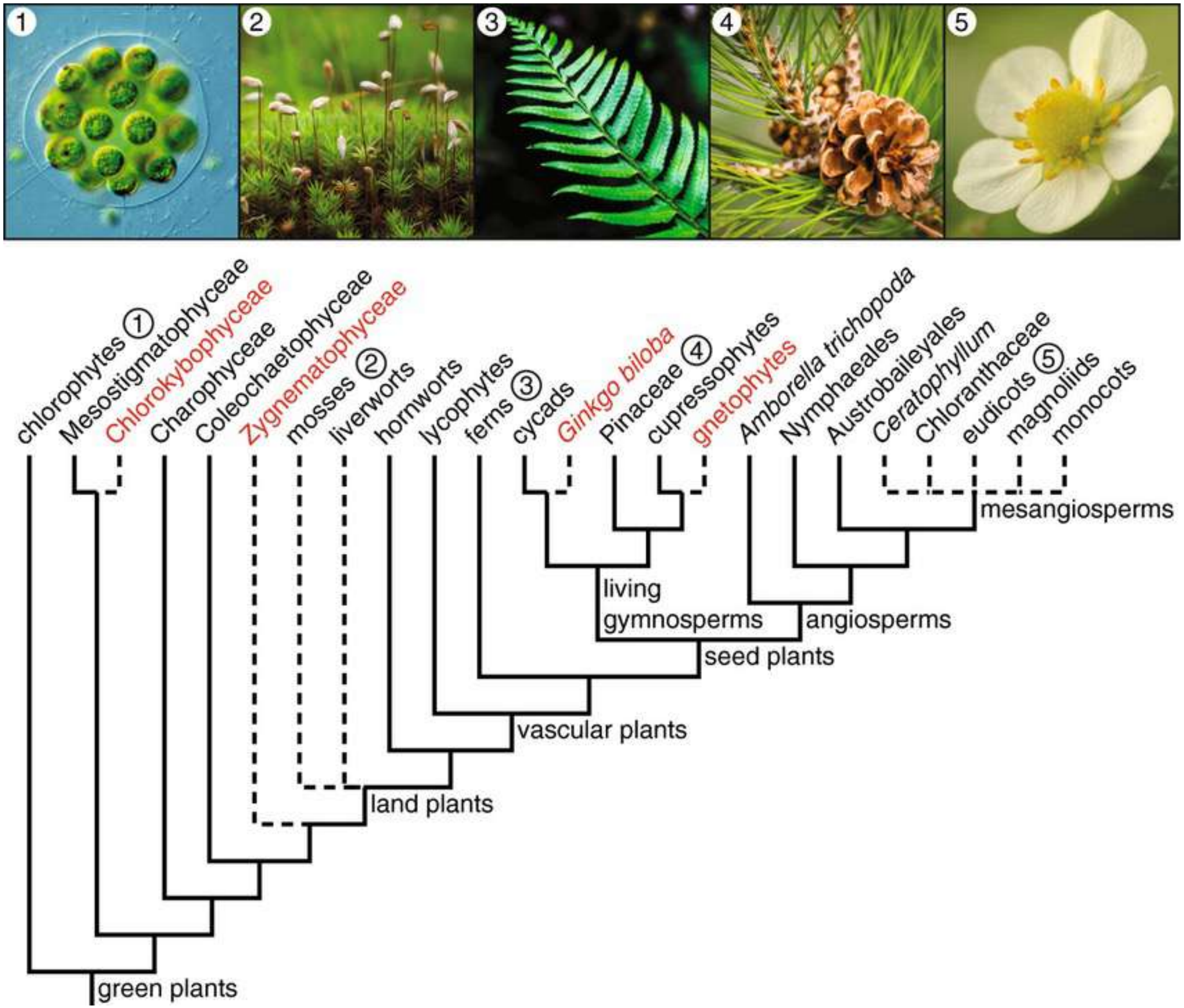


Further interpretation of phylogenetic trees

Sister, **ingroup** and **outgroup** relationships.



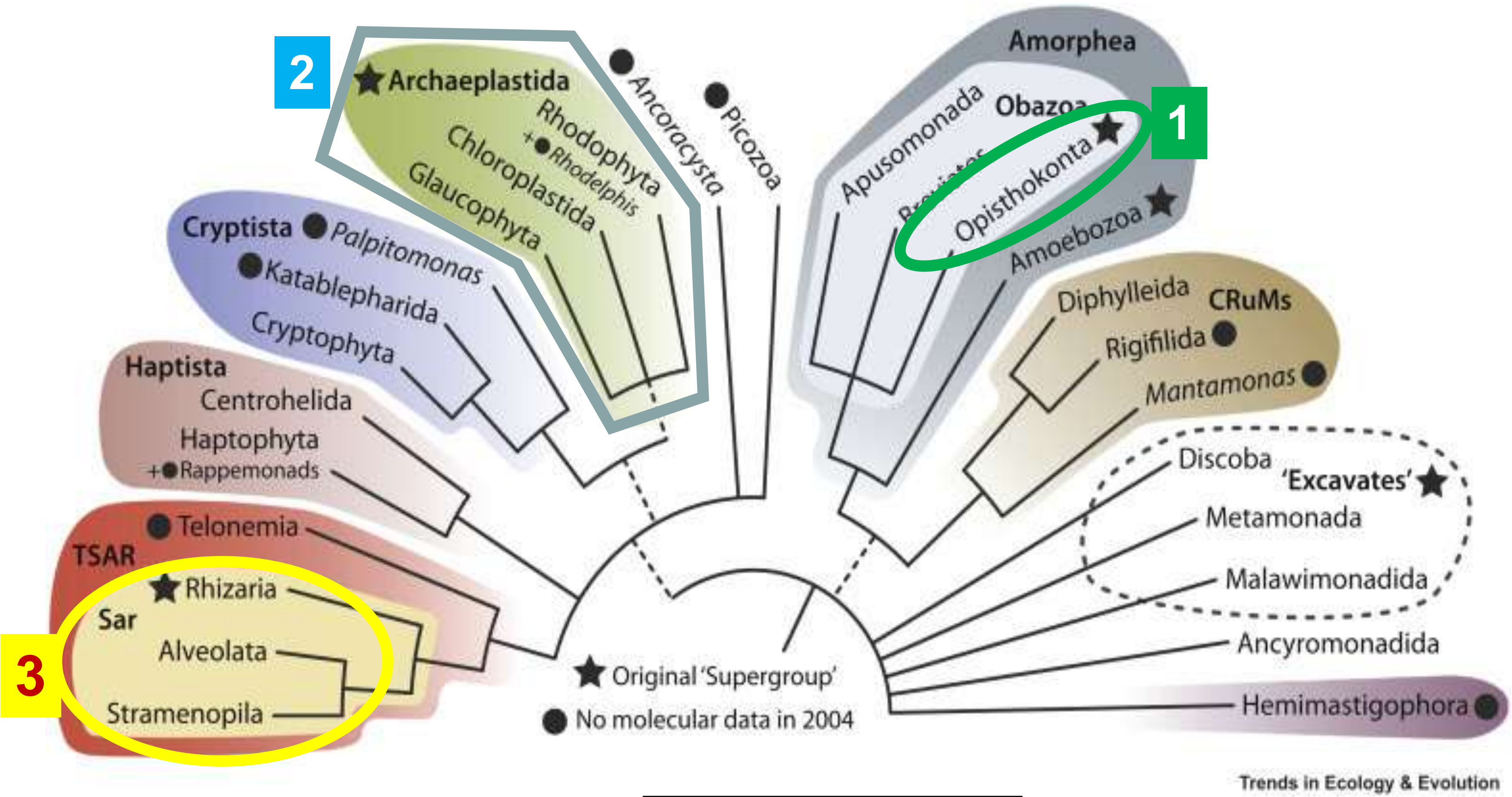
Practical



Davis et al. (2014)

Plants and fungi in the Eukaryote Tree of Life

The latest Tree of Life of Eukaryotes, based on phylogenomic analyses (Burki et al. 2020)



1 OPISTHOKONTA
FUNGI and animals
Topic/Lecture 4

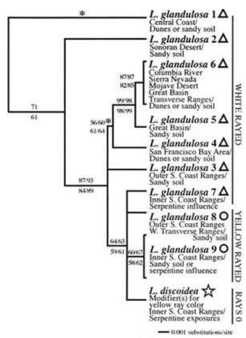
2 ARCHAEPLASTIDA
Plants and algae (green, red and blue)
Topics/Lectures 6-16

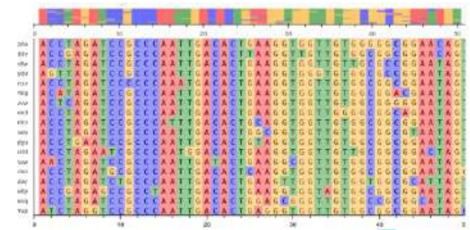
3 Group SAR
Brown algae
Topic/Lecture 6

Take-home message:

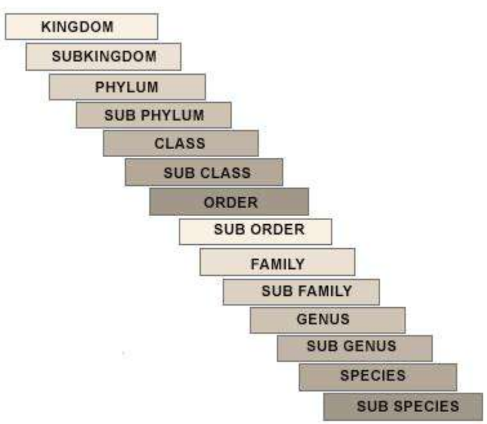
Systematics of plants and fungi seek to understand the evolutionary history of these organisms by combining information obtained from a plethora of studies:

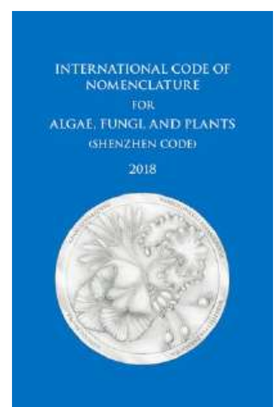
- ➢ morphological
- ➢ anatomical
- ➢ physiological
- ➢ ecological
- ➢ phylogenetic





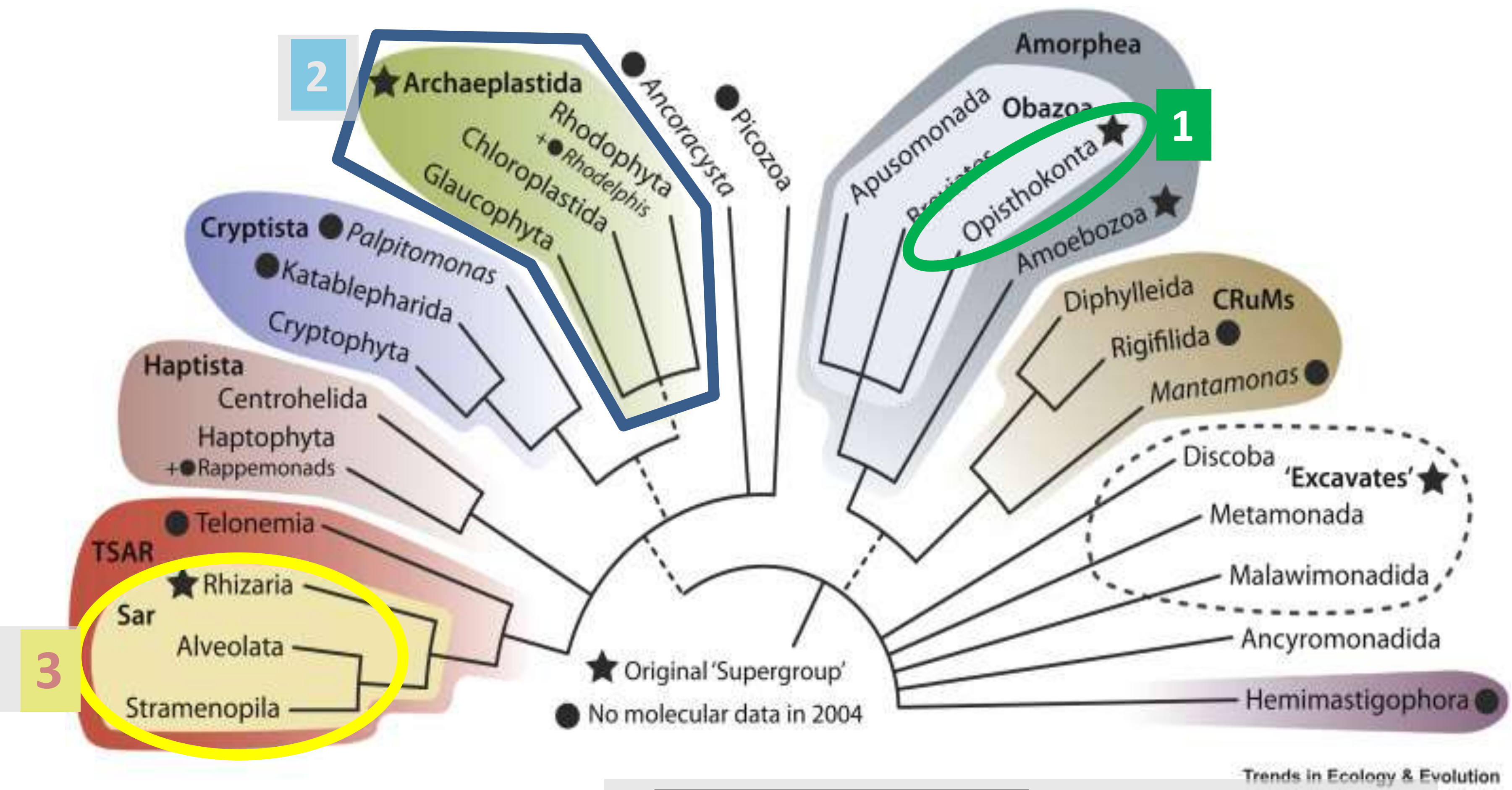
The **naming of species** is ruled by the Code of Nomenclature of Plants and Fungi. When a new species is found, the data obtained from the above studies are used to place the new species under an appropriate taxonomic rank in a process that has been called the "Integrative Taxonomy Approach".





Lecture 04 **part 1**
The Biology of Fungi

Fungi in the Eukaryote Tree of Life



1 OPISTHOKONTA
FUNGI

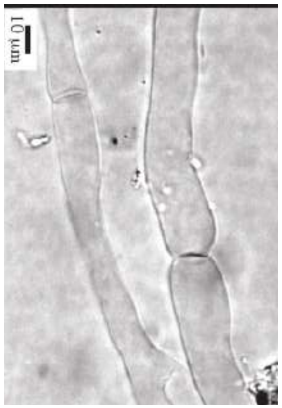
2 ARCHAEPLASTIDA
Plants and algae (green, red and blue)
Topics/Lectures 6-16

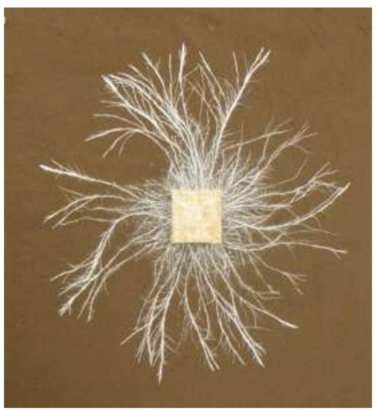
3 Group SAR
Brown algae
Topic/Lecture 6

Topics

- **Main traits**
- Reproduction and life cycles
- Spores and dispersal
- Ecology

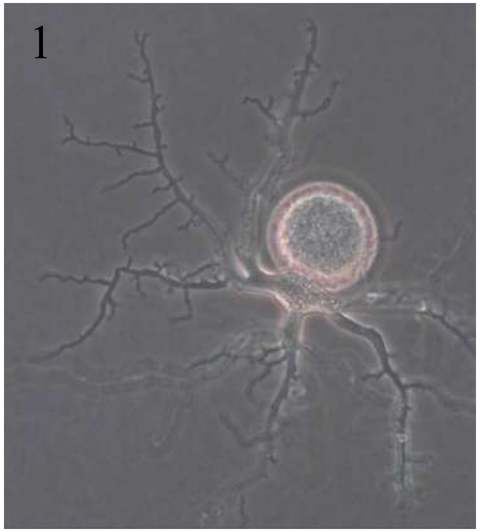
Fungi (opisthokonta)



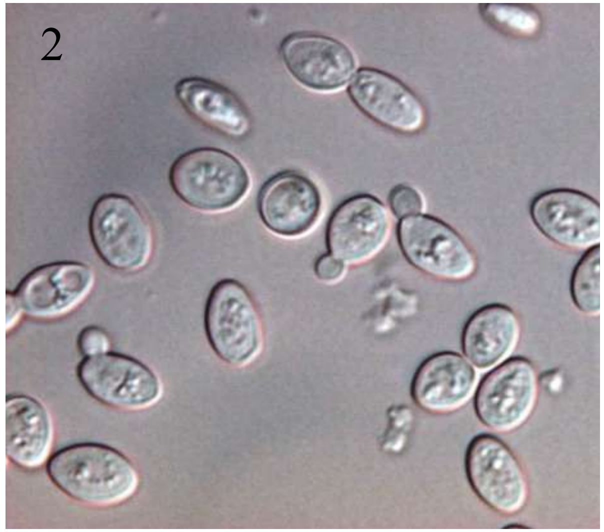


- Fungi are **eukaryotic** organisms.
- They are **non-photosynthetic**.
- Their mode of **nutrition** is heterotrophic (e. g. **lysotrophic**) through absorption (**osmotrophy**).
- They are thallophytes, i.e. they form thalli named **mycelia** (sing. mycelium), which are often **filamentous**; however, some species are **unicellular** (e. g. **yeasts**) and therefore protophytes.
- Their **cell wall** is composed of **chitin** (n-acetyl glucosamine polymer).
- They do not usually form flagellated cells in life cycles; only some groups are **zoosporic** and present zoospores with a **smooth flagellum** (opisthokonts).
- Their **mitochondria** have **flattened lamellae.**
- Their life cycles are **haplo-dikaryotic** (in general).
- There are over **100,000 known species**.

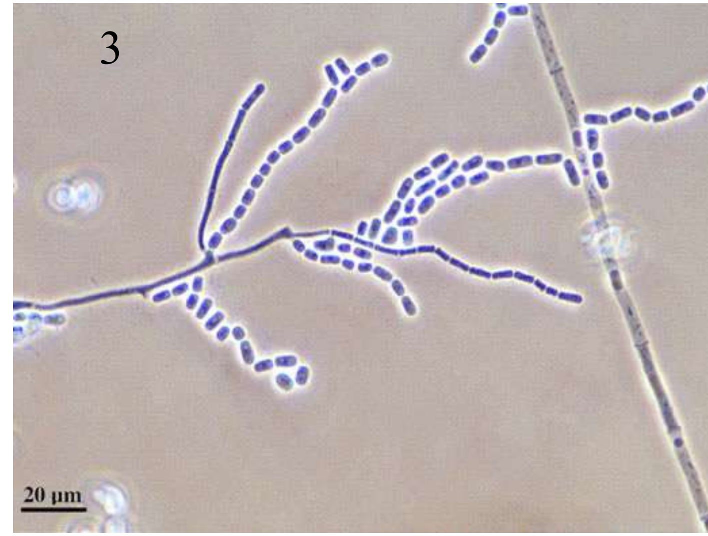
The fungal body



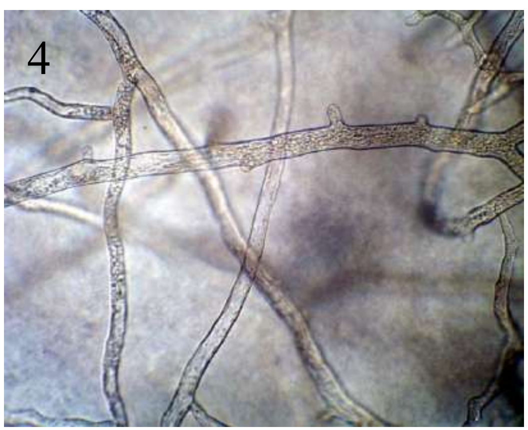
Multinucleate unicellular thalli of chitrids. Sphaerical thallus with rhyzomycelium.



Uninucleate unicellular (protophyte/simple thallophyte). Levuriform thallus: yeasts.



Pseudomyceliar thallus. Thallus formed by gemmation (budding) of the levuriform thallus when the cells do not separate completely.

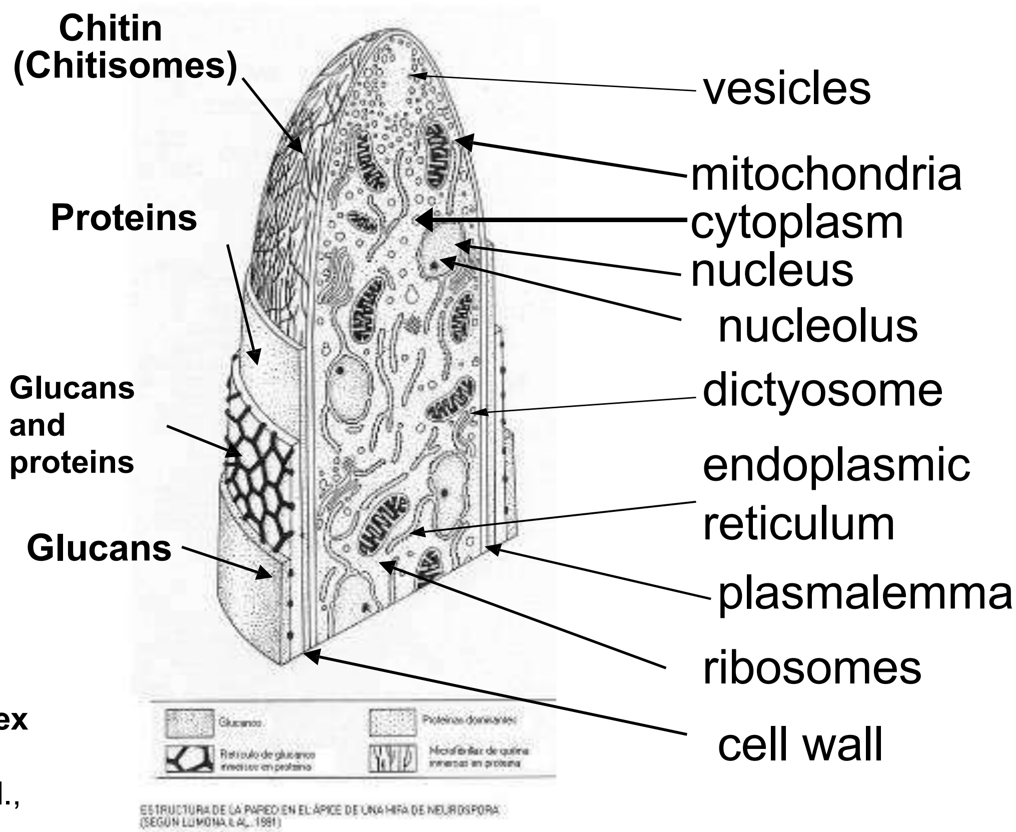


Coenocytic myceliar thalli. Thallus formed by hyphae without septa (coenocytic).

Septate myceliar thalli. Thallus formed by septate hyphae.

Mycelium= a set of hyphae

Ultrastructure of hyphal apices

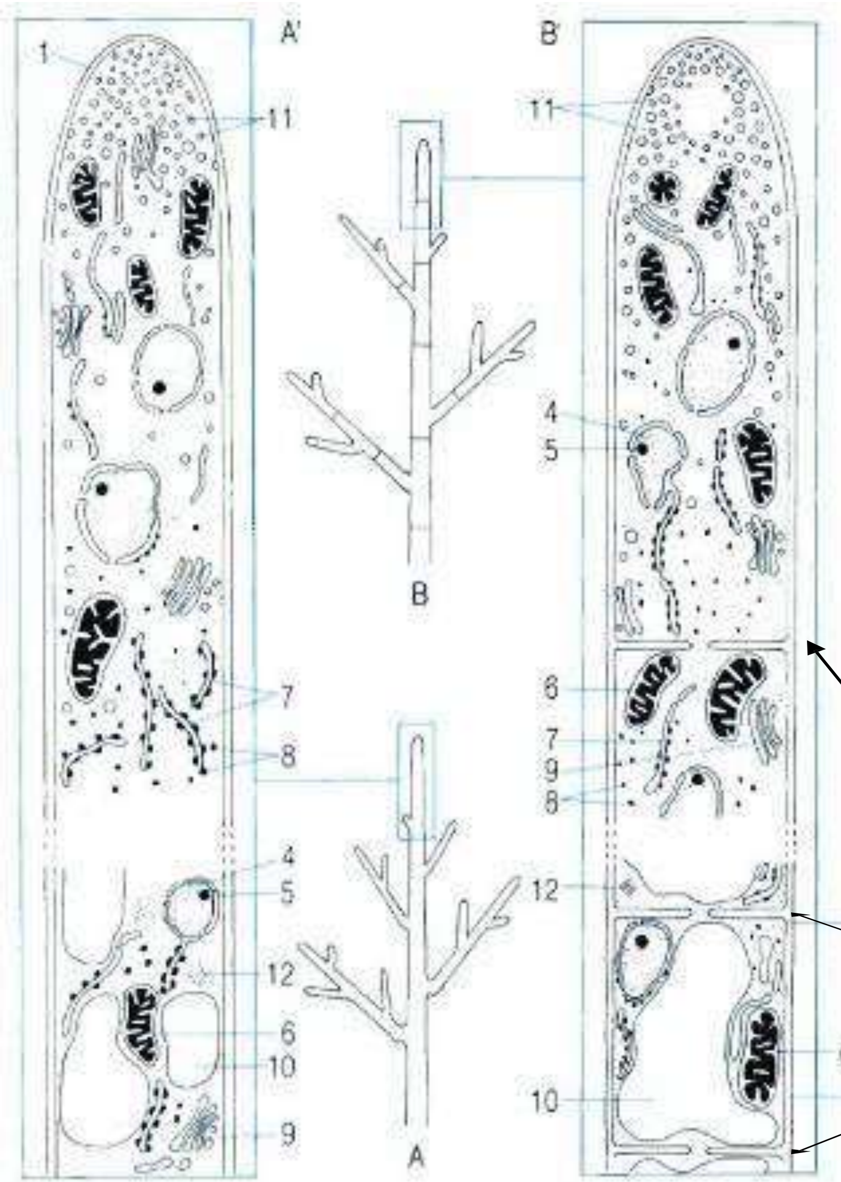


Ultrastructure of the apex of *Neurospora* hyphae according to Llimona & al., 1991

The plasma membrane **lacks cholesterol**; instead, it contains **ergosterol**.

Hyphal types

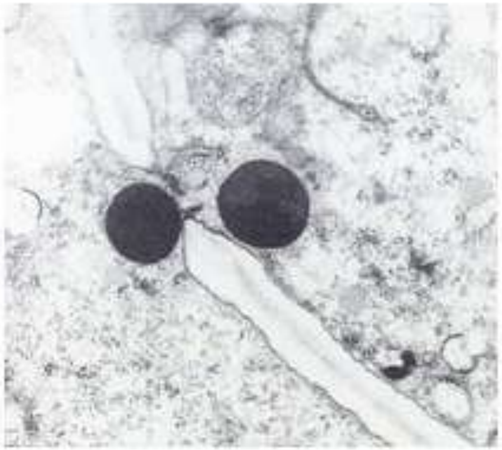
C
O
E
N
O
C
Y
T
I
C

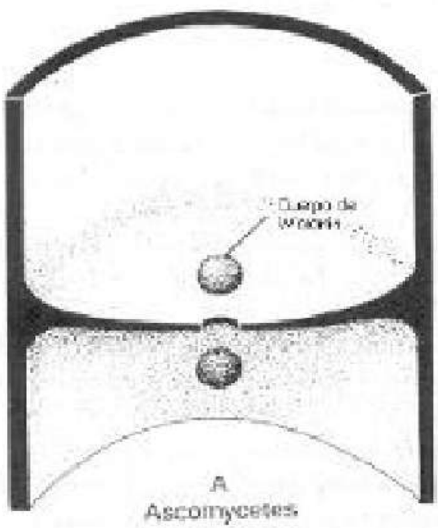


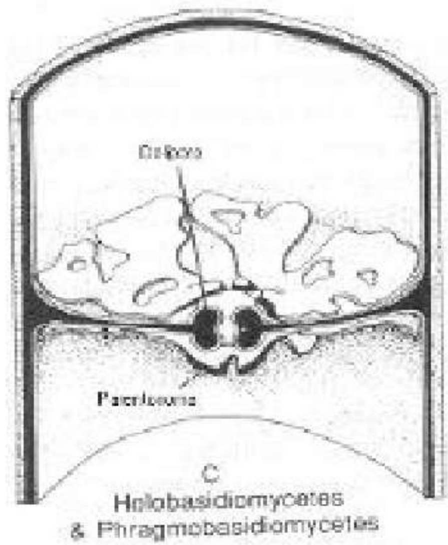
Mycelia can be composed of **septate** or **non-septate hyphae.** Non-septate hyphae are **multinucleate** or **coenocytic**.

SEPTATE
(septa)

Types of hyphal septa







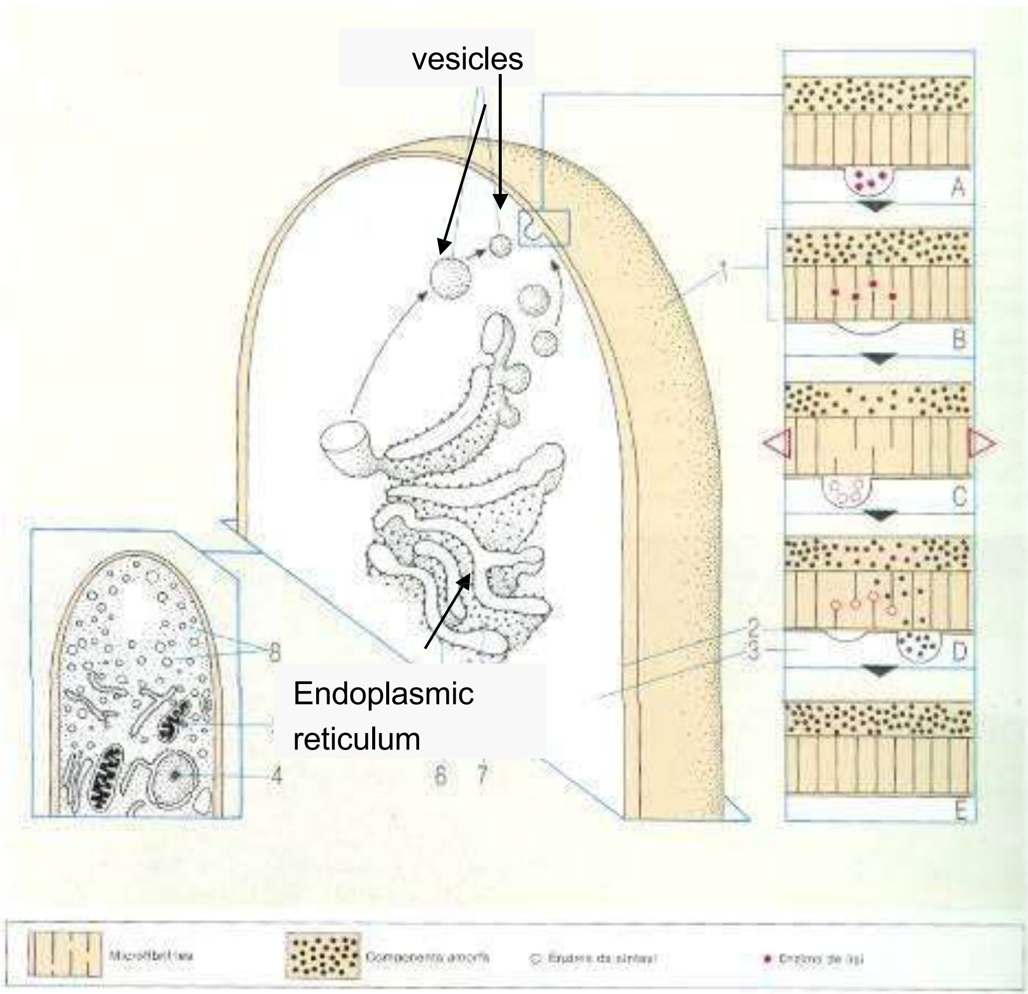
Simple porus

Dolipore

Ascomycte fungi usually have <u>simple pores</u> between hyphae. These show so-called **Woronin bodies** (WBs), a specialised class of peroxisomal-derived organelles that quickly plug the septal pore upon injury to the hypha, thus preventing excessive loss of cytoplasm.

However, in many **basidiomycete fungi**, the pore of the septum has an inflated doughnut-like or barrel-shaped margin called a **dolipore**. On either side of the dolipore there may be membranous caps called **parenthesomes**, so named because in profile they resemble a pair of parentheses.

Hyphal growth

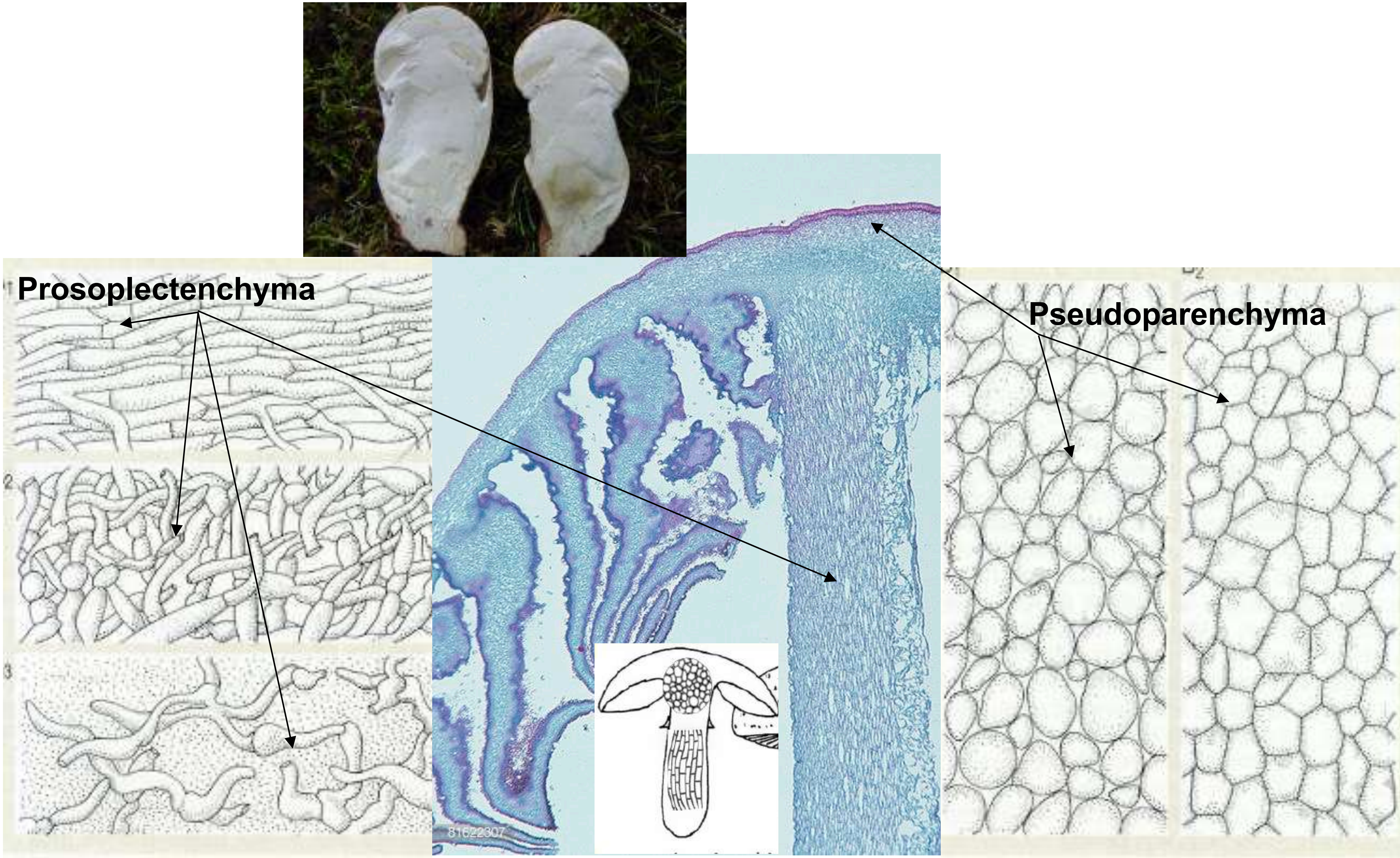


(A, B): vesicles are incorporated with lysis enzymes that soften the wall.

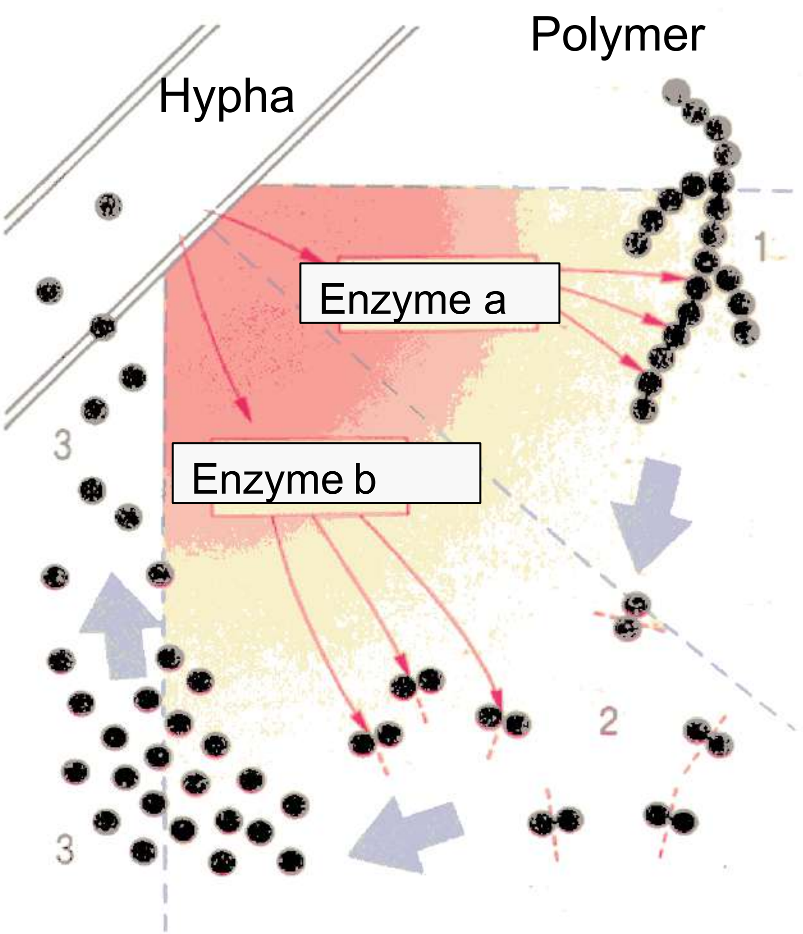
(C): the wall is stretched transversely.

(D,I): reconstruction of the wall from new vesicles loaded with synthesis enzymes and amorphous components.

Plectenchymas: prosoplectenchyma and pseudoparenchyma

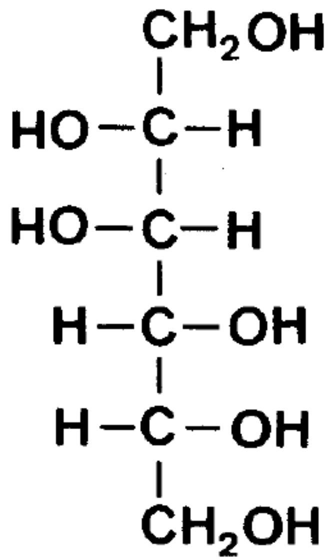


Heterotrophic nutrition by absorption: lysotrophy and osmotrophy

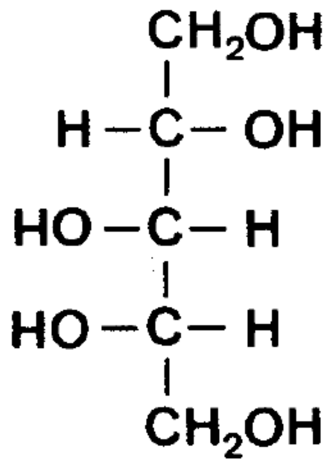


Permeases act as transmembrane carriers.

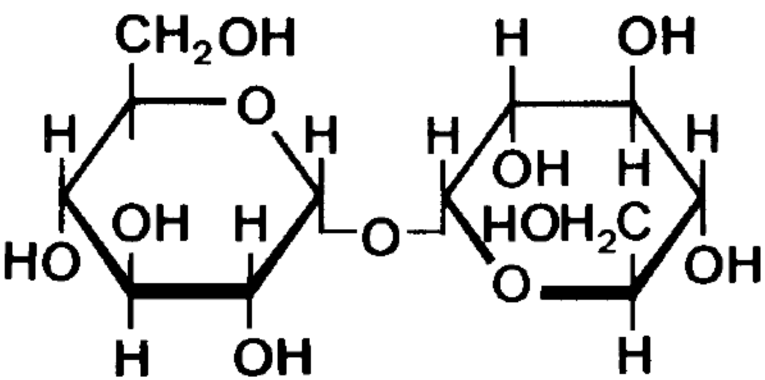
Lysotrophy: external digestion that progressively transforms polymers into smaller soluble units until they can be absorbed by the hyphae (**osmotrophy**) through the pores of the wall. Monomers already predigested can be used by other fungi: secondary saprophytism.



Mannitol



Arabitol



Trehalosa

Reserve storage material

Lipids, glycogen and sugars: mannitol, trehalose and arabitol.

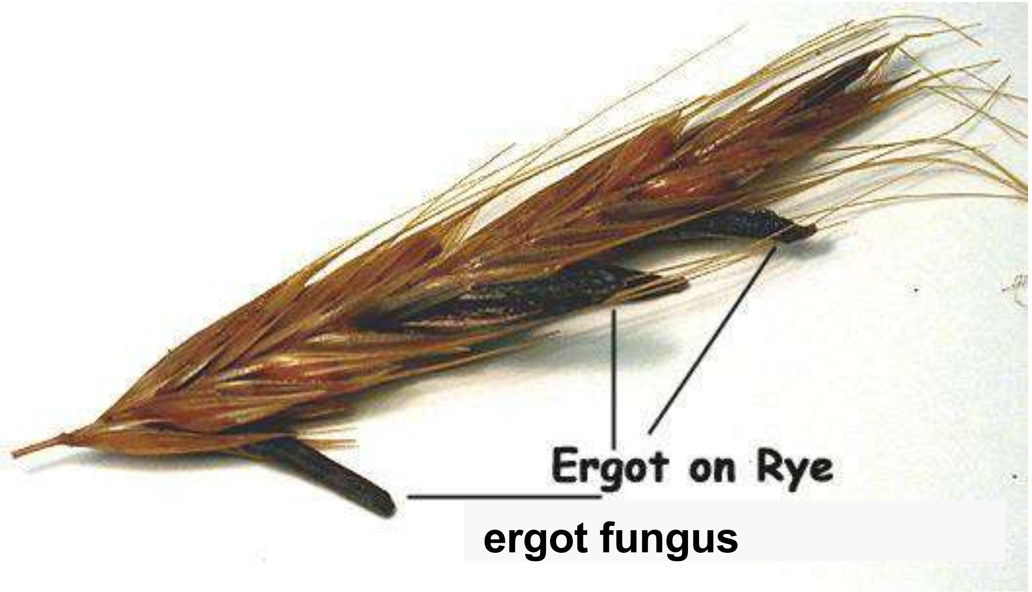
Fungi, along with bacteria, are the main decomposers in the biosphere.

Energy sources

Carbohydrates of plant origin: glucose, sucrose, starch, cellulose and lignin, and all kinds of substrates: keratin, pesticides, shoe polish, paints, etc.

Secondary metabolism

Over 100 fungal metabolites are known: antibiotics such as penicillin; hormones such as gibberellin; mycotoxins such as aflatoxins; alkaloids such as amanitin, ergotamine and ergometrine; LSD (ergot); immunosuppressants such as cyclosporine.

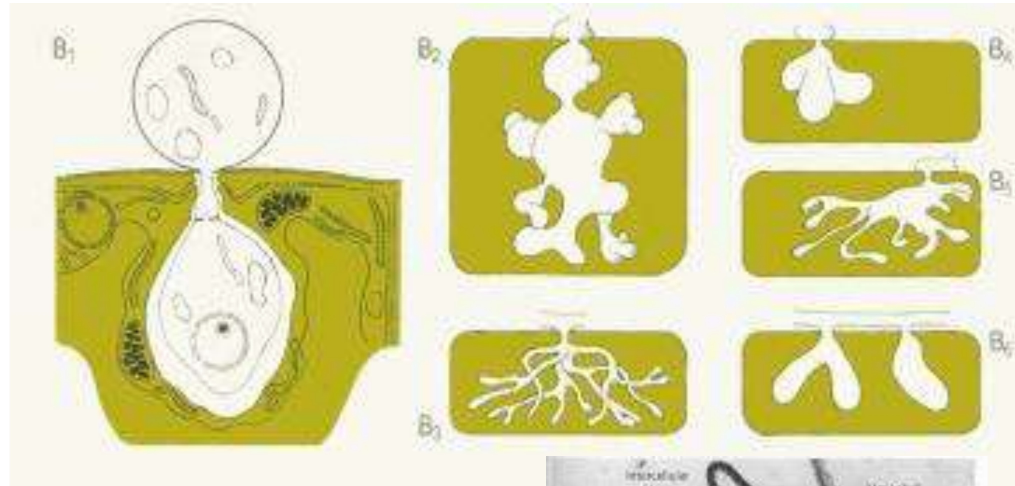


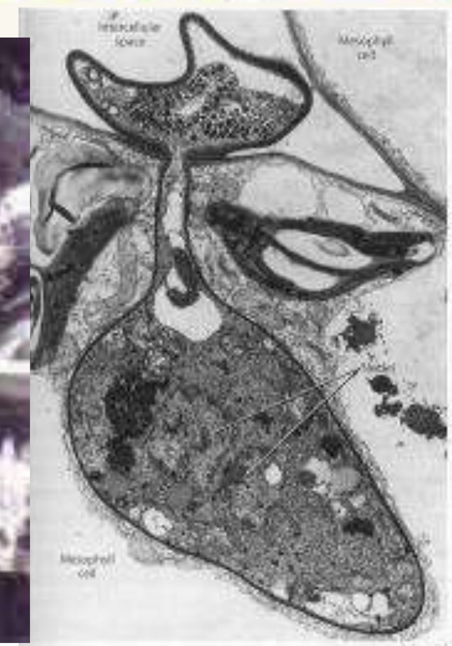
Ingestion of ergot produces hallucinations, ergotism (“St. Anthony’s fire”).

Amanitins in *Amanita muscaria* produce convulsions and hallucinations.

Specialised structures: haustoria (sing. haustorium)

Haustoria are more or less branched hyphae that develop inside the cells of the host.





Fruiting bodies in basidiomycetes (mushrooms) and ascomycetes (cup fungi)

Photographs: Isaac GB

Topics

Main traits

Reproduction and life cycles

Spores and dispersal

Ecology

Sexual reproduction

Isogamy
Anisogamy
Oogamy

In zoosporic fungi (aquatic)

Cystogamy (gametangial copulation or gametangiogamy)

Siphonogamy

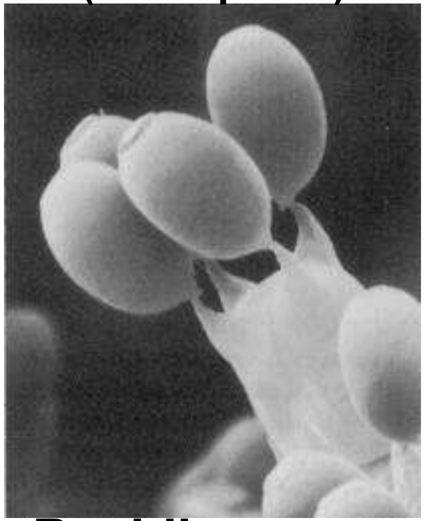
Trichogamy (Spermatisation)

Somatogamy

In other fungi, these modes of sexual reproduction lead to the formation of different types of spores.

Zygospore

Ascospores (meiospores)

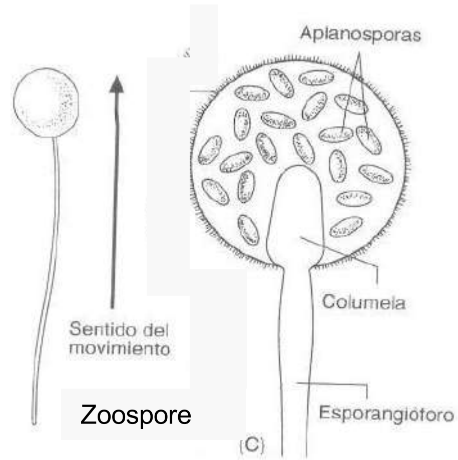


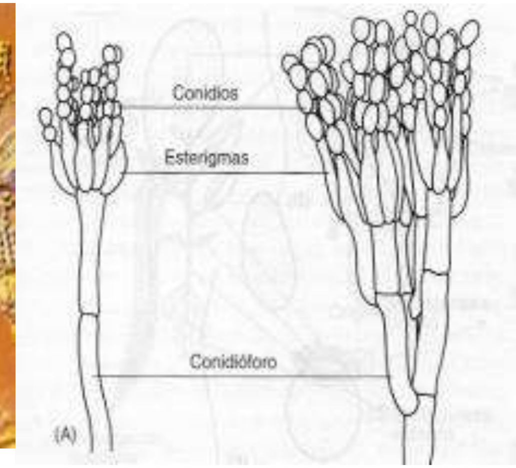
Basidiospores (meiospores)

Asexual reproduction: fragmentation and spore production

Mitospores:

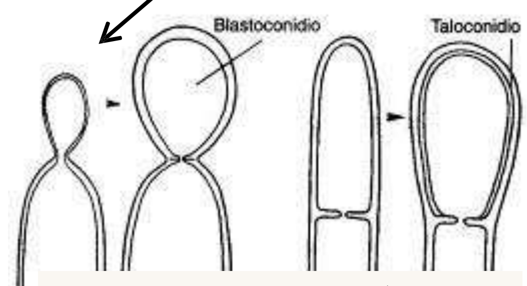
Zoospores
Aplanospores

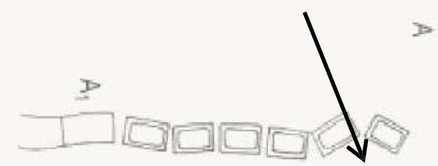




Endospores
Exospores or **conidia** (sing. **conidium**)

Blastic conidiogenesis

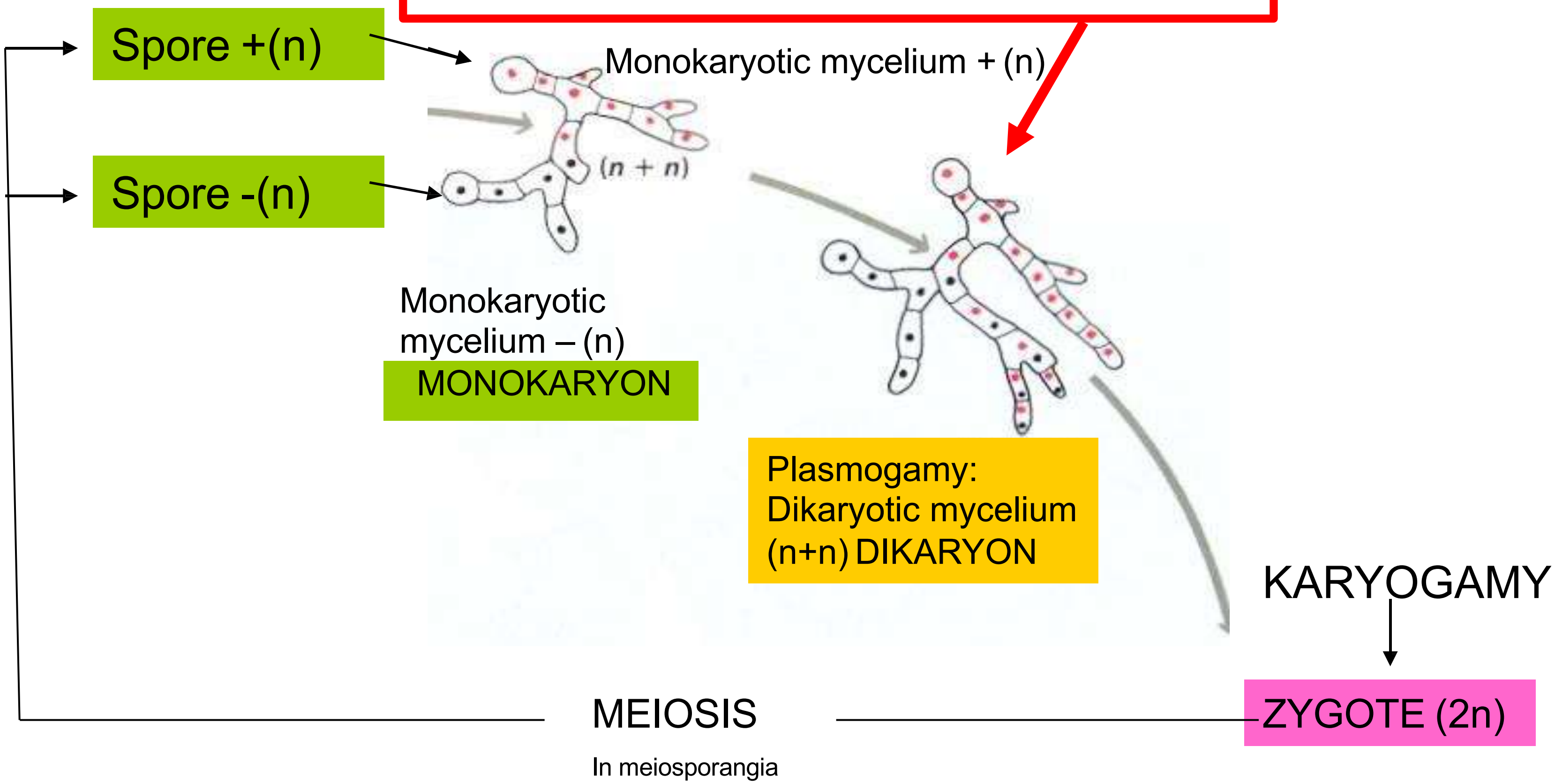




Thallic conidiogenesis

Life cycles in fungi

- monogenetic haploid
- monogenetic diploid
- digenetic haplo-diploid
- **haplo-dikaryotic: Dikaryon**

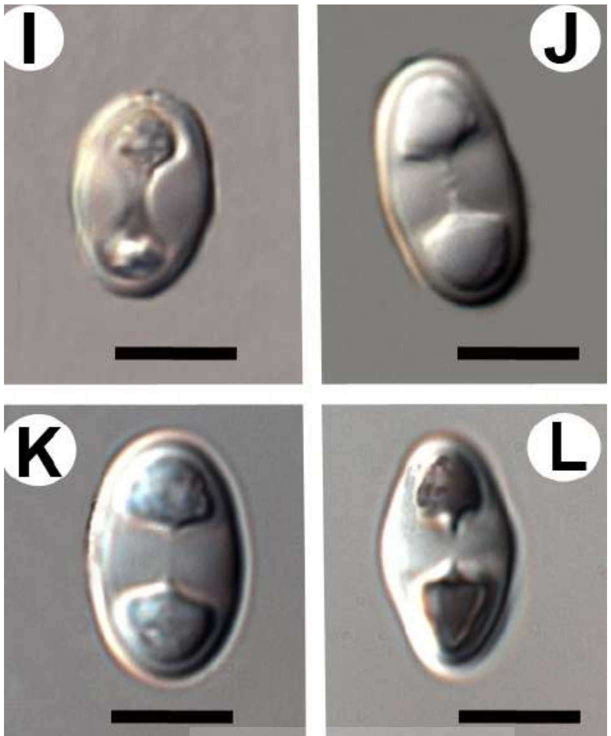


Topics

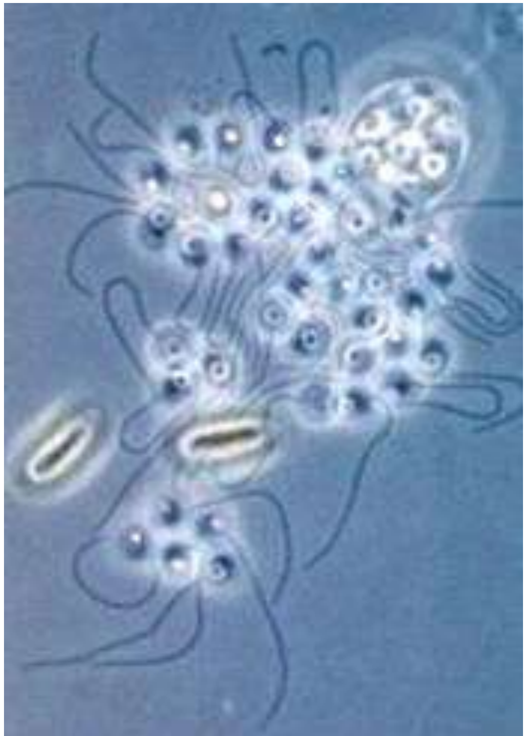
- Main traits
- Reproduction and life cycles
- Spores and dispersal
- Ecology

Spores in fungi

Spores are thick-walled **dispersal units**, sometimes impregnated with melanin and lipids. As an exception, zoospores, which lack a cell wall, are metabolically active.

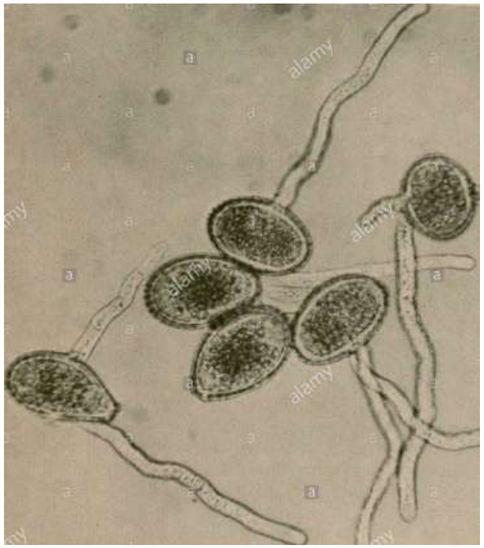


Ascospores

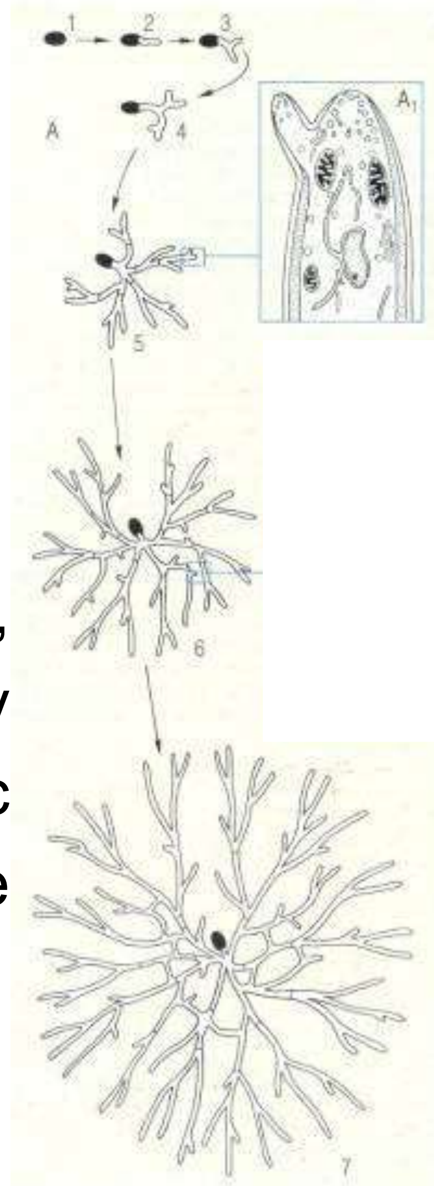


Zoospores

Spore germination

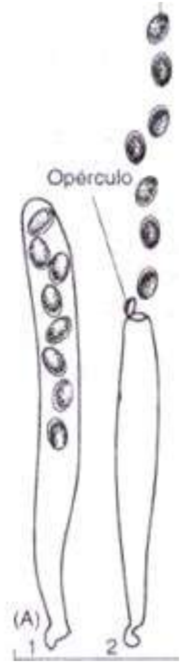


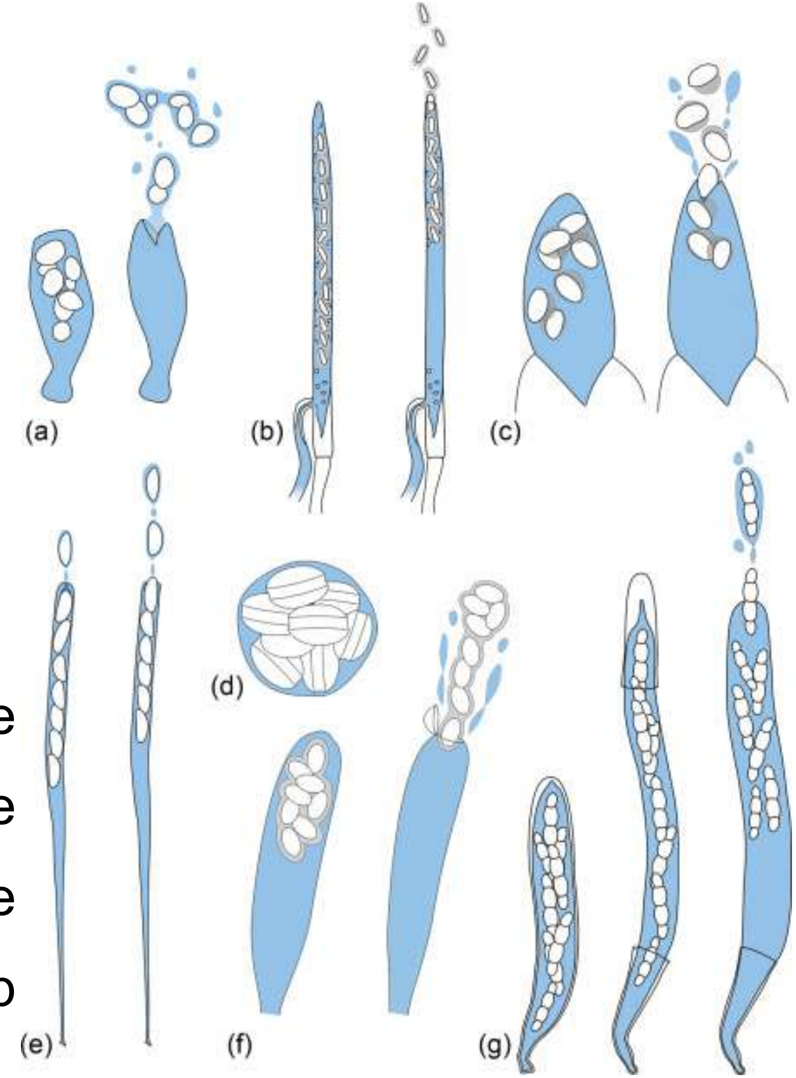
During germination, the spore rapidly incorporates organic compounds from the medium.



"Elf or fairy rings"

Spore dispersal by the wind

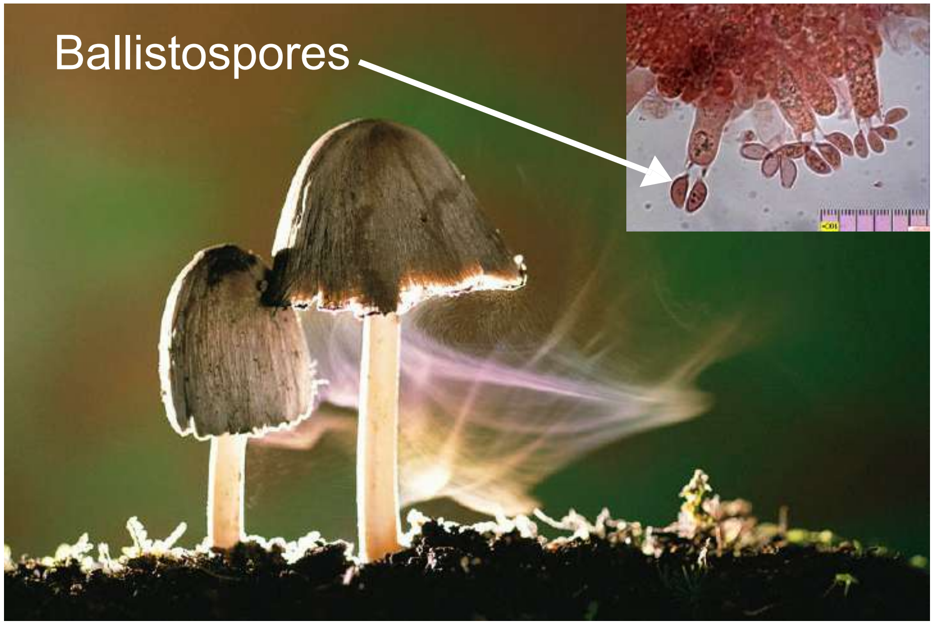




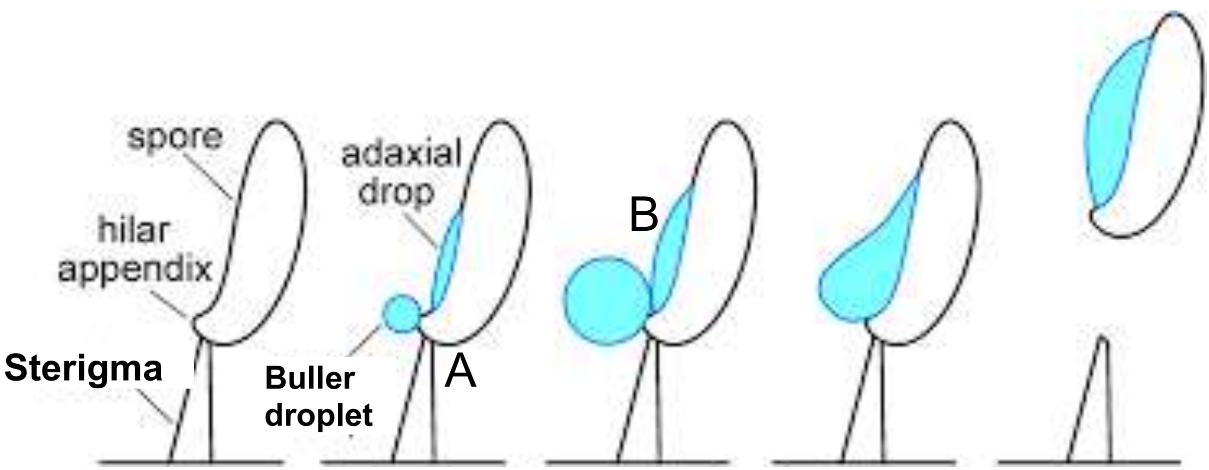
Asci are found in the ascomata. To promote spore dispersal, the asci shoot as if from the barrel of a shotgun due to turgor pressure from the base to the apex. In some cases up to 1,700,000 spores per cm^2 are released.

Mark Fischer, Mount St. Joseph University, Cincinnati.

Ballistospores and dispersal by wind



Hygroscopic condensation of a water droplet (**Buller's droplet**) located probably in a hydrophobic zone at the base of the spore (A); from here, the droplet grows until it reaches the hydrophilic zones of the spore wall (B).

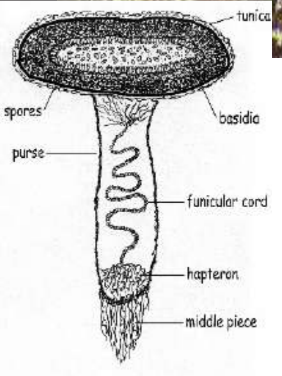


The ballistospores fall by the action of gravity and are transported by air turbulence.

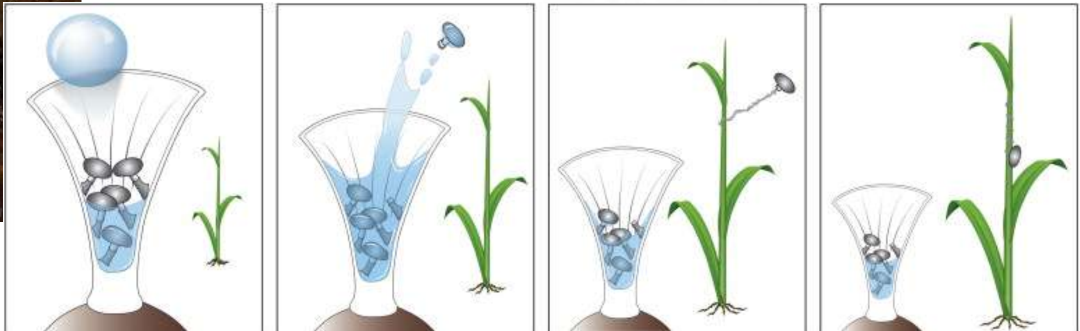
Dispersion by the impact of raindrops

- On the fertile powdery gleba ("earth stars", *Geastrum*)
- On lenticular portions (peridioles within "birds' nests")

peridioles



Peridiole structure



Dispersion by animals

Clathrus ruber (Basidiomycota)

Phallus impudicus (Basidiomycota)

Insects collect the spores on their limbs and disperse them.

Truffles have no other spore dispersal mechanism than to emit substances such as mammalian hormones to be dug up and ingested.

Tuber melanosporum (Ascomycota)

Terfecia arenaria (Ascomycota)

Topics

Main traits

Reproduction and life cycles

Spores and dispersal

Ecology

Ecology

Fungi are **decomposers** of organic matter, release CO_2 into the atmosphere, and return nitrogen compounds and other materials to the soil that are recycled by plants and animals.


Saprophyte fungi: *Rhizopus*

Different modes of life

Fungi have three main ways of obtaining nutrients: 1. **Saprophytes obtain nutrients** from the dead tissues of plants, animals, microorganisms or other fungi; 2. **Biotrophs** obtain them from living cells; these fungi are parasites and also lichens and mycorrhizae. 3. **Necrotrophs** such as *Armillaria mellea* secrete toxins that break the plasma membranes, killing cells and tissues from whose remains they feed. They are initially parasites and saprophytes of the remains of the host once it has died.


Parasite fungi: athlete's foot


Parasite fungi: rusts


Symbiotic fungi: lichenized fungi


Mycorrhizae

Non-pathogenic symbioses: endophytic fungi

Pestalotiopsis microspora: yew endophyte fungus lives in the plant tissue and produces taxol, an anticancer substance used in medicine.

Lecture 04 part 2

The Diversity, Symbioses and Uses of Fungi

Topics

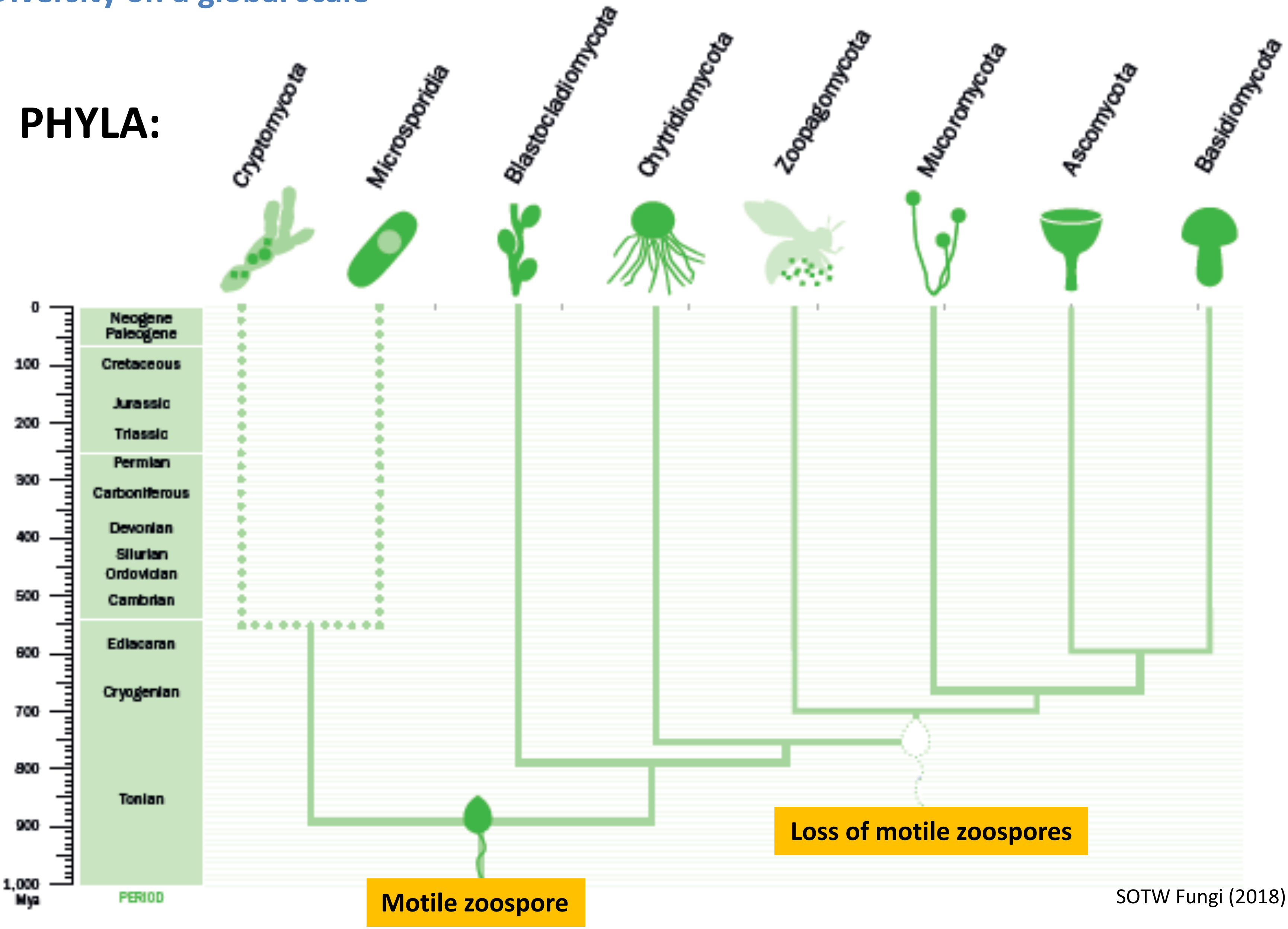
Diversity

Symbioses

Uses

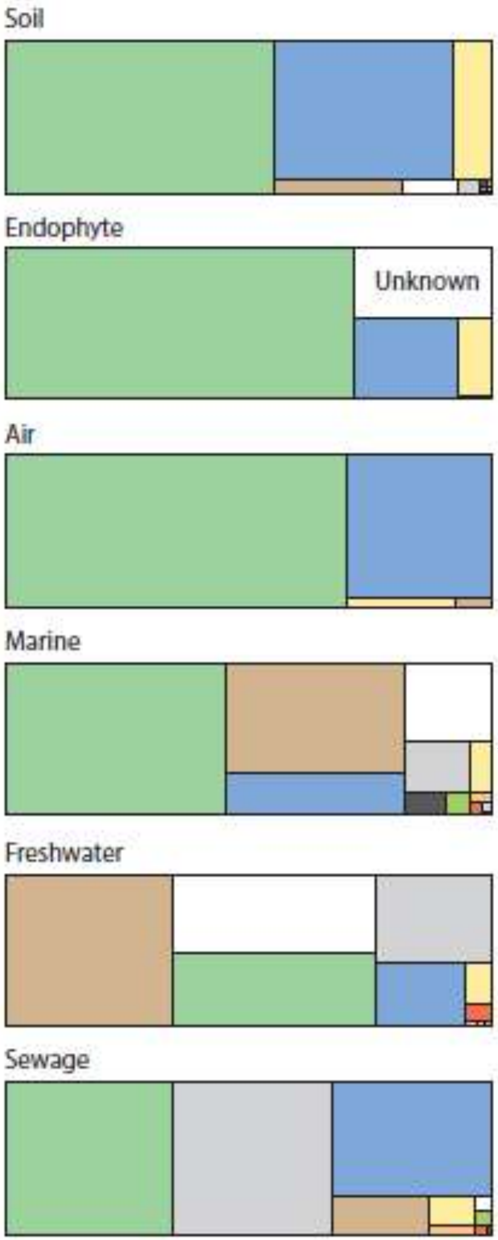
Diversity on a global scale

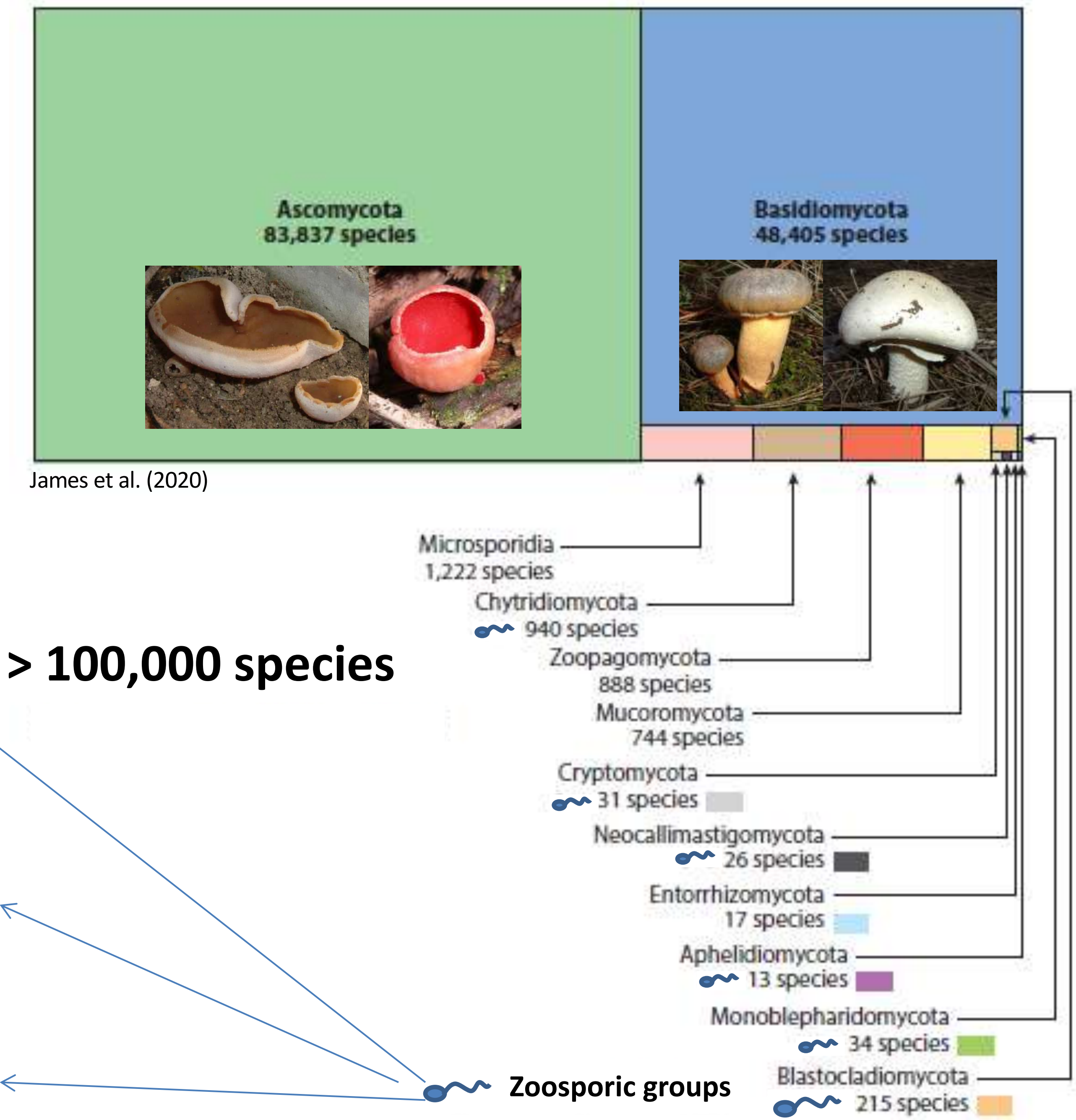
PHYLA:



SOTW Fungi (2018)

Diversity on a global scale





Diversity on a global scale

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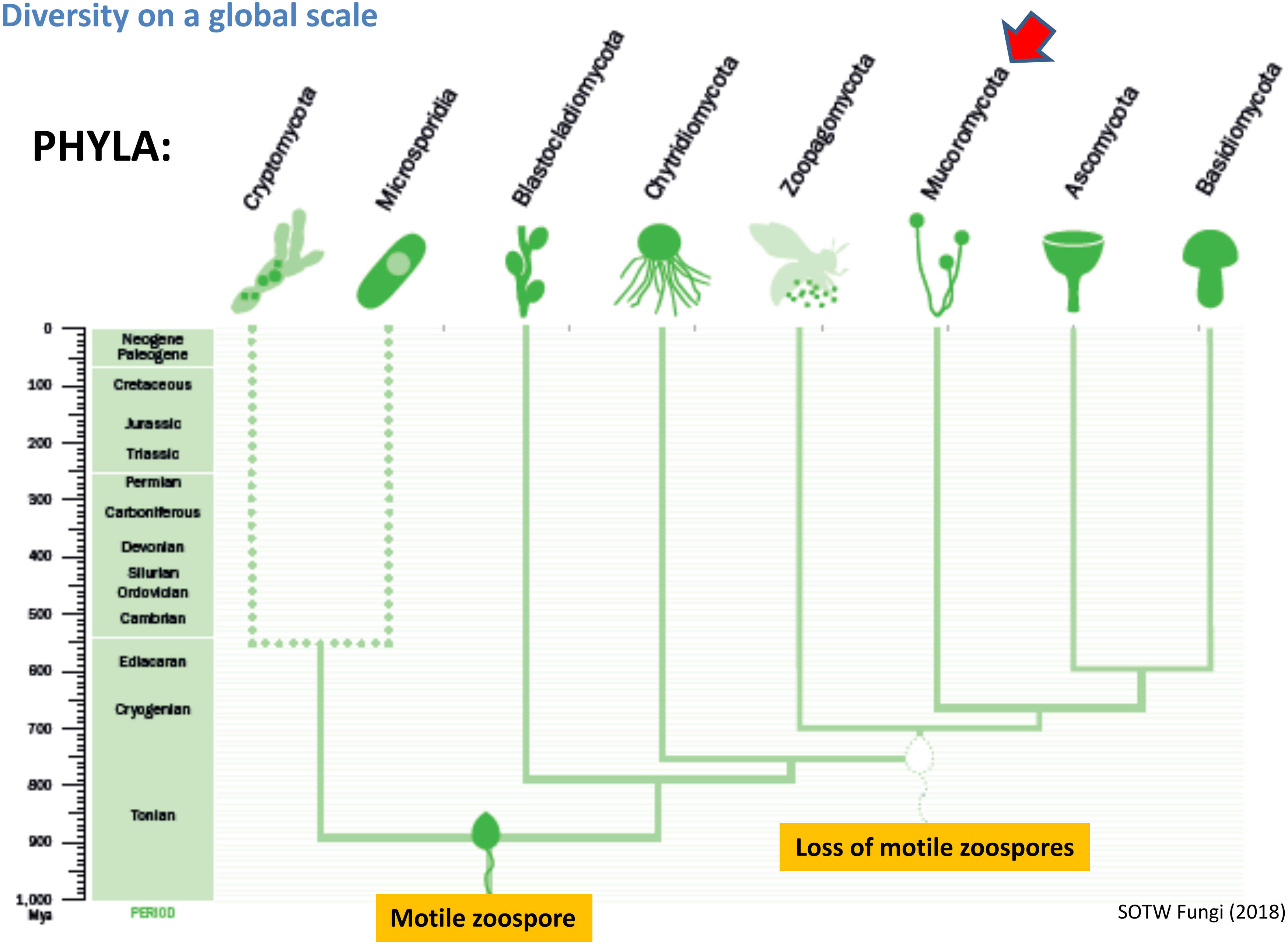
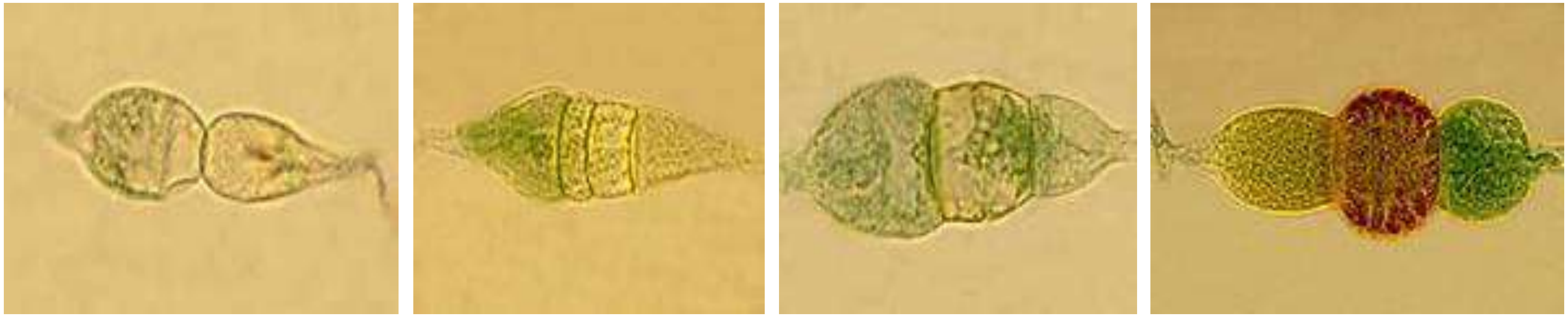


SOTW Fungi (2018)

Diversity of terrestrial, non-zoosporic fungi: the mucoromycetes

Mucoromycetes are the most important and best-studied group of fungi formerly known as Zygomycetes. They are the sister group to the Ascomycetes and Basidiomycetes (Dikarya). Approximately 750 species are known, most of which are saprophytes. Some of these are early colonisers of hydrocarbon substrates. Other mucoromycetes are parasites of plants (that do not form haustoria), animals and other fungi, while others are mycorrhizal (mutualistic symbioses with the roots of some plants). Other noteworthy characteristics of mucoromycetes are:

- they form mycelia of coenocytic (multinucleate) hyphae,
- to reproduce asexually, they form endospores within sporangia, and
- to reproduce sexually, they use cystogamy (gametangiogamy), forming zygospores during their life cycle.



gametangiogamy → Zygospore (in brown)

Diversity of terrestrial, non-zoosporic fungi: the mucoromycetes

SAPROPHYTES: ”pin moulds” (*Mucorales*)

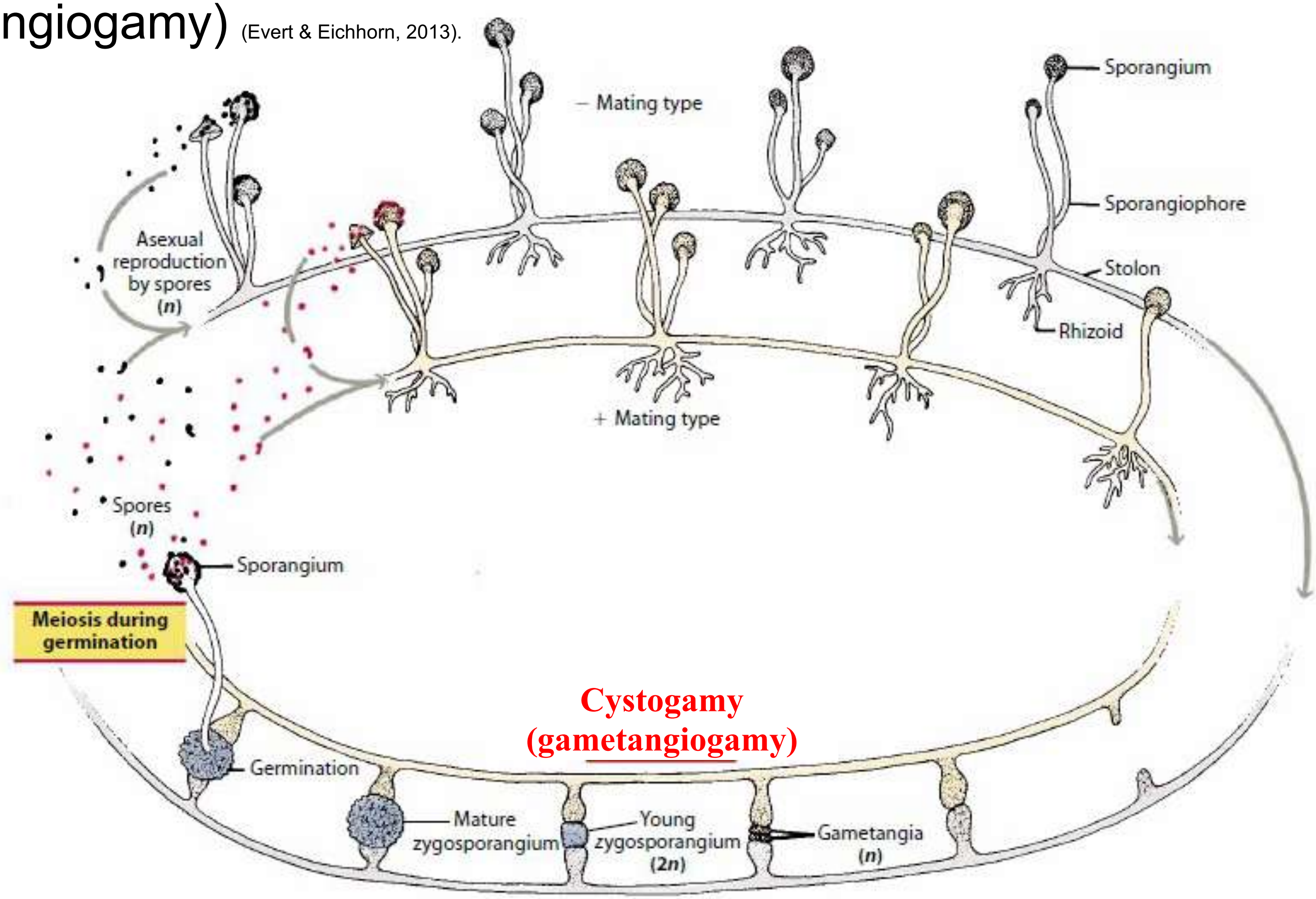
Mucor sp.

MYCORRHIZAL: of vascular plants and some bryophytes (*Endogonales*)

Diversity of terrestrial, non-zoosporic fungi: the mucoromycetes

LIFE CYLE OF *RHIZOPUS STOLONIFER*

Monogenetic haploid, zygotic meiosis, sexual reproduction by cystogamy (gametangiogamy) (Evert & Eichhorn, 2013).



Rhizopus sp. Stolon and rhizoids.

Rhizopus **sp.**

Photographs of developing sporangia. Spores (minute, roundish structures) and the sporangiophore are observed.

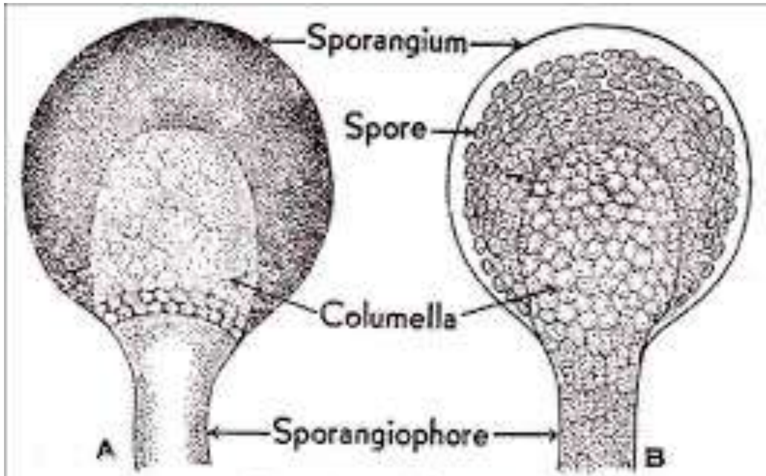
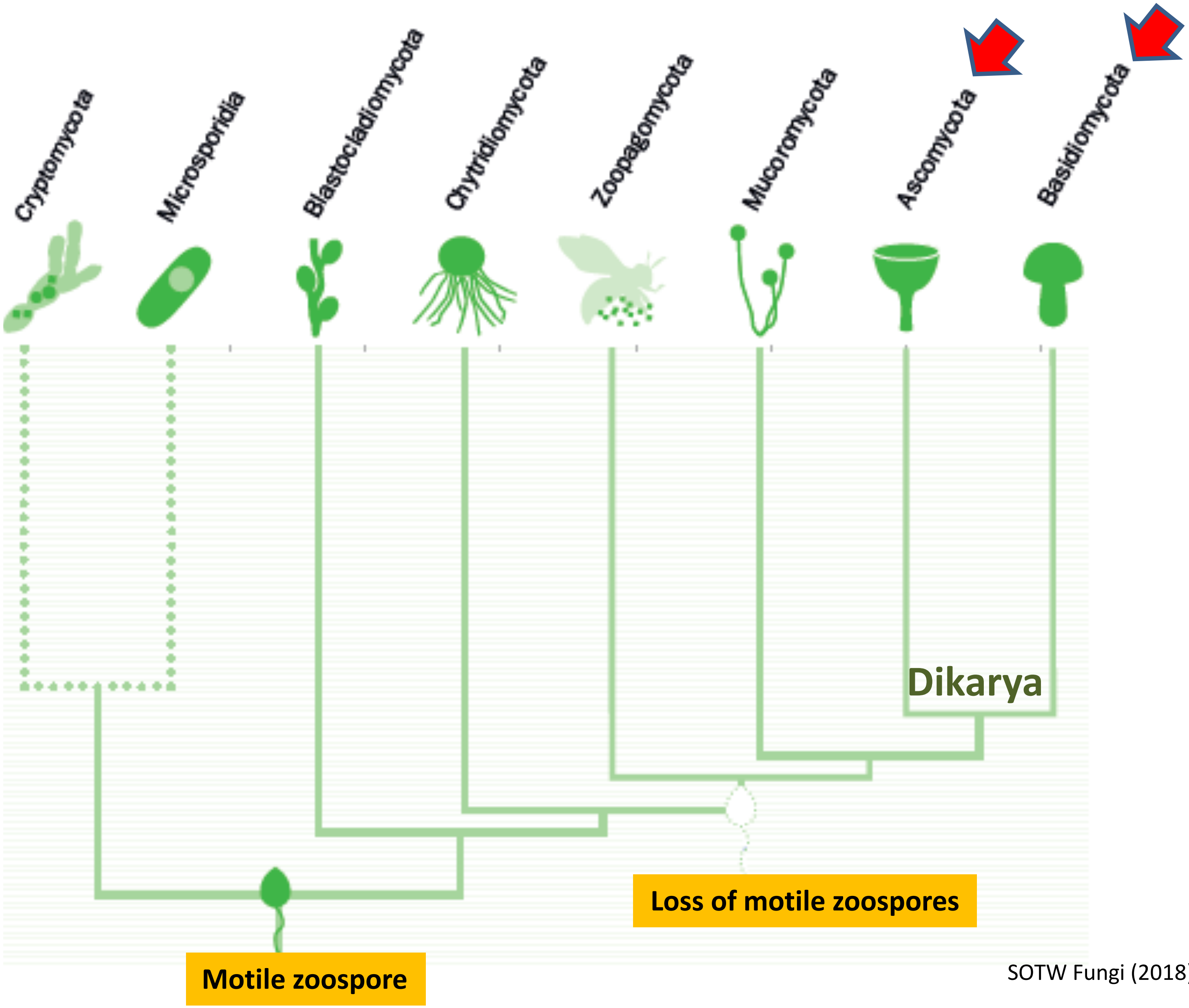


Fig. 149. *Rhizopus*.
A—B, Stages in the development of the sporangium.

Diversity of terrestrial, non-zoosporic fungi: dikaryotic fungi (Dikarya)



SOTW Fungi (2018)

Diversity of dikaryotic fungi (Dikarya)

- Dikaryotic fungi are mostly heterotrophic by absorption (osmotrophy).

- They are thallophytes that form **filamentous MYCELIA** comprising individual cells named **HYPHAE**.

- Their life cycle is **haplo-dikaryotic**.

- They have several nutritional strategies:

  -Parasites

  -Saprophytes

  -Mutualistic symbioses: lichens and mycorrhizae

Ascomycetes

- Meiosporangium: **Ascus** (pl. asci)
- Fruiting body: **Ascoma** (pl. ascomata)

Asci with ascospores

Basidium with basidiospores

Basidiomycetes

- Meiosporangium: **Basidium** (pl. basidia)
- Fruiting body: **Basidioma** (pl. basidiomata)

Diversity of dikaryotic fungi: ascomycetes or “sac fungi” (Dikarya)

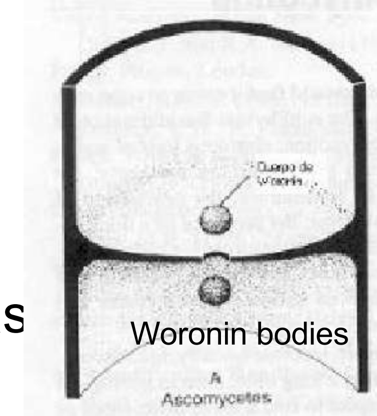
- **Endosporic meiospores** form inside meiosporangia named **asci**.

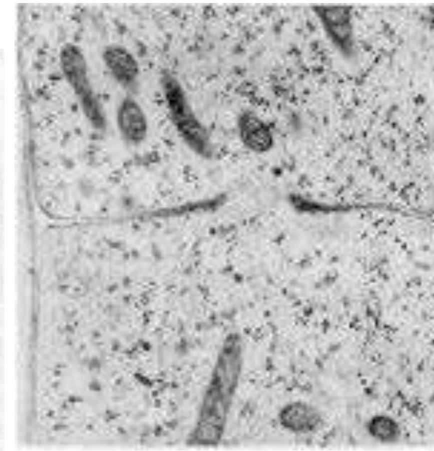
- Formation, except in yeasts, of various types of fruiting bodies (**ascomata**), such as **apothecia**.

- Mycelium is formed by septate hyphae; some are also unicellular or pseudomyceliar.

- Simple septa with plugs (Woronin bodies).

- 83,837 species are known (roughly 20,000 species establish symbiosis with algae to form **lichens**).



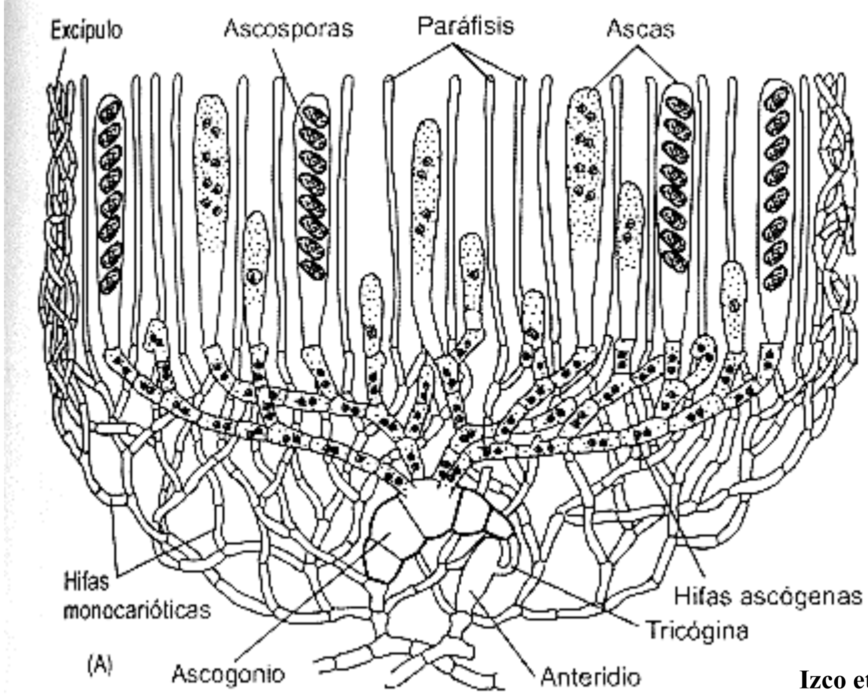


Simple septum

These four images represent apothecia from different species

Diversity of dikaryotic fungi: the ascomycetes or “sac fungi” (Dikarya)

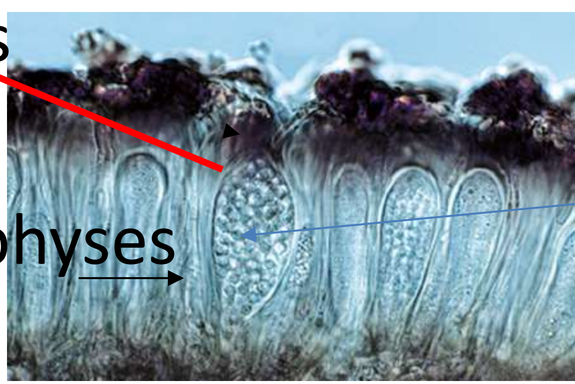
Cross-section of a typical apothecium



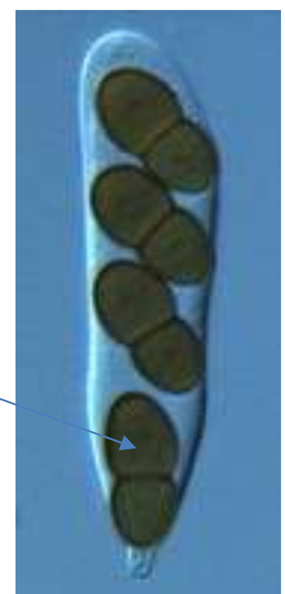
Izco et al. (2004)

Ascus

Paraphyses

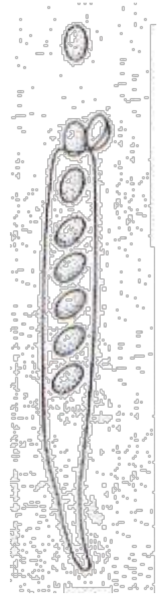


Spores



A portion of hymenium

The **hymenium** is the fertile region of a fungal fruiting body, i.e. where meiosporangia develop and then spores are formed.

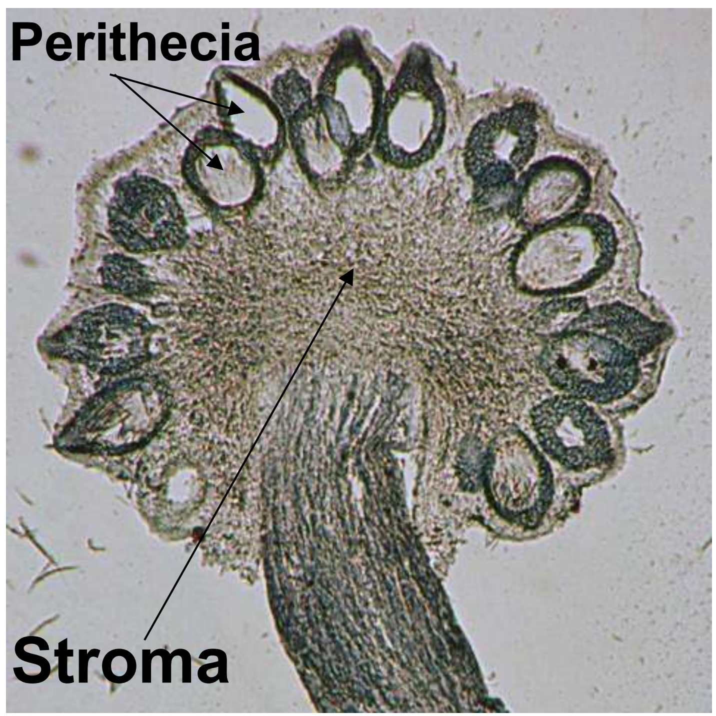


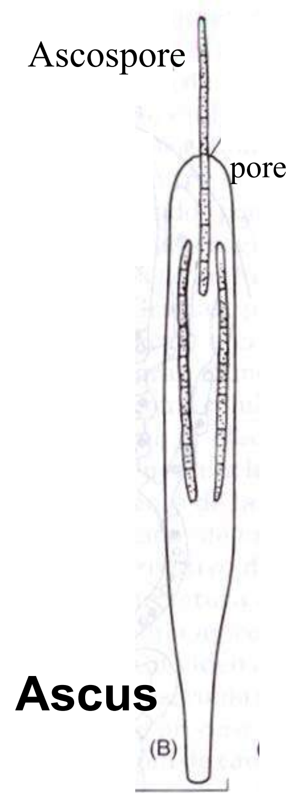
Cup fungi, morels, elfin saddles and truffles are some of the best-known saprophytic or mycorrhizal sac fungi.

Ergot fungus

Claviceps purpurea

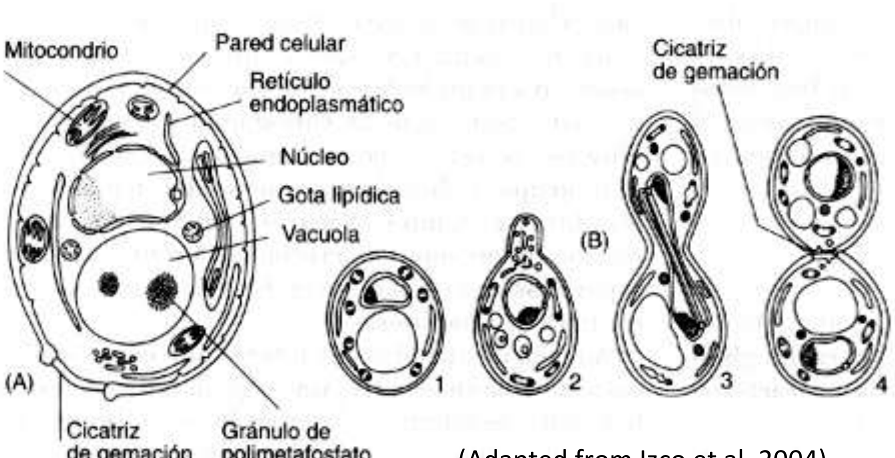
This fungus contains alkaloids (ergometrine and ergotamine) and derivatives of lysergic acid, from which LSD is synthesised.



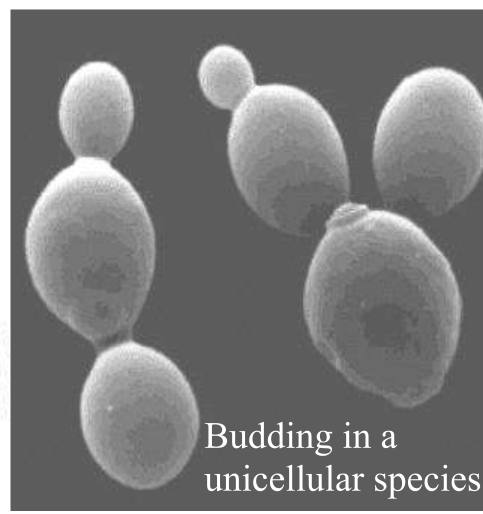


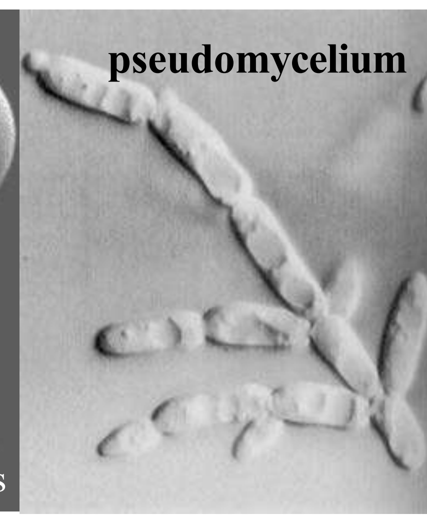
Diversity of dikaryotic fungi: ascomycetes yeasts (*Saccharomycotina*)

- They lack ascomata.
- Their cell walls have low chitin contents (or chitin is absent).
- The species are unicellular or pseudomyceliar.
- Their main propagation mechanism is **budding**.
- They are often saprophytes (= saprophytic).
- They are important in the **food industry** for **fermentation** (in the production of alcohol and CO_2).



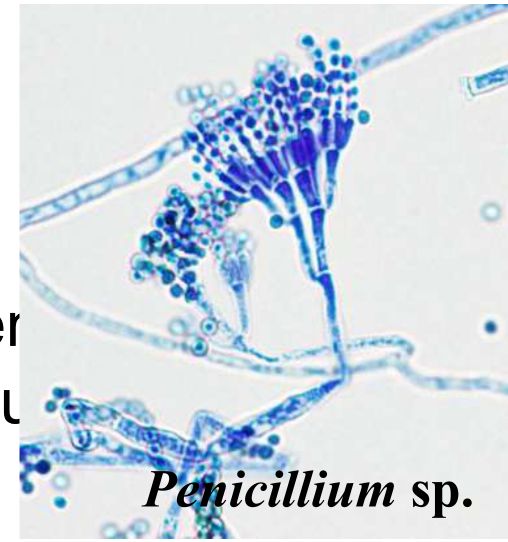
(Adapted from Izco et al. 2004)





Ascomycete fungi whose sexual state is unknown (also called mitosporic fungi or Deuteromycetes)

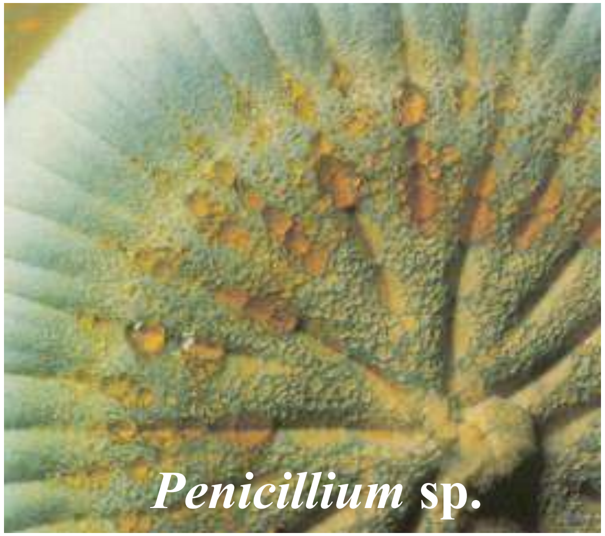

Alternaria sp.


Penicillium sp.


Trichophyton rubrum (ringworm)

Athlete's foot, nail infections, jock itch and ringworm are caused by **anthropophilic saprotrophic fungi** that colonise the upper layers of dead skin.


Aspergillus sp.

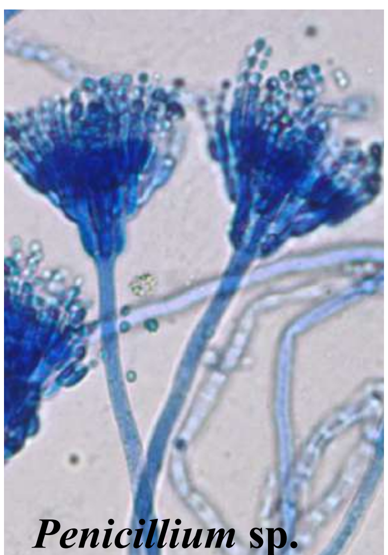


Penicillium sp.

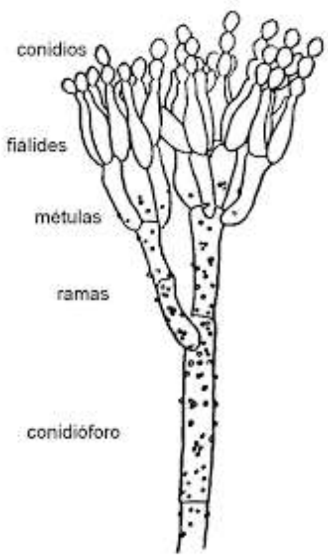
Penicillium roqueforti

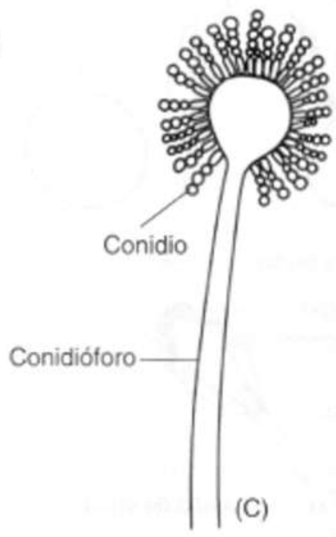
Penicillium digitatum

Green and blue moulds: highly successful mitosporic fungi



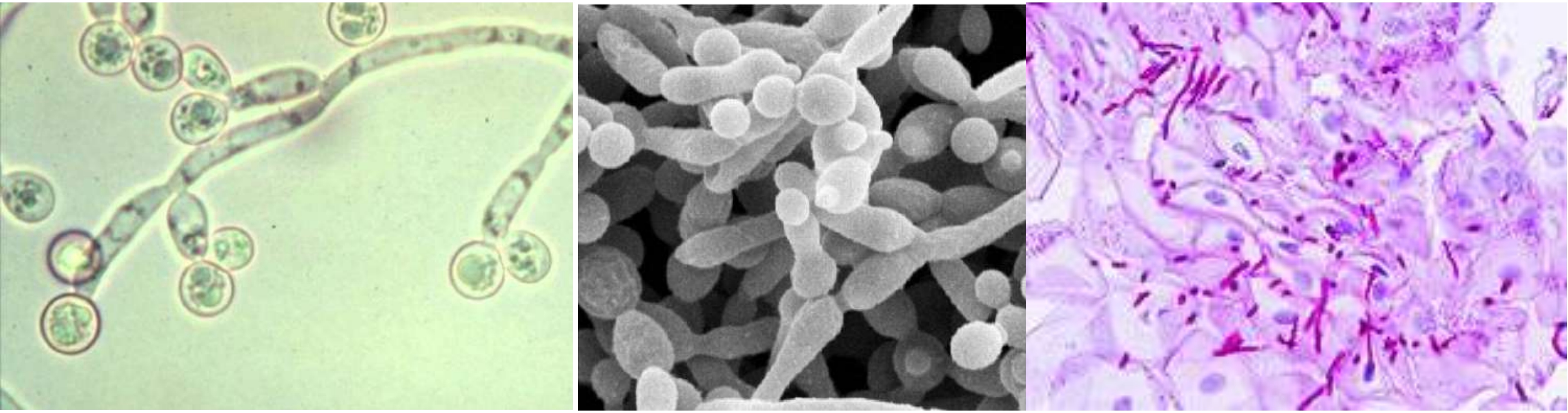
Penicillium sp.





Aspergillus sp.

Penicillium notatum and *P. chrysogenum* are important for the production of **antibiotics** (**penicillin**).
Penicillium roquefortii and *P. camembertii* in **cheese production.**
Aspergillus flavus can produce **aflatoxins**, carcinogenic toxic substances in stored food.



Candida albicans is a yeast that produces only mitospores (asexual phase of the life cycle). It produces white infections called candidiasis.

Diversity of dikaryotic fungi: the basidiomycetes (Basidiomycota)

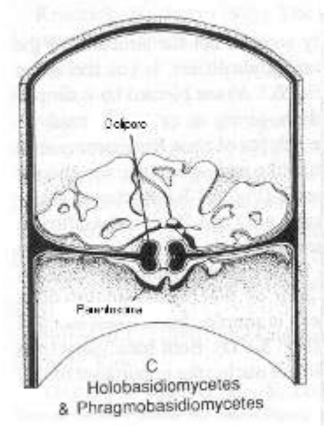
- **Exosporic meiospores** form outside meiosporangia named **basidia**.

- Formation of various types of fruiting bodies (**basidiomata**), such as mushrooms, puffballs, earthstars and tinder fungi.

- Mycelium is formed by septate hyphae.

- Complex septa with **dolipore** and **parenthesomes**.

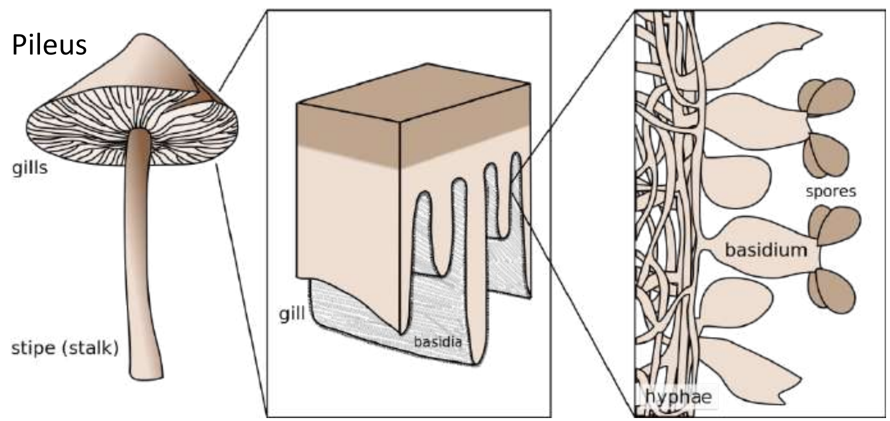
- Over 48,405 species are known.

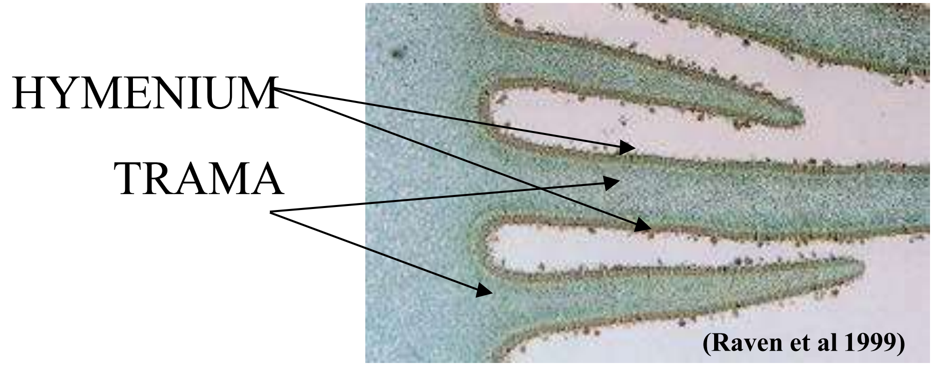


Complex septum with dolipore

A typical basidioma (fruiting body) of the basidiomycete fungus *Amanita muscaria*. These kinds of basidiomata are traditionally called “mushrooms”..

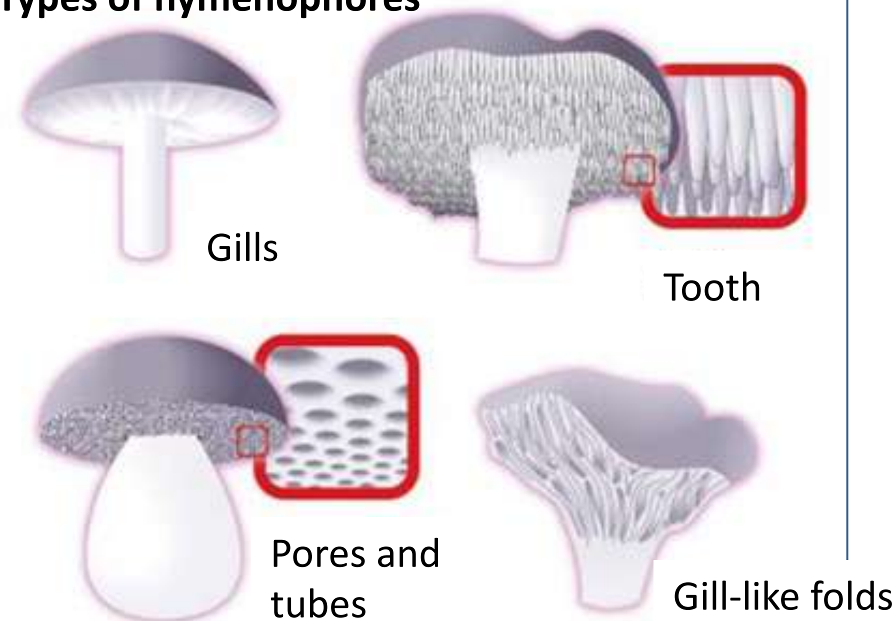
Diversity of dikaryotic fungi: the basidiomycetes (Basidiomycota)

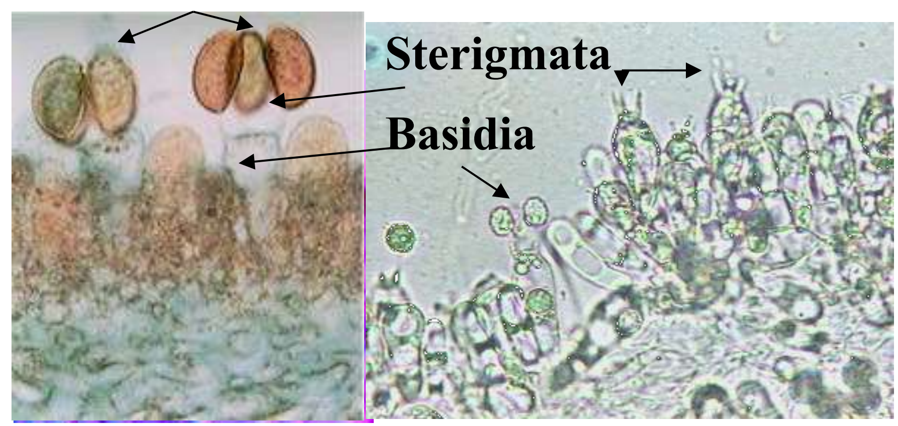




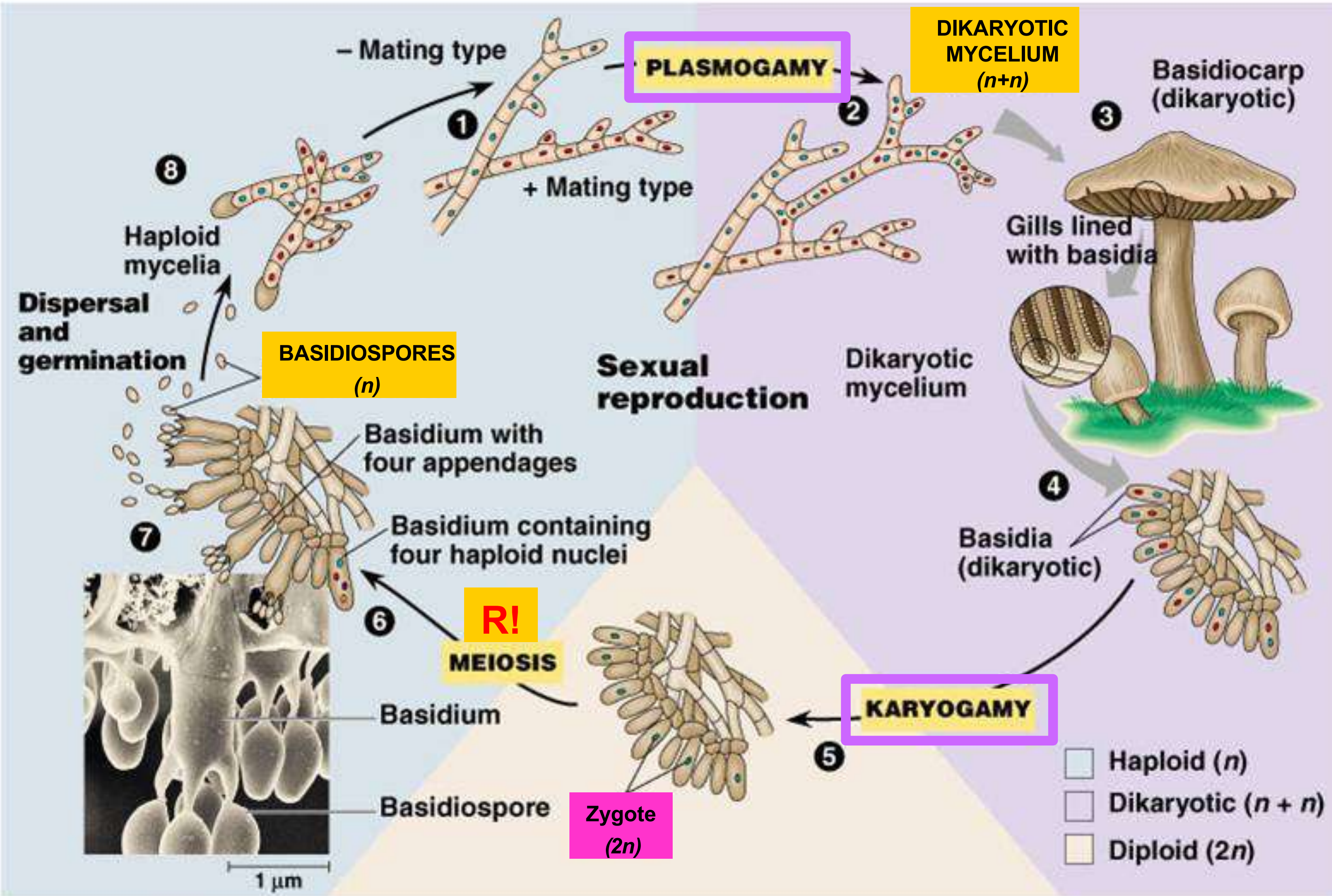
Cross-section of a gilled hymenophore

Types of hymenophores

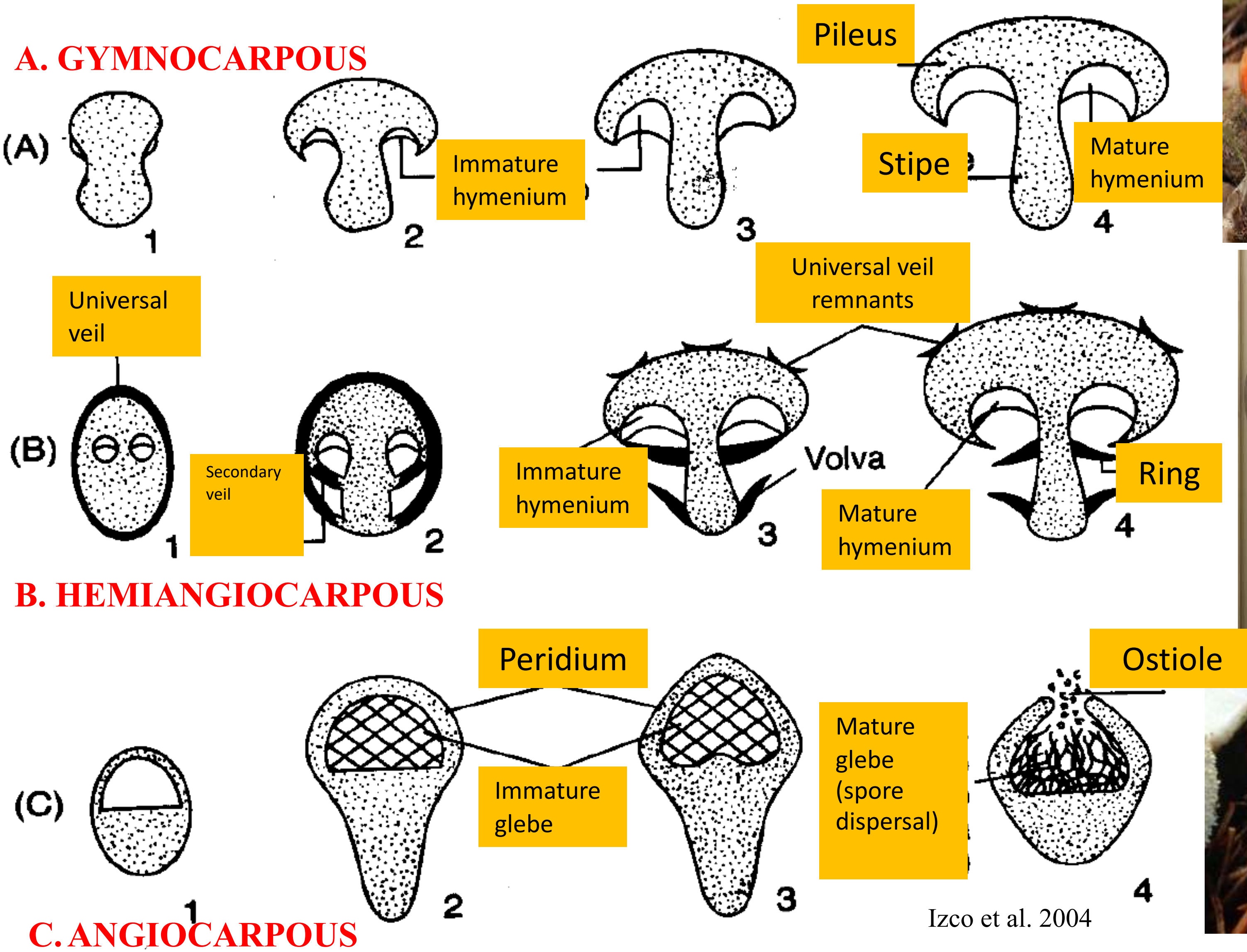




Haplo-dikaryotic life cycle of a mushroom-producing basidiomycete fungus



Parts of a basidioma and different developmental types



Izco et al. 2004

Important orders of basidiomycete fungi: Agaricales, Russulales and Boletales

Typical putrescible, hemiangiocarpic and gymnocarpic basidiomata with gilled or porous hymenophores

Photographs: Isaac GB

Russula monspeliensis

Psilocybe coprophila

Tricholoma atrosquamosum

Agaricus campester

Craterellus lutescens

Craterellus cornucopioides

Fomes inzengae

Hydnellum ferrugineum

Fomitopsis pinicola

Photographs: Isaac GB

Phallus impudicus

Clathrus ruber

Lycoperdon perlatum

Puffballs, birds' nests, phallus, earthstars, latticed stinkhorn

Crucibulum laeve

Astraeus hygrometricus

Geastrum sessile

Topics

Diversity

Symbioses

Uses

Remember the concept of Symbiosis

"An association based on physical contact between two or more organisms (symbionts) of different species (belonging to the same or different Kingdoms) for a significant part of their life history".

There are three types of symbiosis:

MUTUALISM

PARASITISM

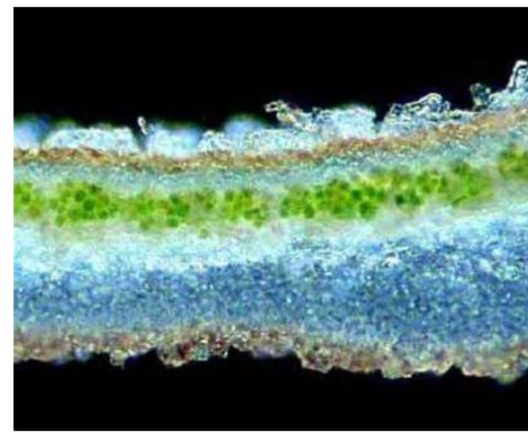
COMMENSALISM

Mutualistic symbiotic fungi

These fungi physically interact throughout their lives with a photosynthetic organism (the **photobiont**), which obtains energy from light. Secondarily, these fungi become photoautotrophs and thus **primary producers**.

- Fungus + photobiont (cyanobacteria/green alga)

Lichen



- Fungus + plant root

Mycorrhiza

Lichens

Cyclic symbiotic associations between at least two different types of organisms: a heterotrophic fungus (mycobiont) and a photosynthetic symbiont (photobiont) that provides the necessary sugars for metabolism, fixing CO_2 and releasing oxygen in the process.

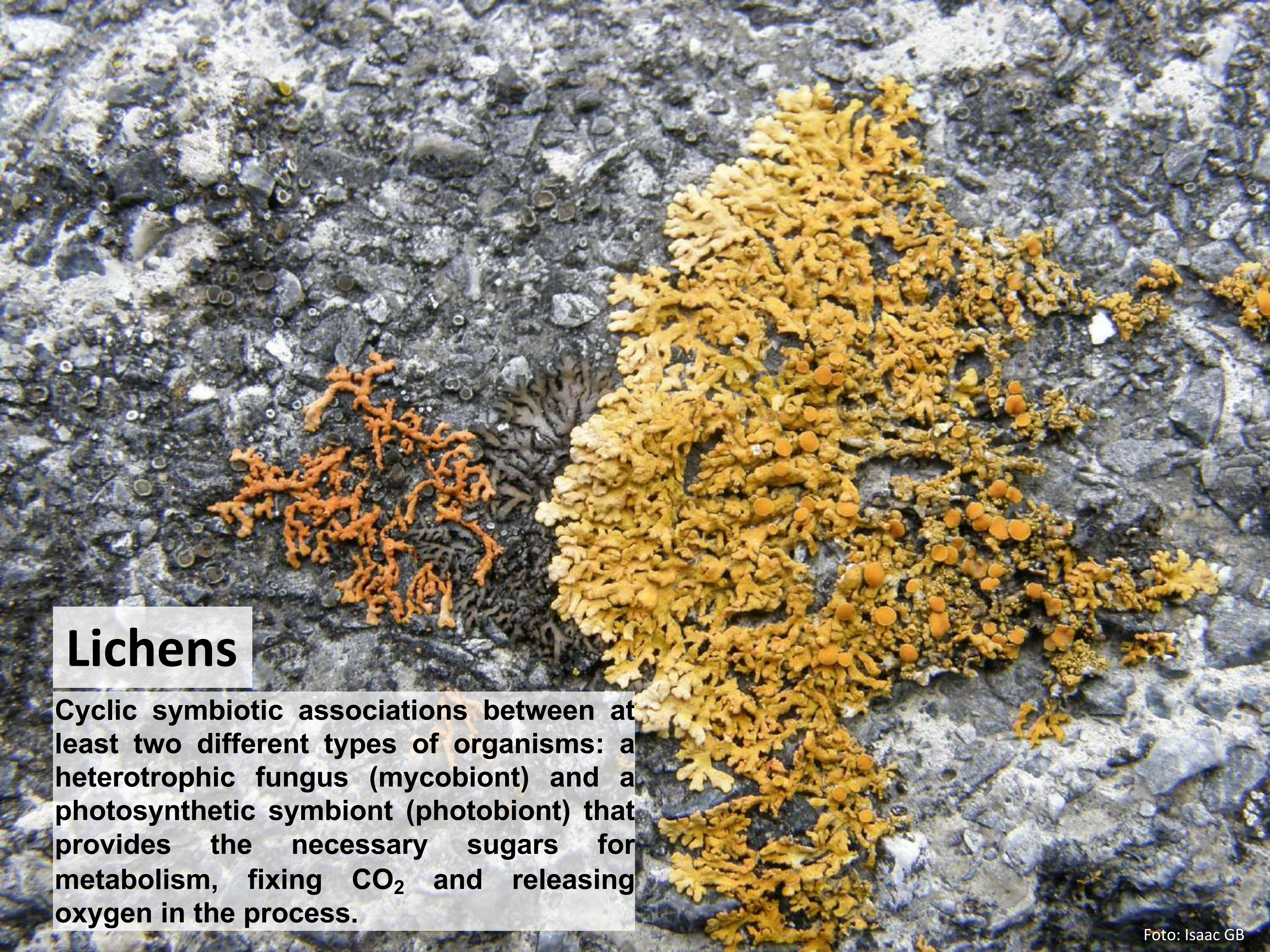


Foto: Isaac GB

Diversity of lichen mycobionts and photobionts

Fungi (mycobionts) **20,000 species**

Ascomycetes (98 %)

Basidiomycetes (0.4 %)

Others (1.6%)

Algae and Cyanobacteria (photobionts)

Chlorophyta (green algae)

Trebouxia, Asterochloris, Trentepohlia, Vulcanochloris

Cyanobacteria (blue-green algae)

Nostoc, Rivularia, Scytonema

Main characteristics of the lichen symbiosis

- Interaction between the two symbionts results in the formation of individualised entities called **lichen thalli**.

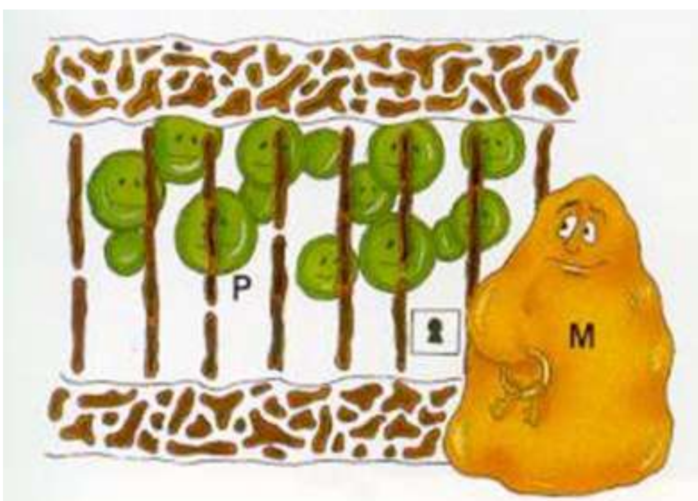
- The symbionts are poikilohydrous organisms: they acquire water and mineral nutrients mainly from the atmosphere through rain, mist and dust, etc.

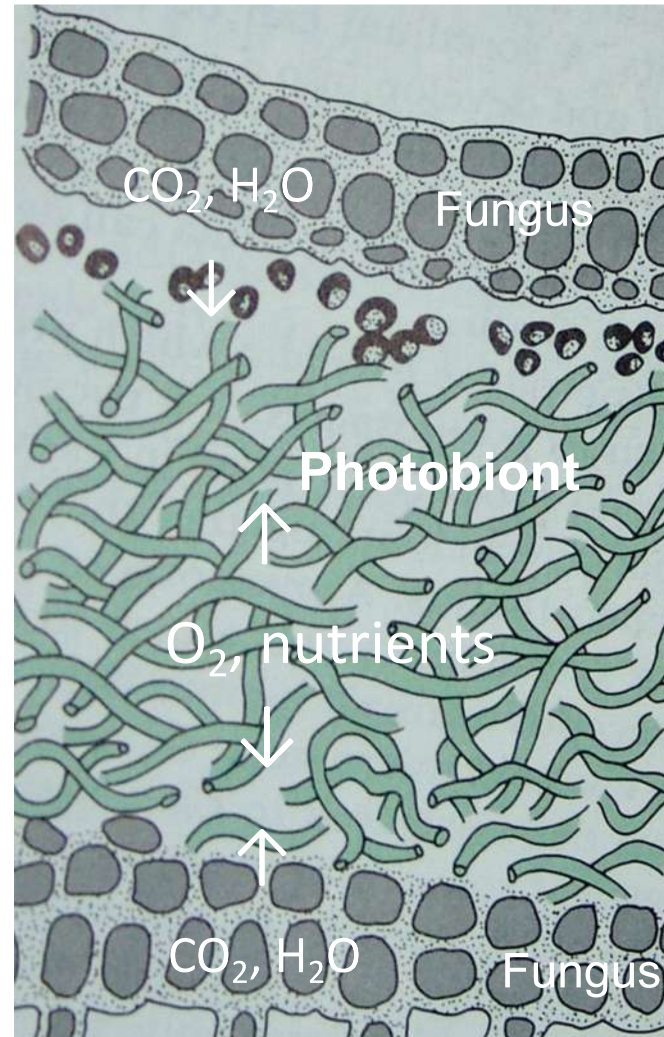
Lichen thallus comprising a fungus from the genus *Parmelina* and a green microalga of the genus *Trebouxia*.
(Photograph: Isaac GB)

Main characteristics of the lichen symbiosis

- The **benefits for the mycobiont** are clear, since it receives:
  - **carbohydrates** and **energy** from the photobiont and/or **nitrogen** from cyanobacteria.
  - **oxygen** from the atmosphere and from photosynthesis.

- The **benefits for the photobiont** are not so clear, though:
  - the fungus produces hygroscopic substances that absorb water, which is transferred to the photobiont.
  - symbiosis protects the photobiont from mechanical damage, predation, and intense light.
  - symbiosis enables the photobiont to extend its range of distribution and use the mycobiont as a means of anchoring itself to the substrate.
  - the mycobiont provides the photobiont with CO_2 through respiration.



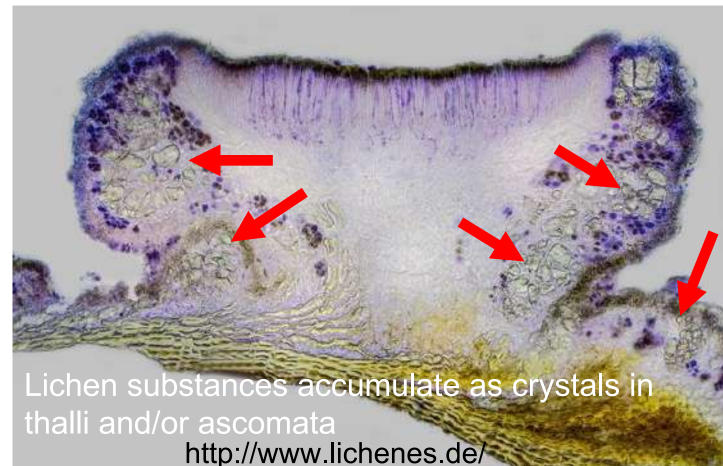


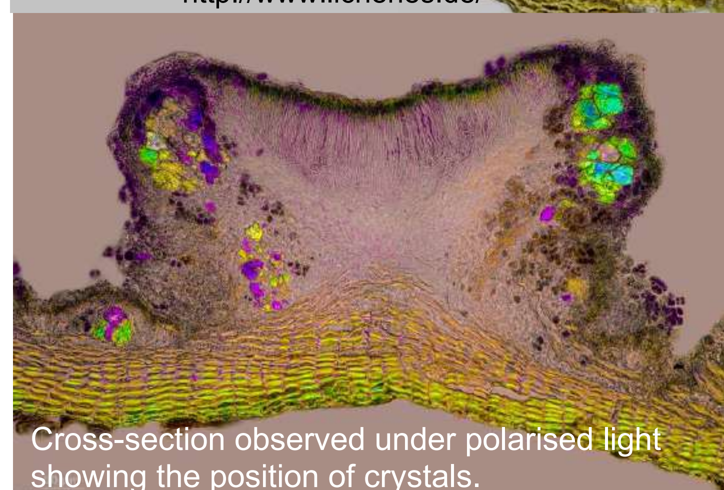
Lichen substances – products of the mycobiont's secondary metabolism

The attractive colours of lichens derive from pigments produced by the thallus hyphae as a result of secondary metabolism. Some secondary metabolites act as sunscreens, while others act as antibiotics. Over 400 different substances are known.

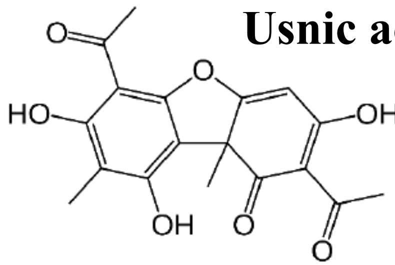
Adapted from Purvis (2000)

These substances are identified through spot tests using potassium hydroxide (KOH) and bleach (C)

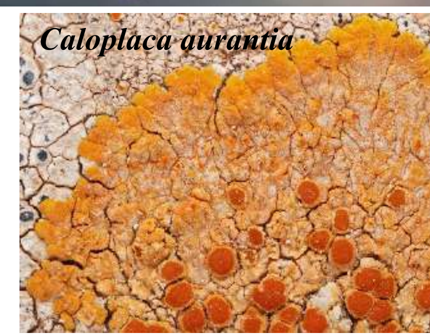

Lichen substances accumulate as crystals in thalli and/or ascomata
http://www.lichenes.de/


Cross-section observed under polarised light showing the position of crystals.

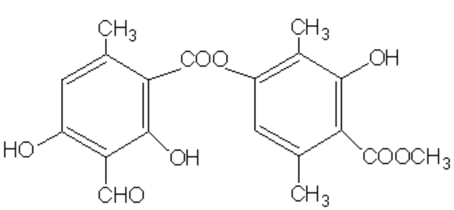
Lichen substances – products of the mycobiont's secondary metabolism



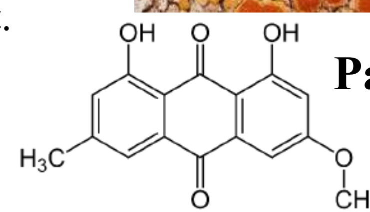
Usnic acid



They **prevent predation** by animals, since they are mostly toxic.
They exert an **antibiotic** action against bacteria, mosses and other fungi.
They **increase water absorption**.
They **increase photoprotection** of the photobiont.



Atranorin



Parietin

MYCORRHIZAE

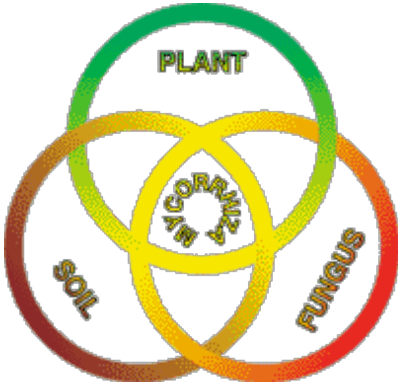
Wood Wide Web

Mycorrhizae

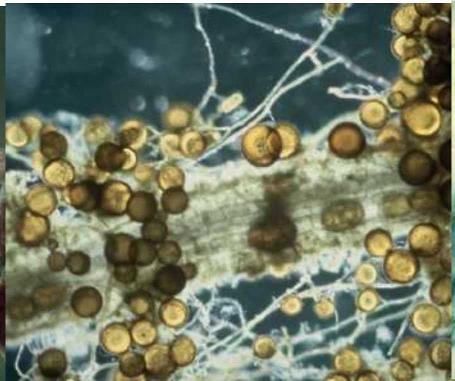
This concept, which means "fungus-root", was proposed by Frank in 1885.

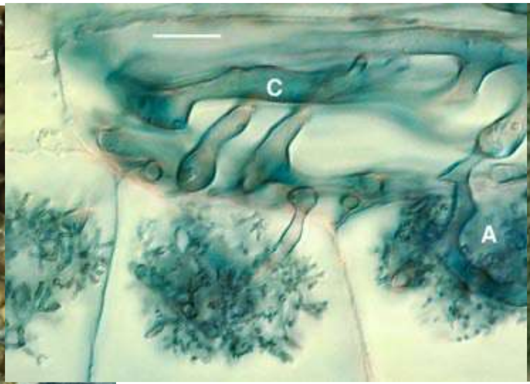
It reflects cyclic mutualistic symbiosis between a fungus and the root of a plant:

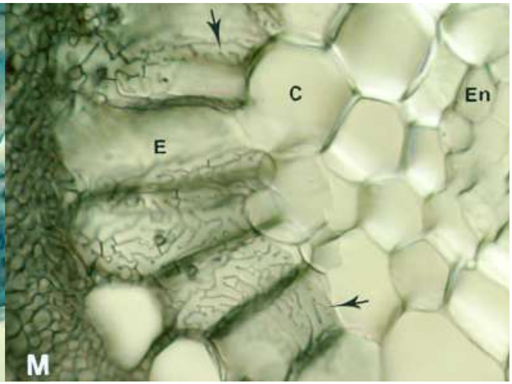
- **angiosperms**
- **gymnosperms**
- **ferns**
- And even some **bryophytes**



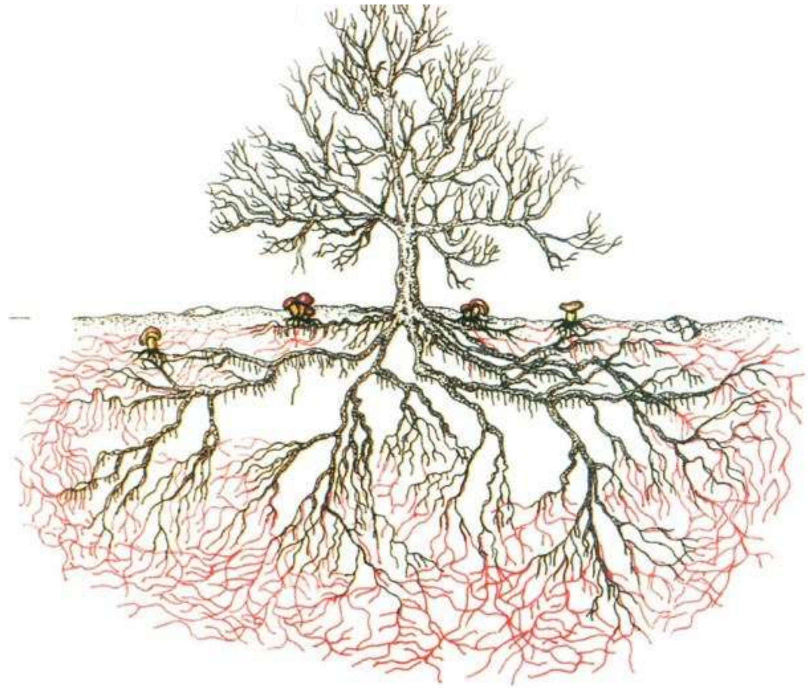
Carbon-rich compounds flow from the plant to the fungus, while inorganic nutrients (especially phosphorus) and water flow in the opposite direction.







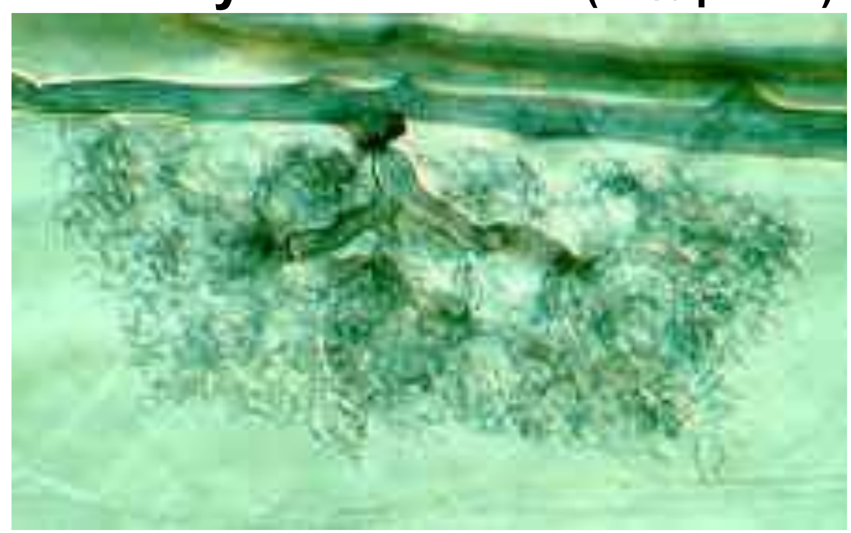
Mycorrhizal types



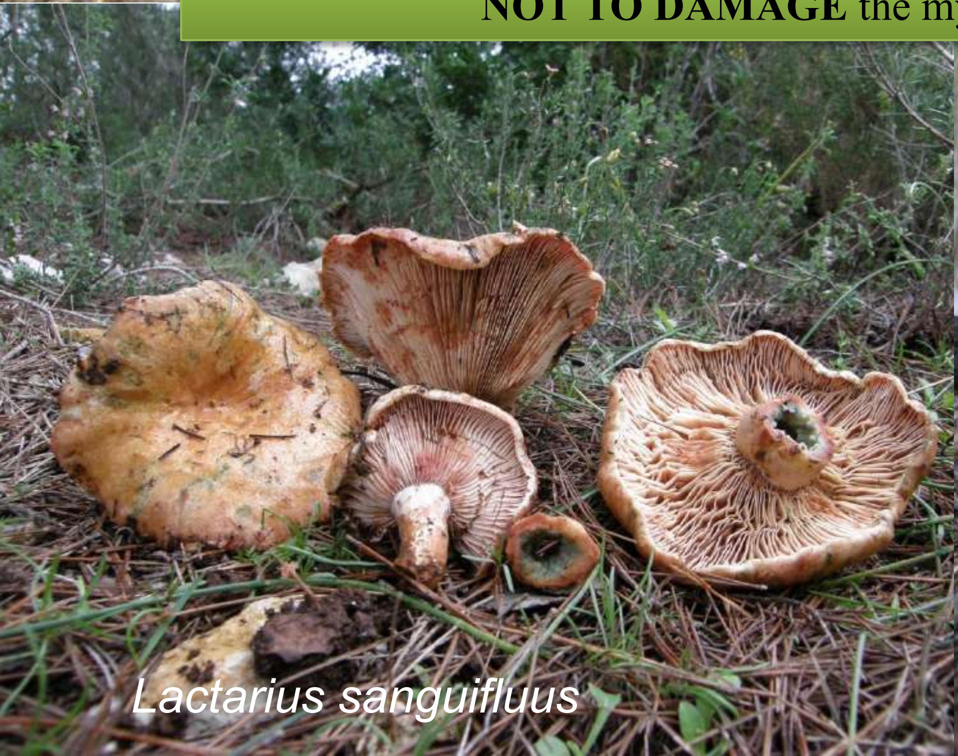
One mycelium or several mycelia?

Ectomycorrhizae (2% plants)

Endomycorrhizae-VA (80% plants)



Many edible fruiting bodies found in forests belong to ectomycorrhizal fungi. It is important **NOT TO DAMAGE** the mycelium when picking mushrooms.



Topics

Diversity

Symbioses

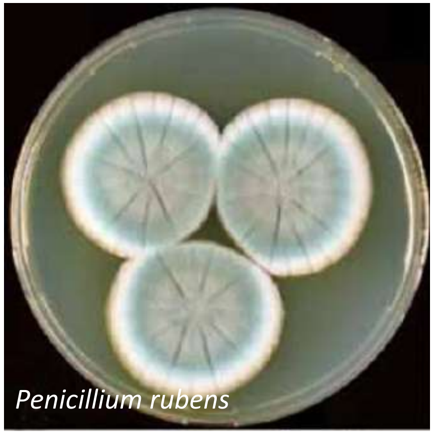
Uses

Uses of fungi for humans

At least 350 species are consumed as foods

15% of all vaccines and therapeutic proteins are made in yeast

Fungi are being used to turn crop waste into bioethanol



Penicillium rubens

Tolypocladium inflatum

216 species of fungi are thought to be hallucinogenic

$C_5H_6O_4$

Itaconic acid from fungi is used to make Lego®

FUNGAL PHARMACEUTICALS

Fungi have made major contributions to the world of medicine. For example, penicillin from the fungus *Penicillium rubens* revolutionised the treatment of bacterial infections, while cyclosporine from the fungus *Tolypocladium inflatum* made organ transplantation possible by helping to prevent rejection of the donated organs. Other notable examples include the cholesterol-lowering drug lovastatin, from *Aspergillus terreus*, and fingolimod, which is used to treat multiple sclerosis. The chemical structure of fingolimod took inspiration from myriocin, a chemical compound produced by *Isaria sinclairii*.

Adapted from SOTW Fungi (2018)

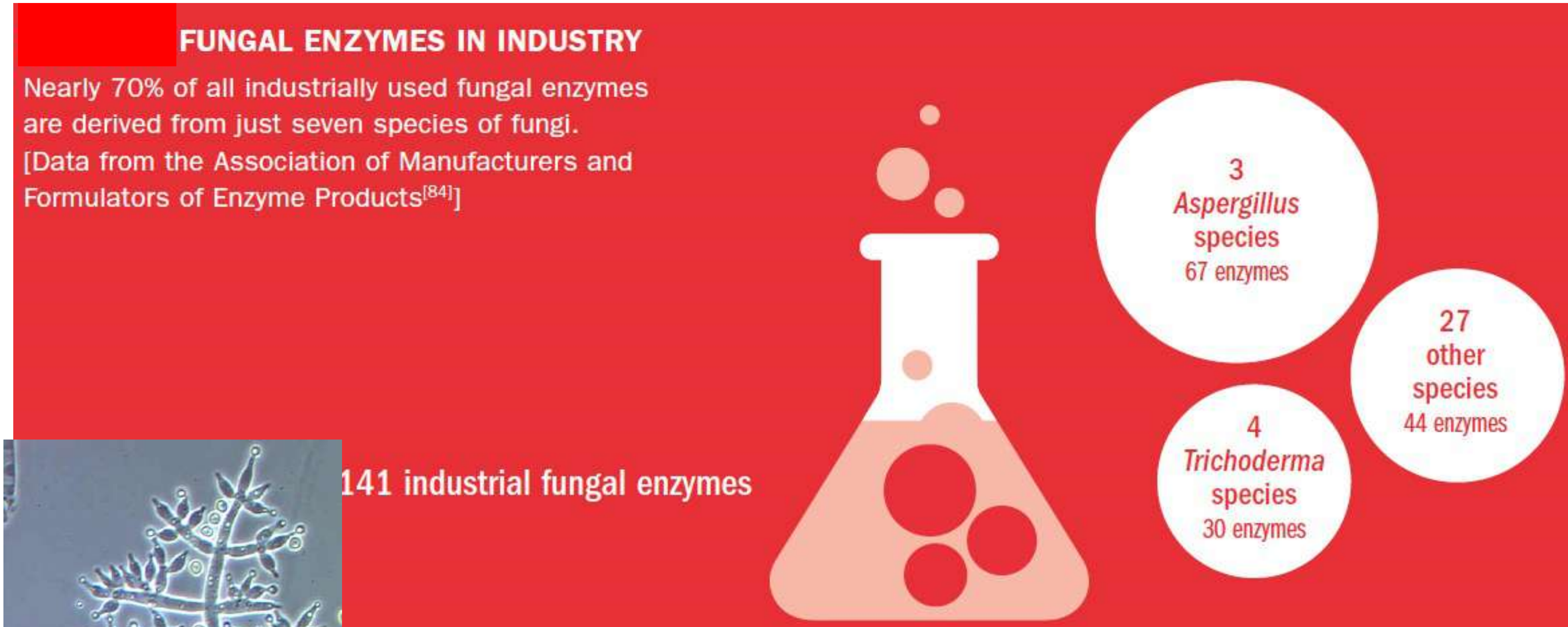
Uses of fungi for humans

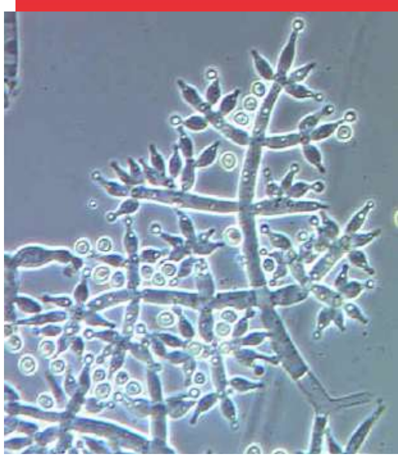
The entomopathogenic fungus *Isaria sinclairii* infects cicada larvae; it grows inside its host, initially without killing it but instead replacing the host tissue with fungal mycelium. Eventually its spore-bearing structures emerge from the dead larvae. *Isaria sinclairii* produces an immunosuppressant chemical compound called myriocin. Extensive chemical redesign of myriocin resulted in the immunosuppressive multiple sclerosis treatment fingolimod. Fingolimod is a blockbuster drug with sales of US$2.48 billion in 2018[83].


Isaria sinclairii

Adapted from SOTW Fungi (2018)

Uses of fungi for humans

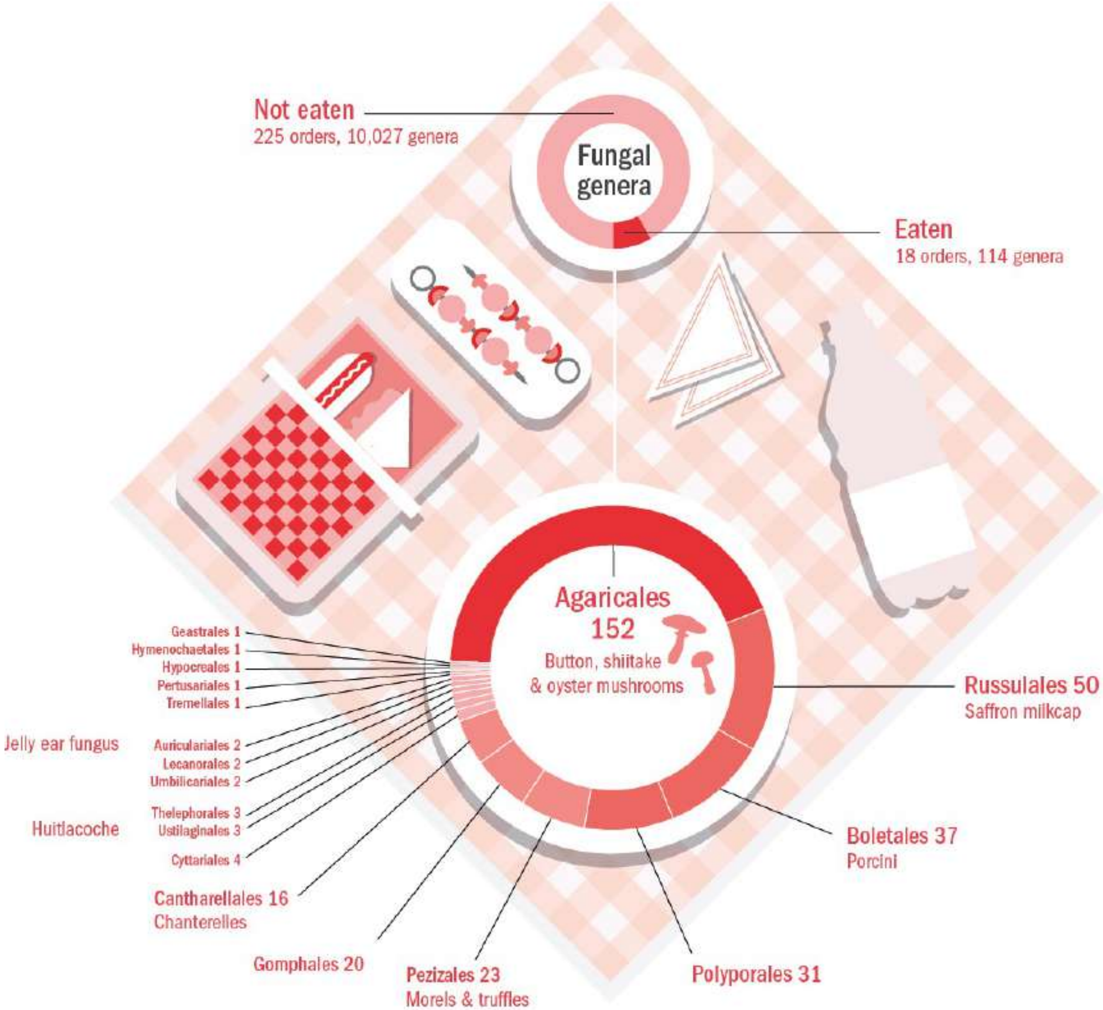




Trichoderma harzianum

Adapted from SOTW Fungi (2018)

Uses of fungi for humans



Adapted from SOTW Fungi (2018)

Uses of lichens

Té Respi-bien

Descongestiona las vías respiratorias, alivia los síntomas de la tos, gripa, bronquitis, laringitis, desinflama la garganta. Expectorante, balsámico, refrescante.

www.OmSati.com

Cont. Net. 100 gramos

OmSati "por una vida sin diabetes"

INGREDIENTES:
Equinacea (Echinacea paradoxa), Sambucus mexicana, Eucalipto, Anacahuite (cordia boissieri), Cirial (Cresentia alata), Juliana adstringens, Flor de tabachin (Caesalpinia pulcherrima), Pinus teocote, Lobaria pulmonaria, Cordia alliodora, Cassia fistula, Sicta pulmonocea, Gnaphalium semiamplexicaule, Gordolobo, Cathartocarpus fistula, Crescentia cuajete.

Modo de preparación:
Agregar una cucharada sopera del té para 200 ml de agua. Calentar hasta que hierva y dejar hervir durante 10 minutos. Tomarlo antes de los alimentos. Una o dos tazas al día.

1 cucharada por taza

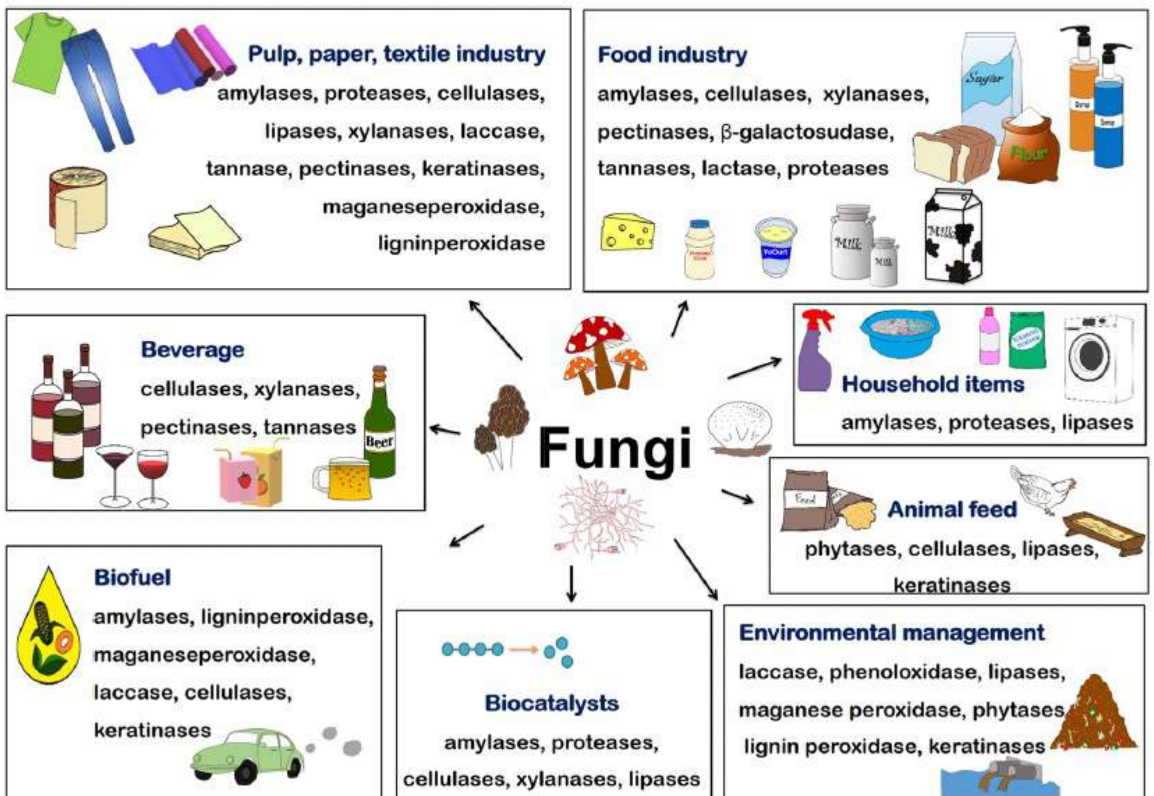
Hervir durante 10 minutos

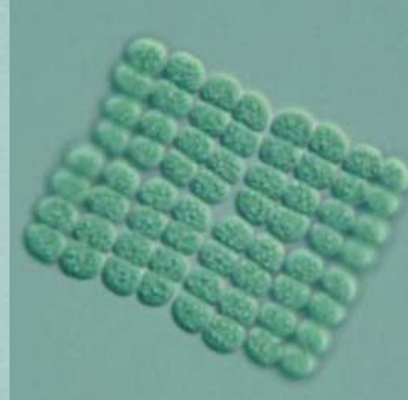
Lichens are used in medicine and herbalism, as dyes for decorations and models, in perfumes, and as indicators of atmospheric pollution.

Further reading

Willis, K. J. (2018). State of the world's fungi 2018. Report. State of the world's fungi 2018. Report.

Hyde, K. D., Xu, J., Rapior, S., Jeewon, R., Lumyong, S., Niego, A. G. T., ... & Stadler, M. (2019). The amazing potential of fungi: 50 ways we can exploit fungi industrially. Fungal Diversity, 97(1), 1-136.



Lecture 05
(Algae I)
Cyanobacteria
(Domain *Bacteria*, prokaryotes).

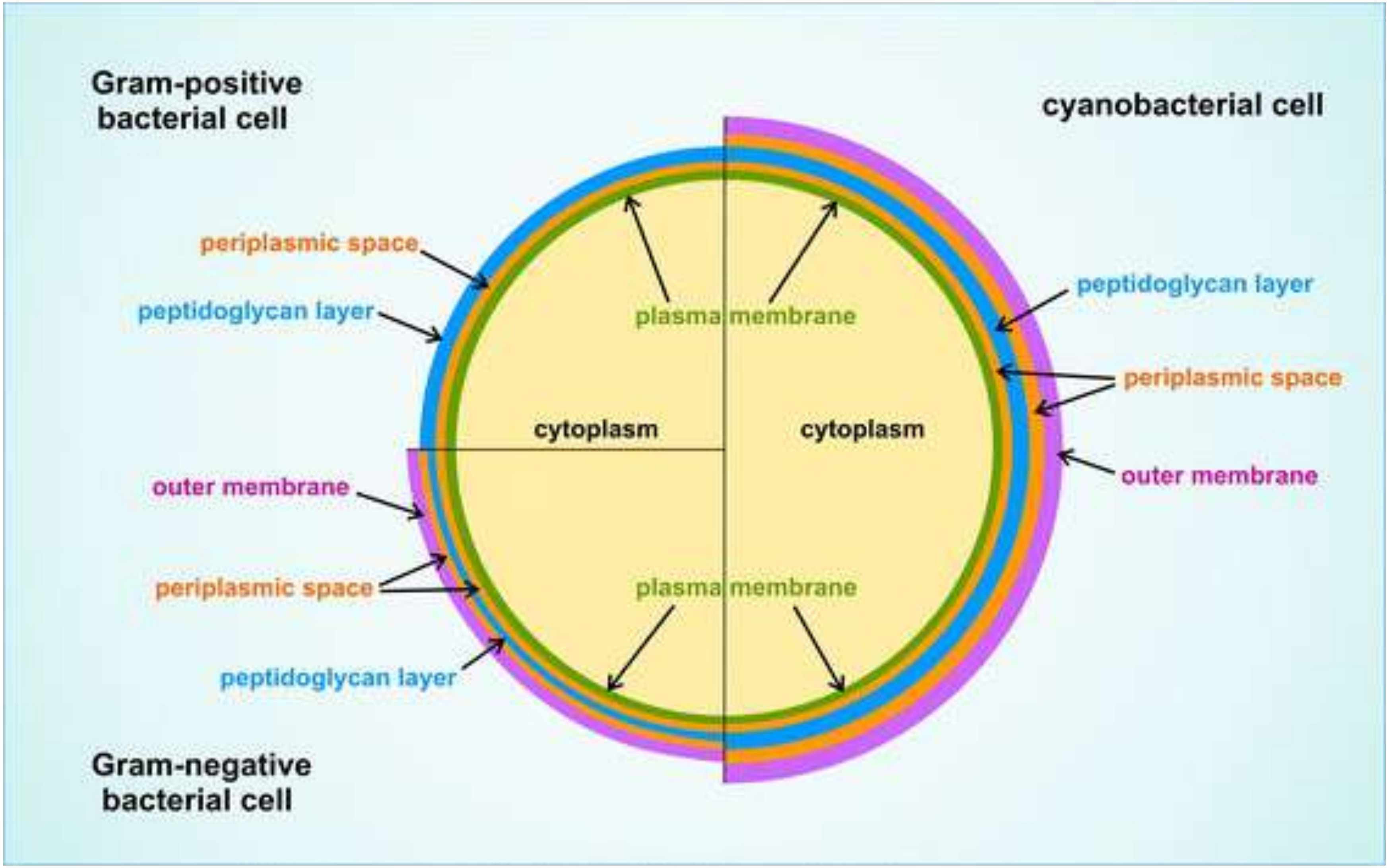



Domain *Bacteria*, Phylum *Cyanobacteria*

– Cyanobacteria, or “blue-green algae”

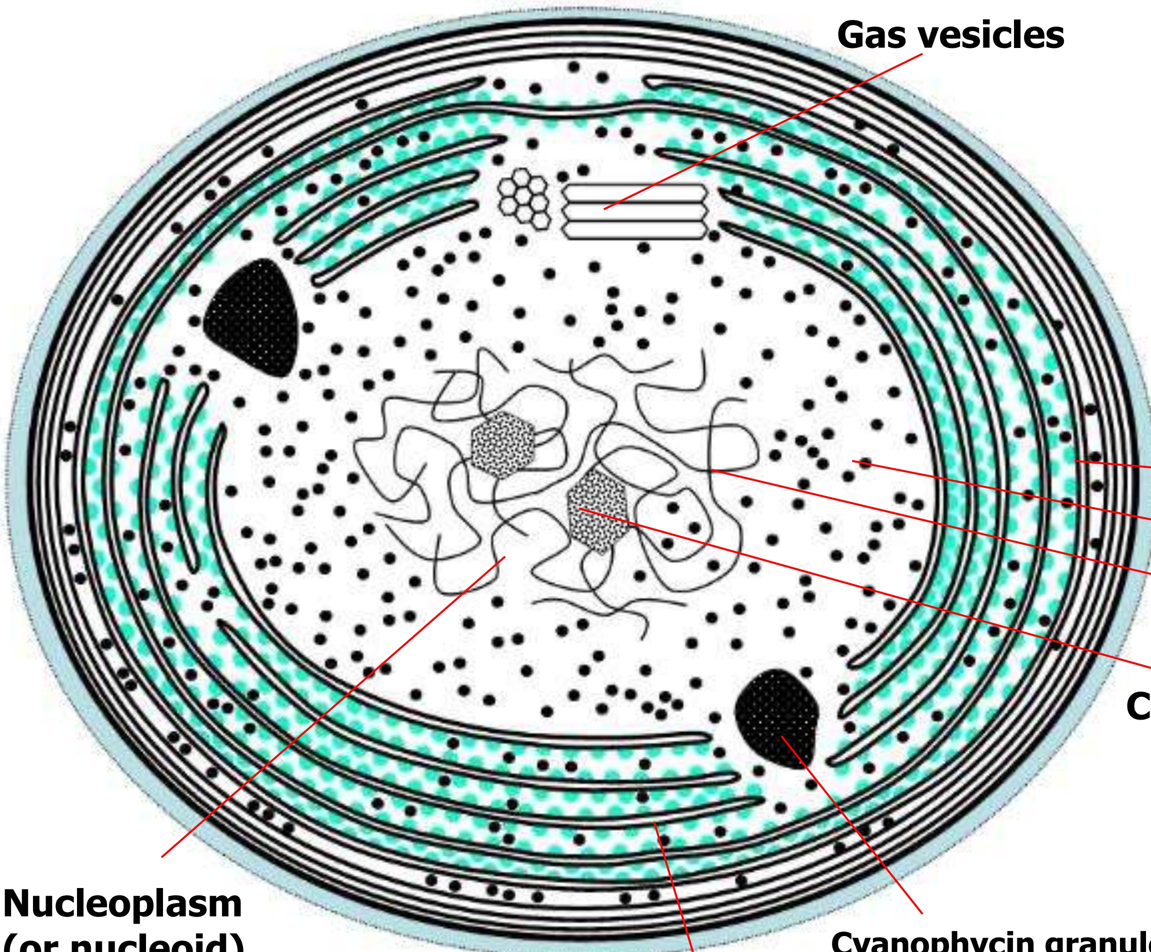
- Cyanobacteria are photoautotrophic gram-negative bacteria that obtain energy from sunlight.
- Approximately 2,000 species of Cyanobacteria exist.
- Protophytes (unicellular, colonial, coenobia).
- Cyanobacteria are one of the most evolutionarily (endosymbiosis theory) and ecologically important groups of prokaryotes.
- They play a crucial role in the carbon biogeochemical cycle on a global scale.
- Many species are atmospheric nitrogen fixers.
- Some species associate symbiotically with other organisms (e.g. fungi, hornworts and vascular plants).

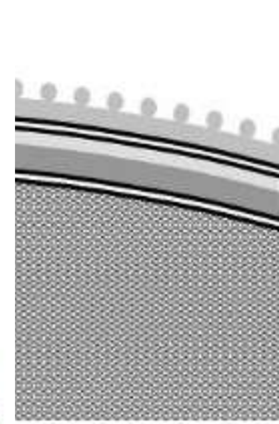
Comparison of cyanobacteria with other bacterial cells

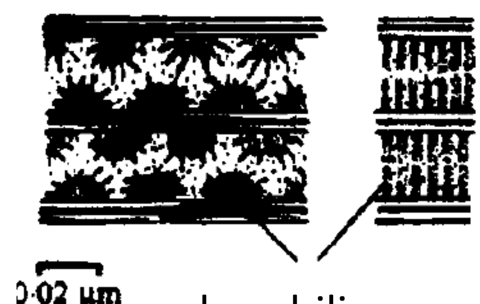


Adapted from Sciuto, K., Moro, I. Cyanobacteria: the bright and dark sides of a charming group. *Biodivers Conserv* **24,** 711–738 (2015)

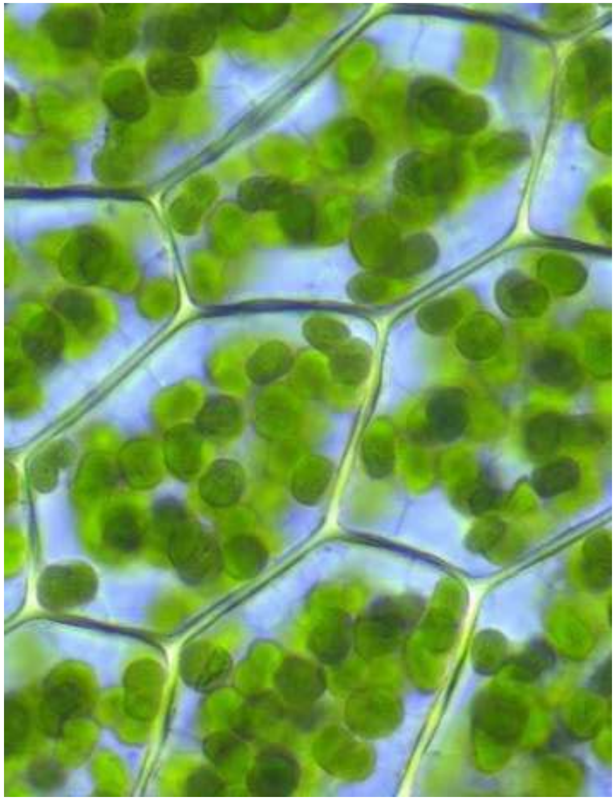
Main structural and biochemical characters of a cyanobacteria cell







Comparison with the chloroplast of a eukaryotic cell



Mesophyll cells

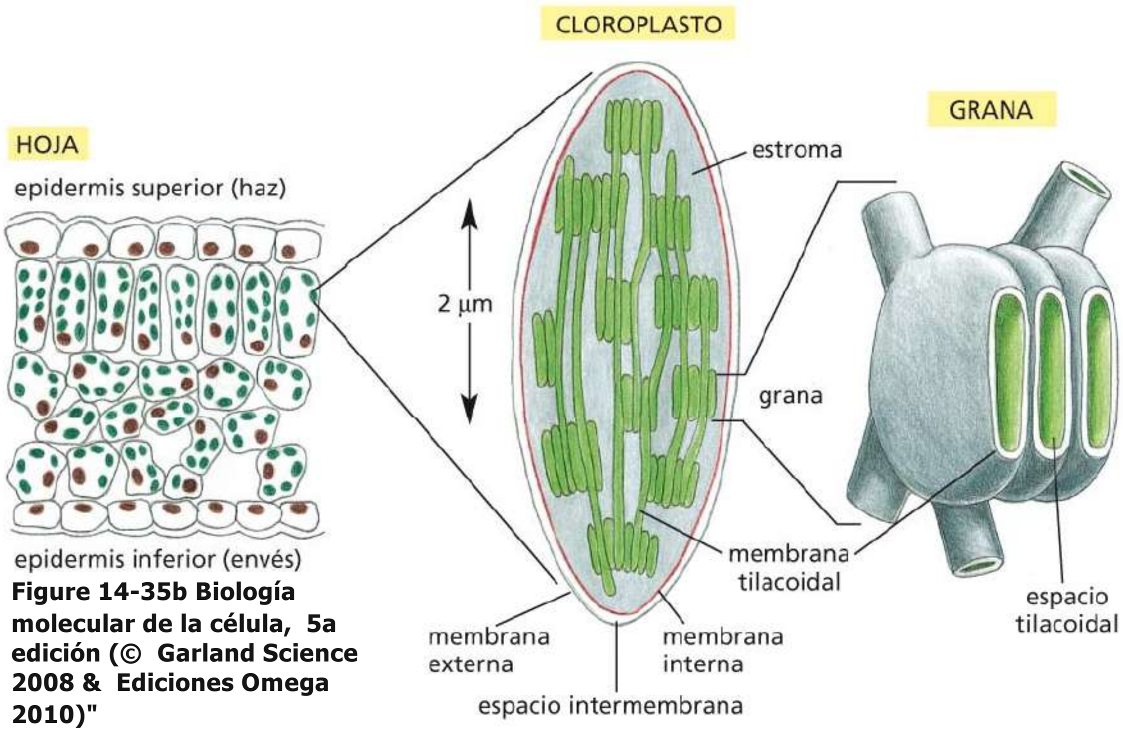
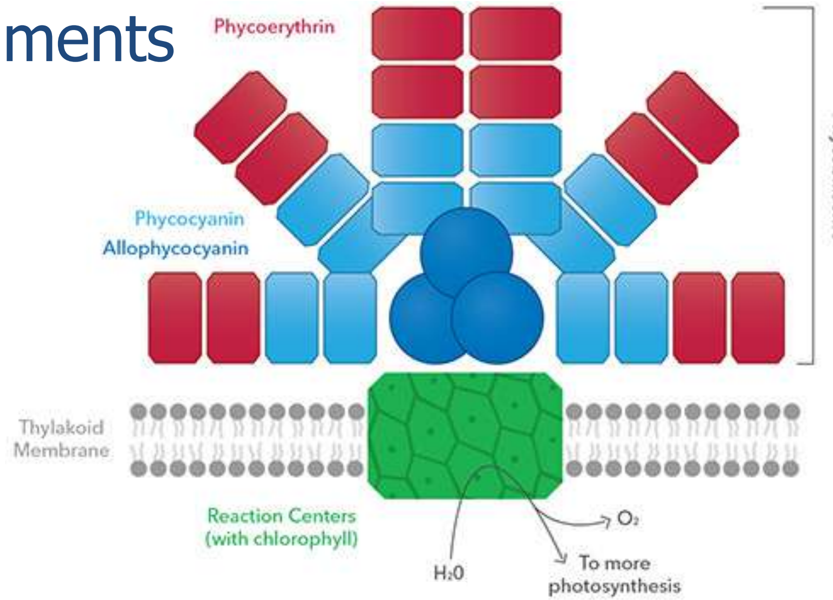


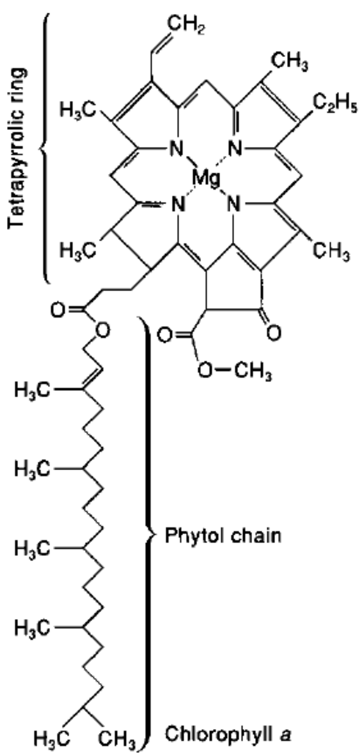
Figure 14-35b Biología molecular de la célula, 5a edición (© Garland Science 2008 & Ediciones Omega 2010)"

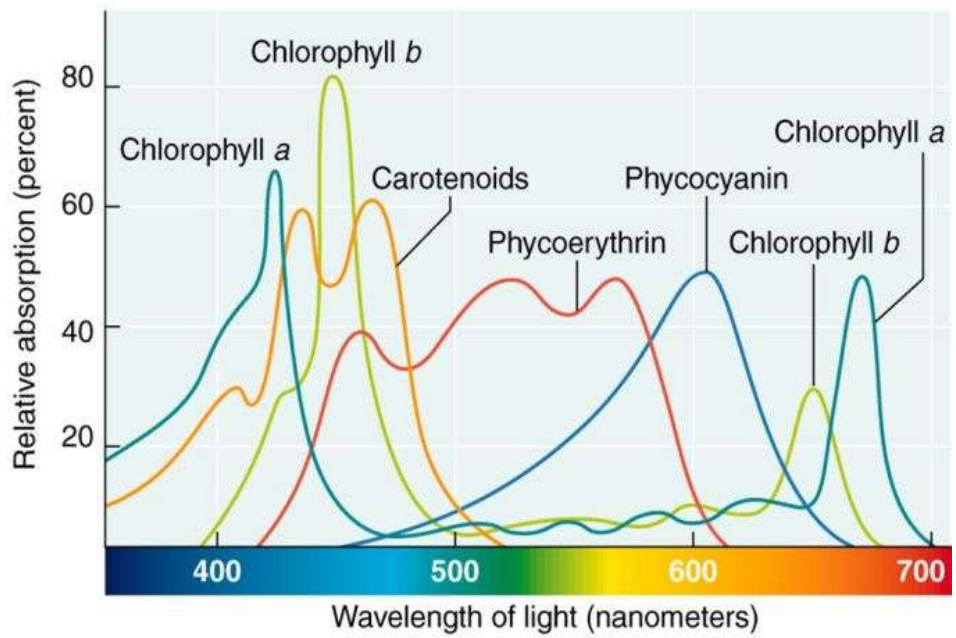
Thylakoid (light) reactions: inner membranes of chloroplasts (thylakoids); ATP and NADPH products.
Carbon fixation (dark) reactions: <u>stroma</u> of chloroplasts; RuBisCO enzyme involved; carbohydrates as product.

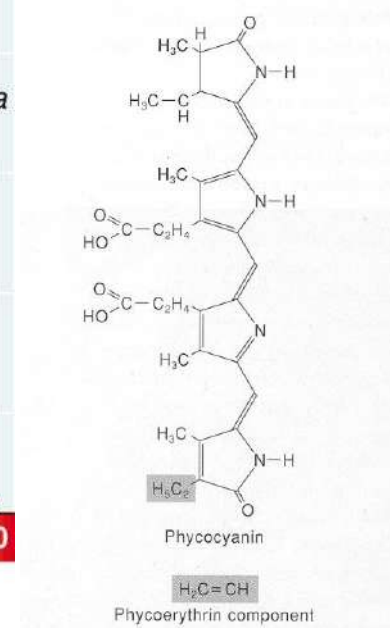
Cyanobacterial photosynthetic pigments

- Chlorophyll ***a*** (exceptionally ***b***)
- Phycobilins:
  - .- phycocyanin **blue**
  - .- phycoerythrin **red**

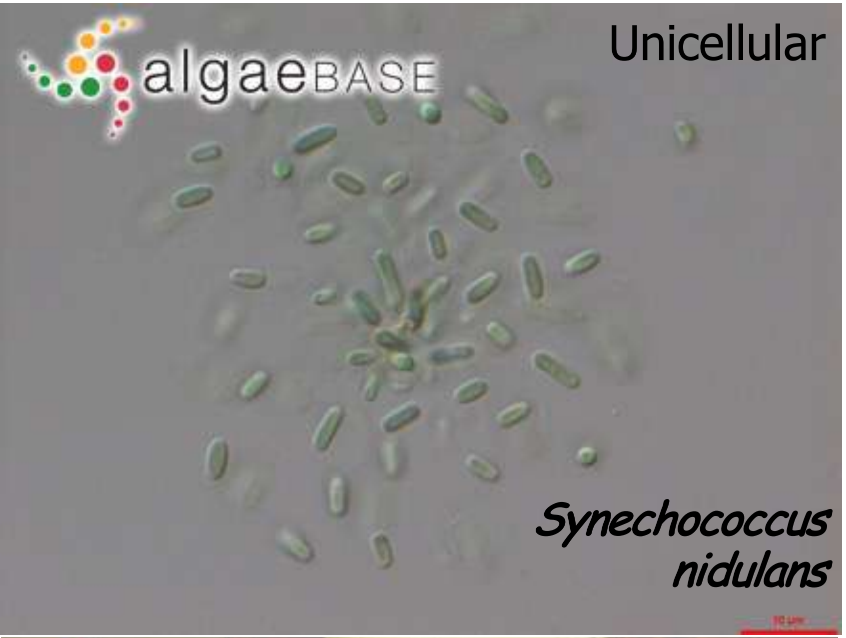


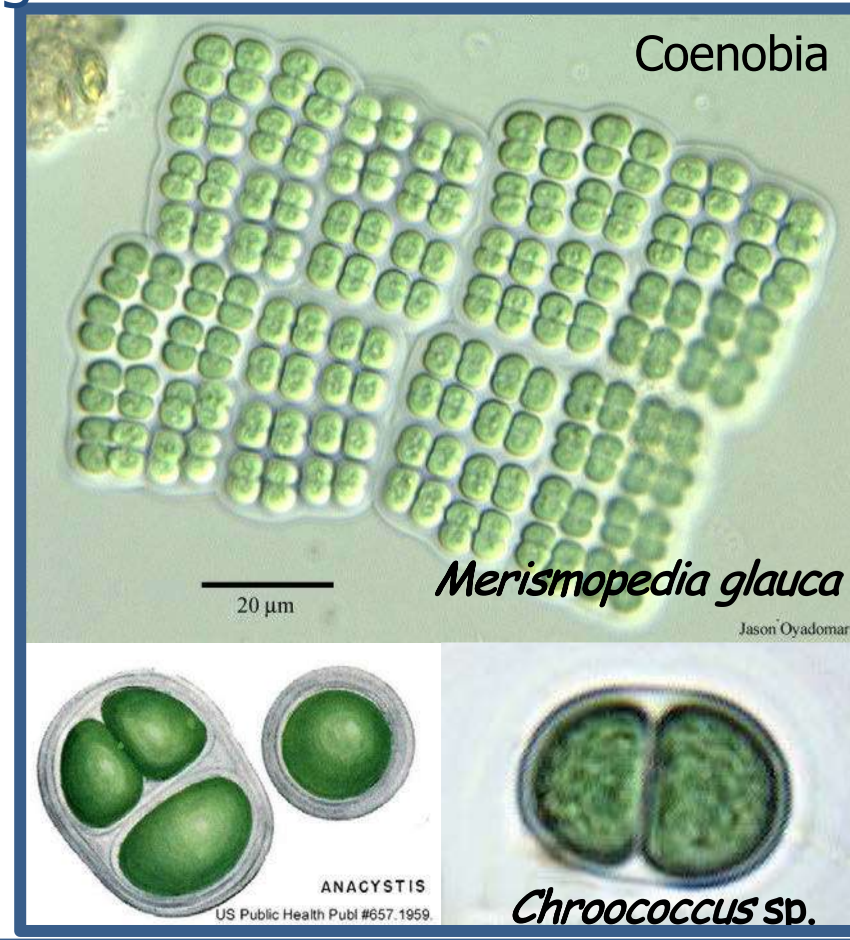


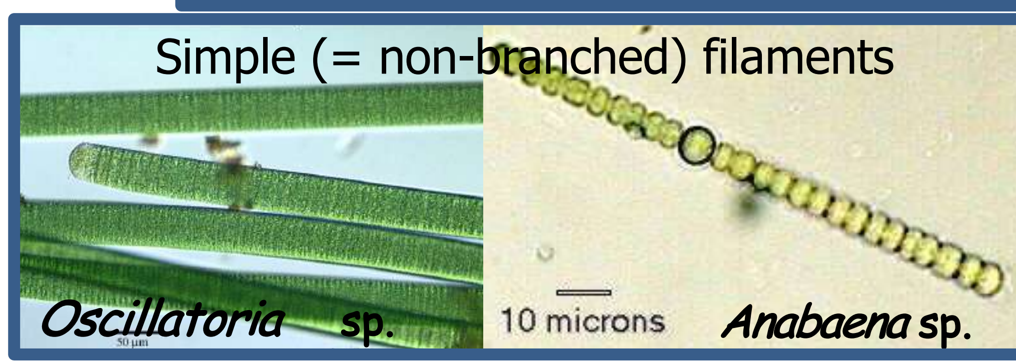




Structural complexity and cell organisation







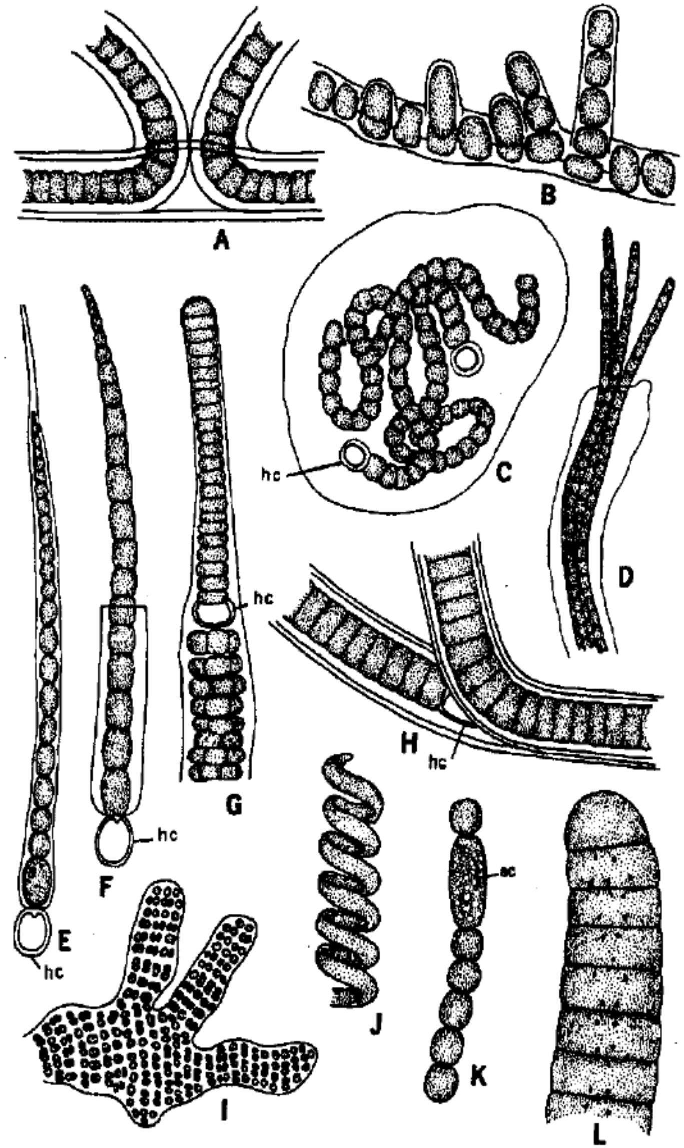
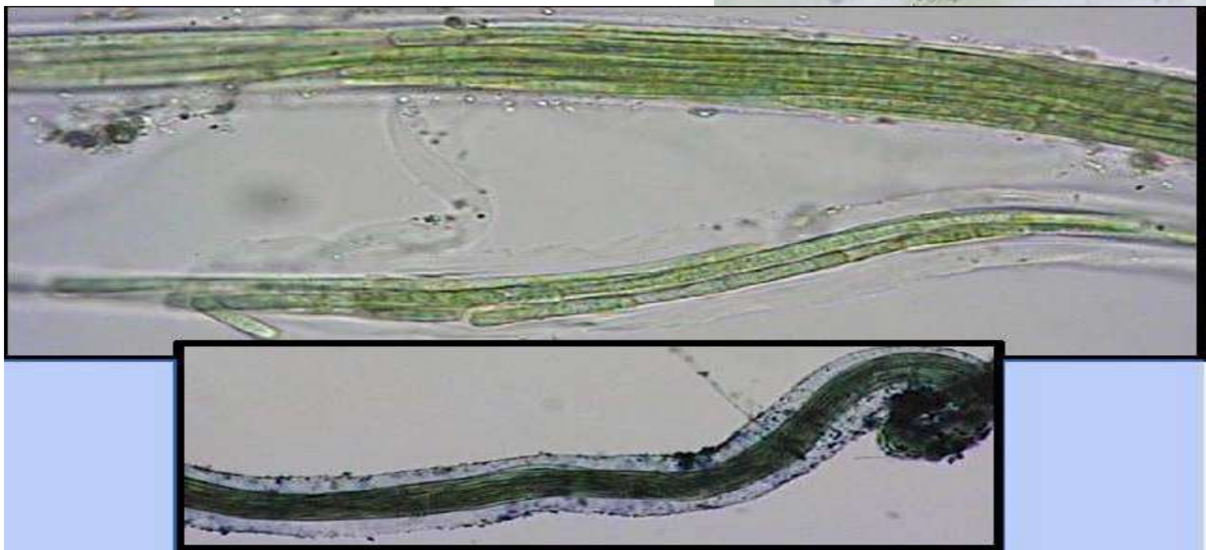
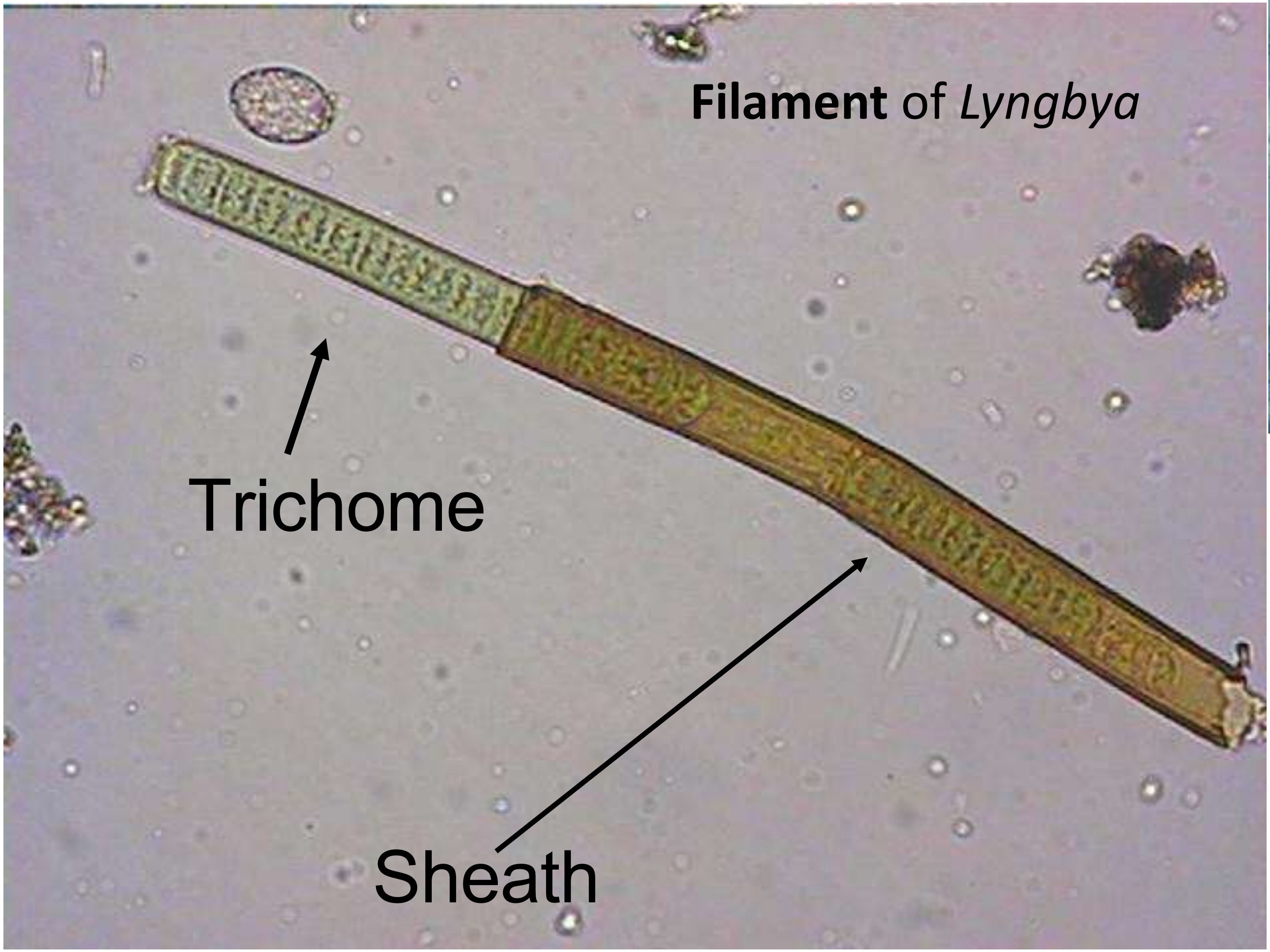


FIGURA 8-7 Cianófitos filamentosos: A, H, con falsa ramificación; B, G, I, ramificación verdadera. A, *Scytonema*, x 570; B, *Hapalosiphon*, x 1150; C, pequeña colonia de *Nostoc*, x 1000; D, *Schizothrix*, con varios tricomas encerrados en una sola vaina, x 1000; E, *Rivularia*, con un heterociste basal, x 1095; F, *Gloeotrichia*, con un heterociste basal, x 1100; G, *Stigonema*, x 500; H, *Tolypothrix*, x 915; I, *Stigonema*, x 170; J, *Spirulina*, x 1800; K, *Cylindrospermum*, con un gran acineto subterminal, x 880; L, *Oscillatoria*, x 2355. *hc*, heterociste; *ac*, acineto.

From Scagel et al. (1973)





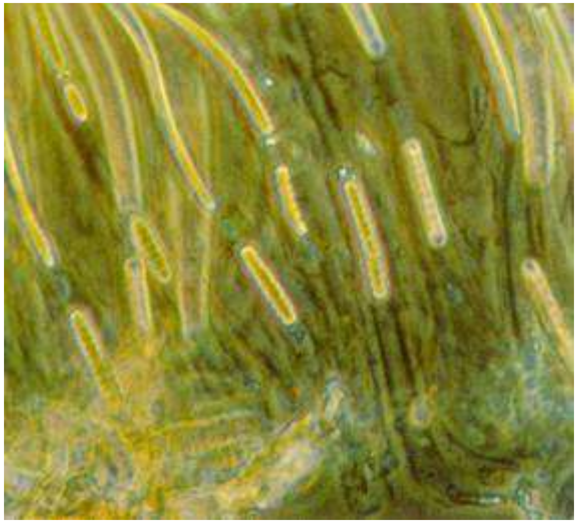
Sheath ("*vaina*"): mucilage layer that surrounds the trichome, which can have various colourations.

Reproduction

Sporulation

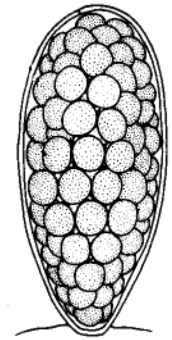
Binary fission

Fragmentation

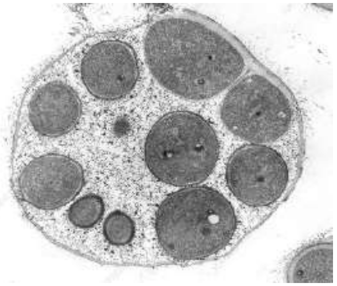


Hormogonia (sing. hormogonium)

Endospores

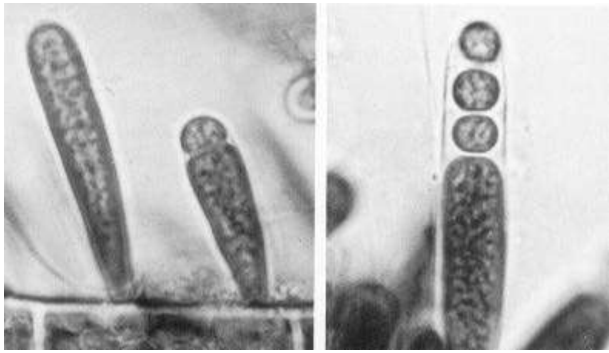


Tomado de Scagel et al.,1973



Akinete

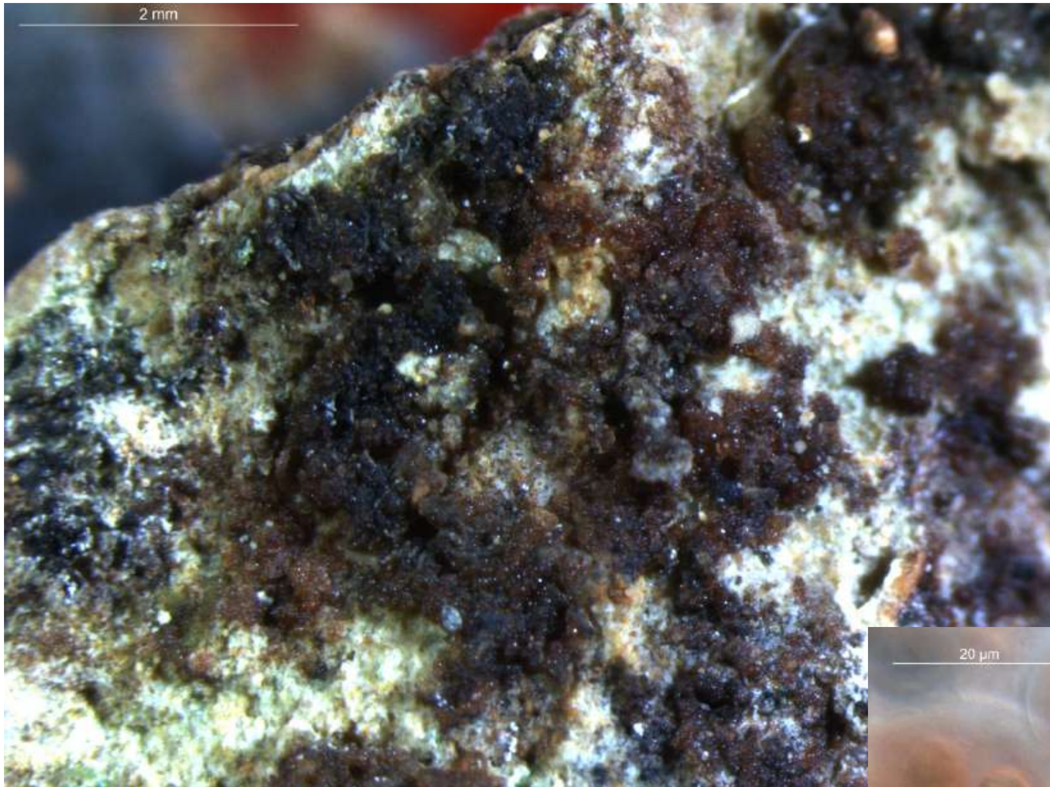
Exospores



Chamaesiphon, exospores

Habitat and geographic distribution

- Both freshwater and marine species exist.
- Some inhabit thermal springs (thermophilic) but they are absent from waters with a very low pH (acidic).
- They are found under the ice (cryophilic) or in soils (terricolous).
- Some establish mutualistic symbioses with other organisms (fungi, plants, eukaryotic algae).



Gloeocapsa sanguinea
(Xeresa, La Safor)

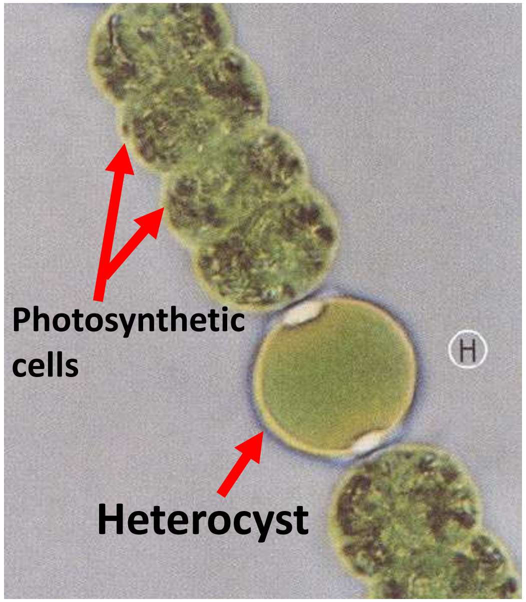
Gloeocapsin: the colour changes depending on the pH.

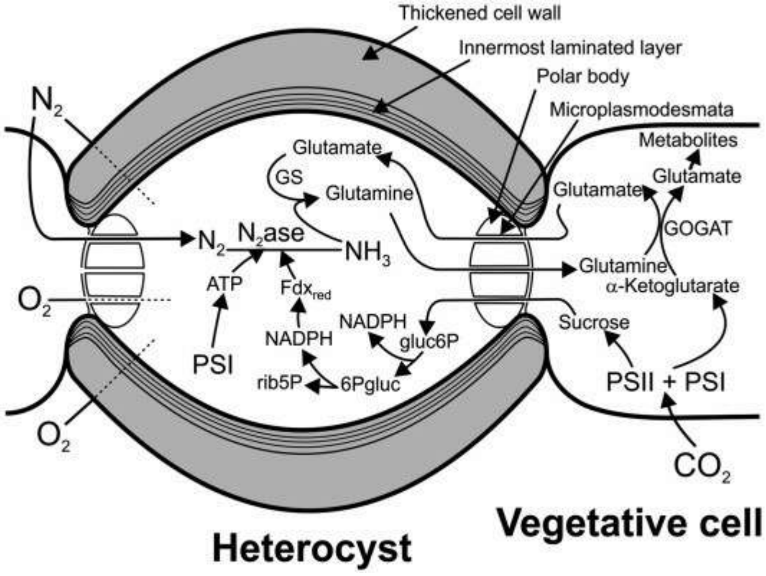
Importance of cyanobacteria

Atmospheric nitrogen fixation	Evolution and terrestrial oxygenation
Toxin production	Symbioses with other organisms

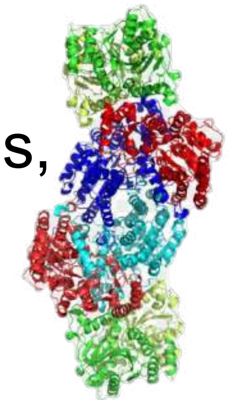
Some filamentous cyanobacteria contain **heterocysts**, i.e. cells specialised in the **fixation of atmospheric nitrogen**. Their main cellular traits are:

- a thickened cell wall
- a refractory (*"refringente"*) appearance
- absence of photosystem II





- Cyanobacteria are able to **fix atmospheric nitrogen**.



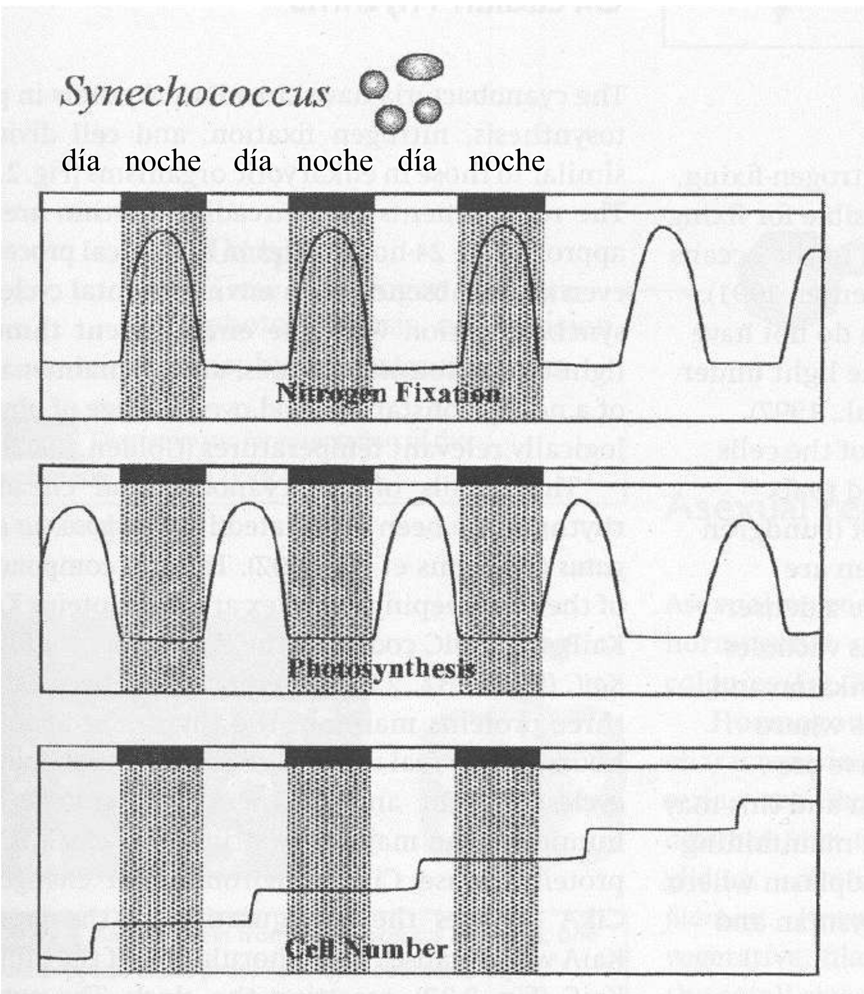
- **Nitrogenase**, the enzyme responsible for the process, is inhibited in the presence of oxygen.

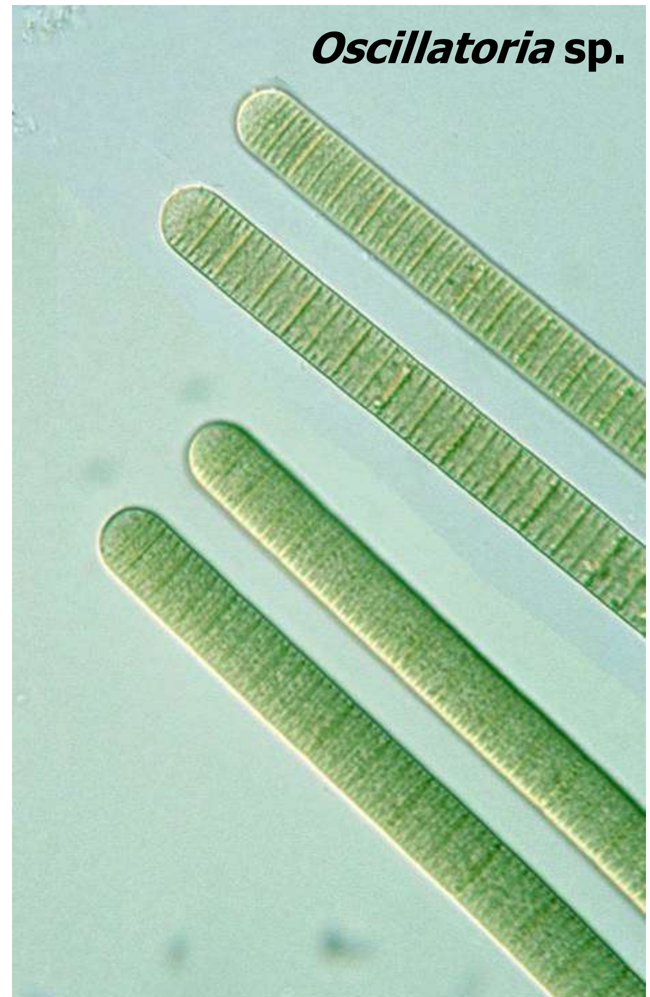
- Since cyanobacteria produce oxygen as a result of photosynthesis, there is a separation of the two processes:

  - ❑ **Heterocysts** (spatial separation)

  - ❑ **Nitrogen fixation in the dark** but not in light; this process occurs in cyanobacteria that do not have heterocysts (temporal separation).

Cyanobacterial species that exhibit **temporal separation of nitrogen fixation lack heterocysts, and the nitrogen fixation process occurs at night** (or in the dark) so that it is unaffected by photosynthesis.

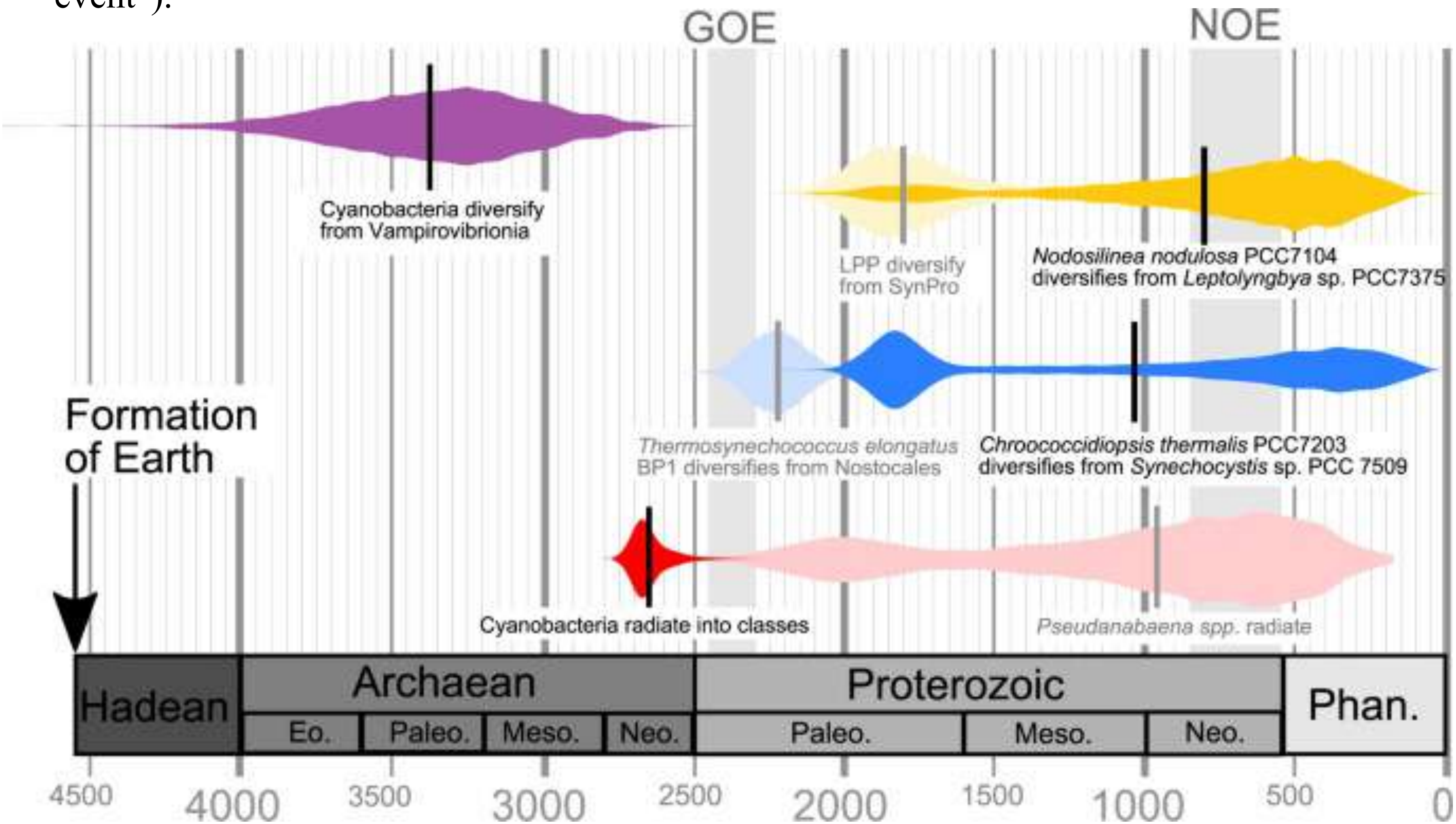




The importance of cyanobacteria

Atmospheric nitrogen fixation	Evolution and terrestrial oxygenation
Toxin production	Symbioses with other organisms

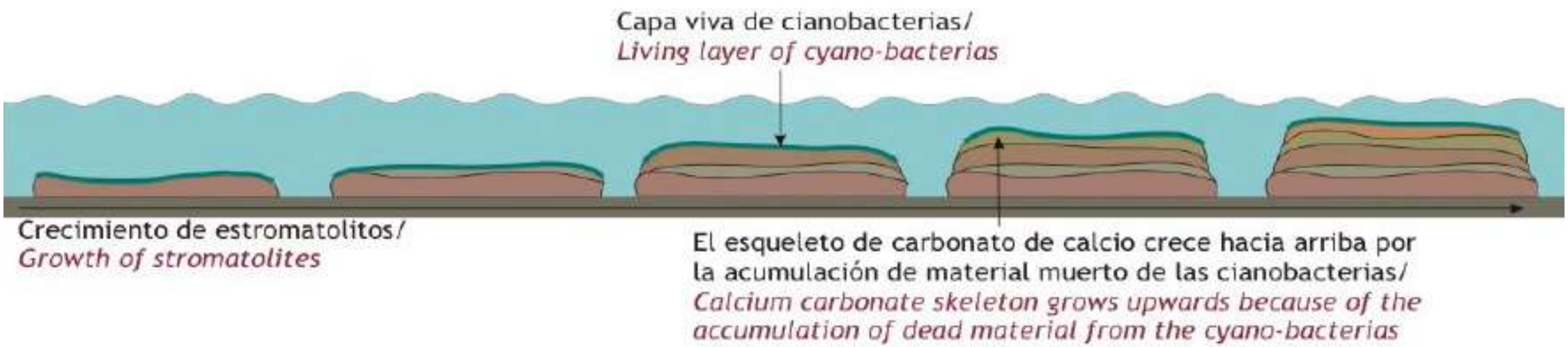
The **diversification of cyanobacteria** preceded or coincided with **oxygenation events on Earth** (GOE: "Great oxygenation event"; NOE: "Neoproterozoic oxygenation event").



Taken from: Boden, J.S., Konhauser, K.O., Robbins, L.J. *et al.* Timing the evolution of antioxidant enzymes in cyanobacteria. *Nat Commun* **12,** 4742 (2021).

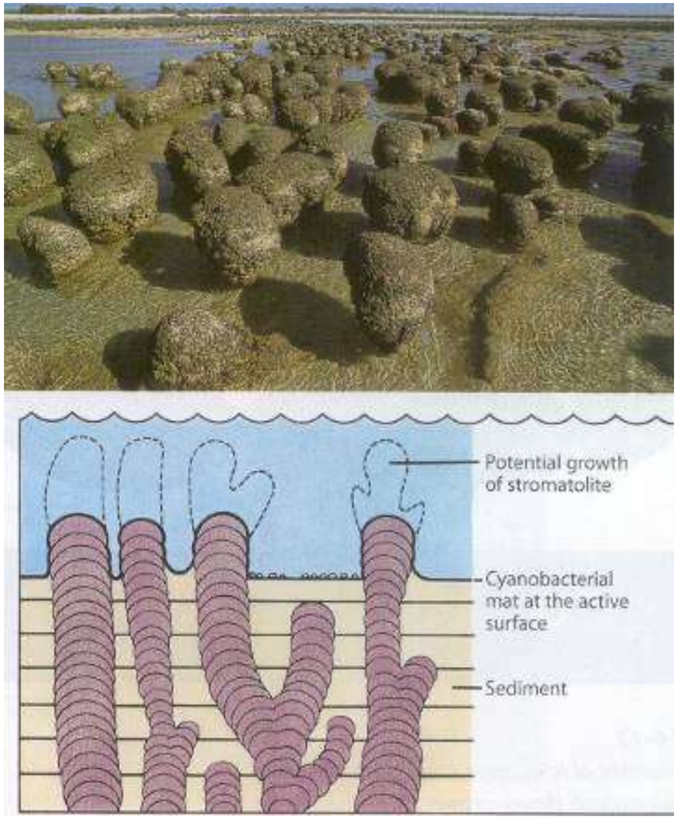
Stromatolites

def.: layered deposit, mainly of limestone, formed by the growth of blue-green algae. These structures are usually characterised by thin, alternating light and dark layers that may be flat, hummocky, or dome-shaped. The alternating layers are largely produced by the trapping of sediment washed up during storms on some occasions and **by limestone precipitation by blue-green algae** on others.



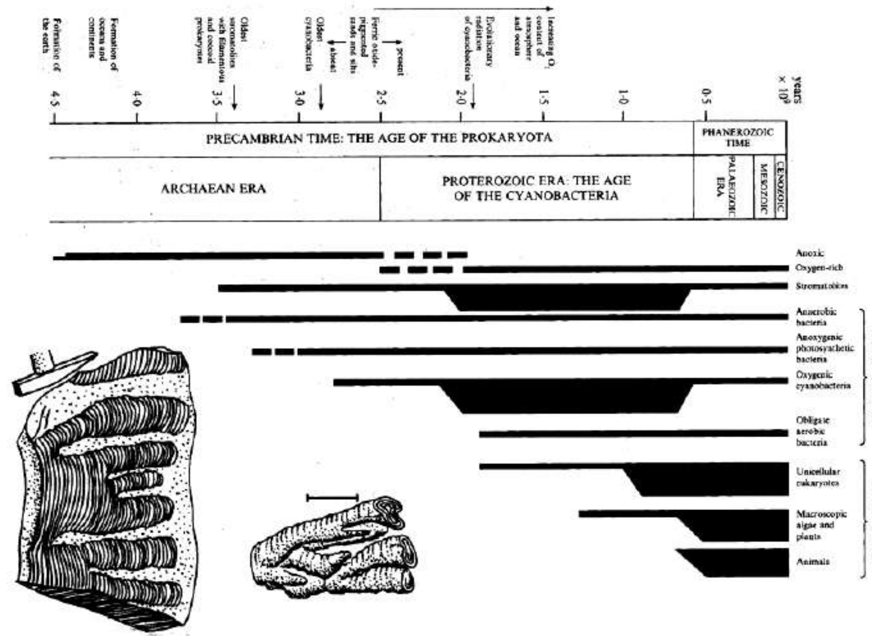
At present, stromatolites are only formed in some areas of Australia and South America.

Stromatolites



Taken from: Evert & Eichhorn (2013)

Stromatolites have been found dating back to around 3500 m.a. They indicate the beginning of the existence of oxygenic photosynthetic organisms (cyanobacteria) in the Archean Eon.



This makes cyanobacteria the oldest known organisms with oxygenic photosynthesis.

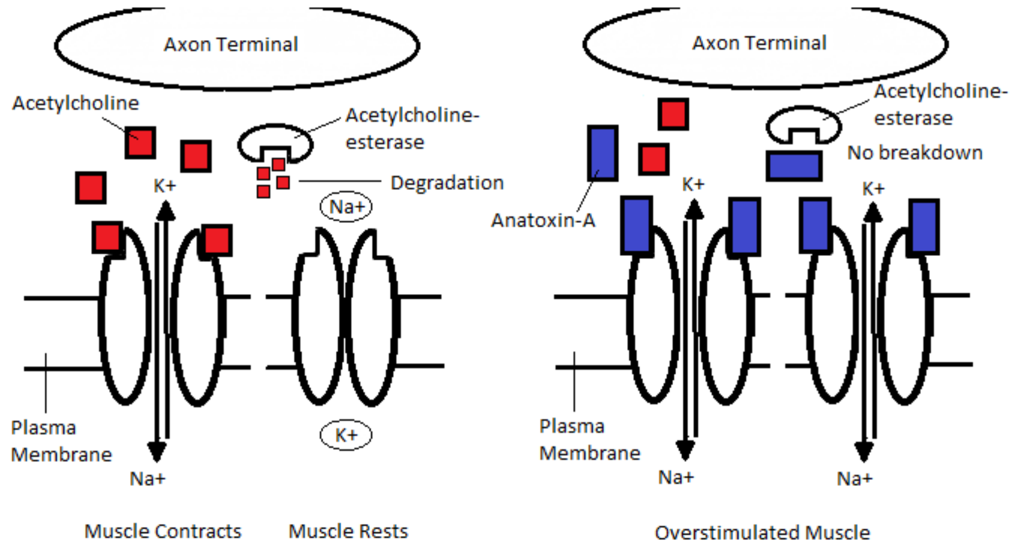
They are generally involved in the formation of calcareous rocks.

The importance of cyanobacteria

Atmospheric nitrogen fixation	Evolution and terrestrial oxygenation
Toxin production	Symbioses with other organisms

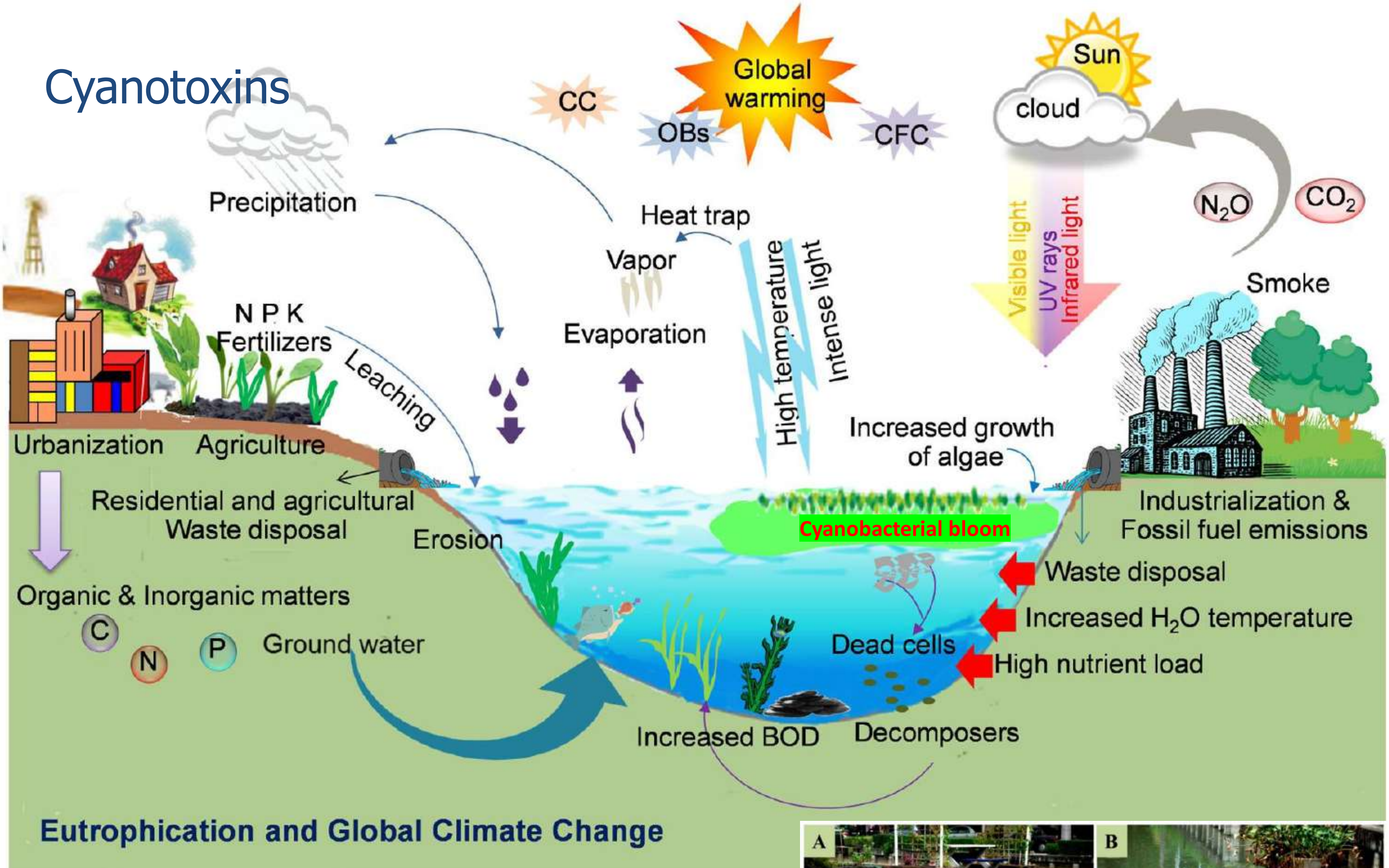
Cyanobacteria toxins (cyanotoxins)

– **Neurotoxins** block the transmission of nerve impulses to muscles (*Anabaena*, *Oscillatoria*).



– **Hepatotoxins** inhibit phosphatase in the liver and produce hepatic haemorrhages (*Anabaena*, *Oscillatoria*, *Nostoc*).

Cyanotoxins

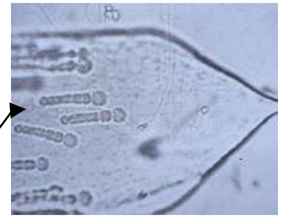


Formation of cyanobacterial blooms. The illustration shows the key factors in this process, such as anthropogenic eutrophication, increased temperature and daylight hours, as well as other biotic and abiotic factors responsible for the formation of the blooms (adapted from Rastogi et al. 2015, *Frontiers in Microbiology* 6: 1254).

Importance of cyanobacteria

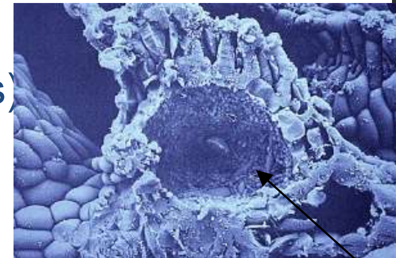
Atmospheric nitrogen fixation	Evolution and terrestrial oxygenation
Toxin production	Symbioses with other organisms

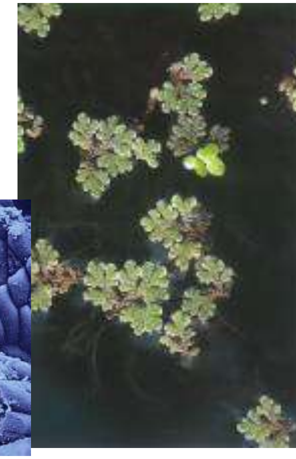
Symbioses



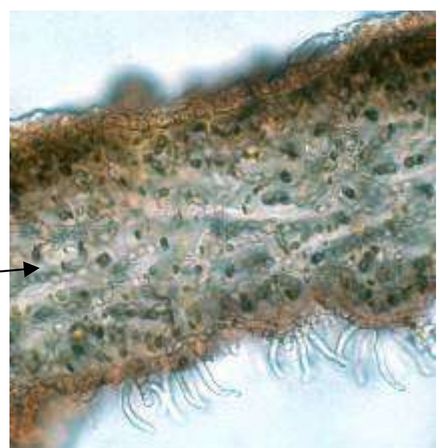
Richelia* in *Rhizosolenia

- With microalgae (*diatoms &*dinoflagellates)
- With fungi that form *lichens
- With bryophytes (**Nostoc* and hornworts)
- With ferns (**Azolla*-**Anabaena*)
- With other vascular plants **Gunnera*-**Nostoc*
- With protozoa (amoebas)
- With *metazoa (sponges)





Azolla-Anabaena (in leaves)



Nostoc in lichens

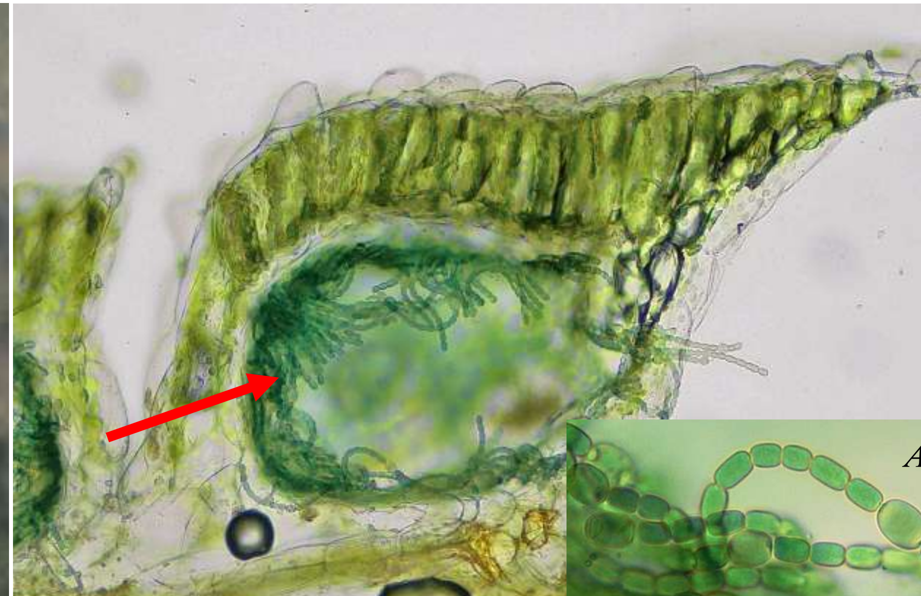
Gunnera rhizomes with *Nostoc*

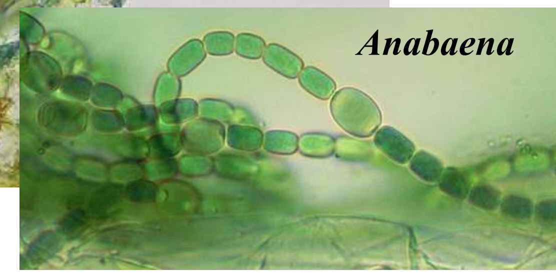
Lichens: *Peltigera canina*

Collema fuscovirens

Bryophytes: *Anthoceros* sp.

Blasia sp.



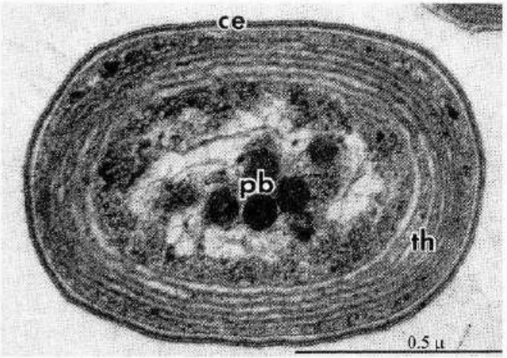


Symbiosis with:

- ferns: *Azolla*
- seed plants: *Cycas*, *Gunnera*

Prochlorococcus marinus

- This cyanobacteria belongs to a group formerly known as prochlorophytes (chloroxybacteria), which contain **chlorophylls *a* and *b*** and carotenoids but lack phycobilins.



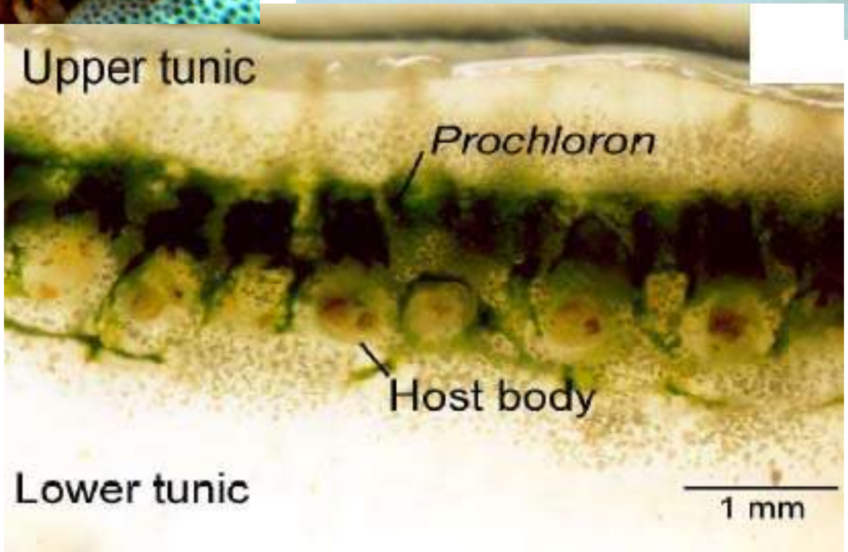
ce: Cell Envelope
pb: Polyhedral Bodies
th: Thylakoids

- Prochlorophytes are found in oceans between 40ºN and 40ºS and they are usually very abundant: 1-3*10^5 cells per millilitre in the first 100 m depth, down to depths of 150-200 m, where light is only 1% of that found on the surface.

- They are one of the most abundant organisms on Earth and responsible for roughly 15% of the oceans' primary production.

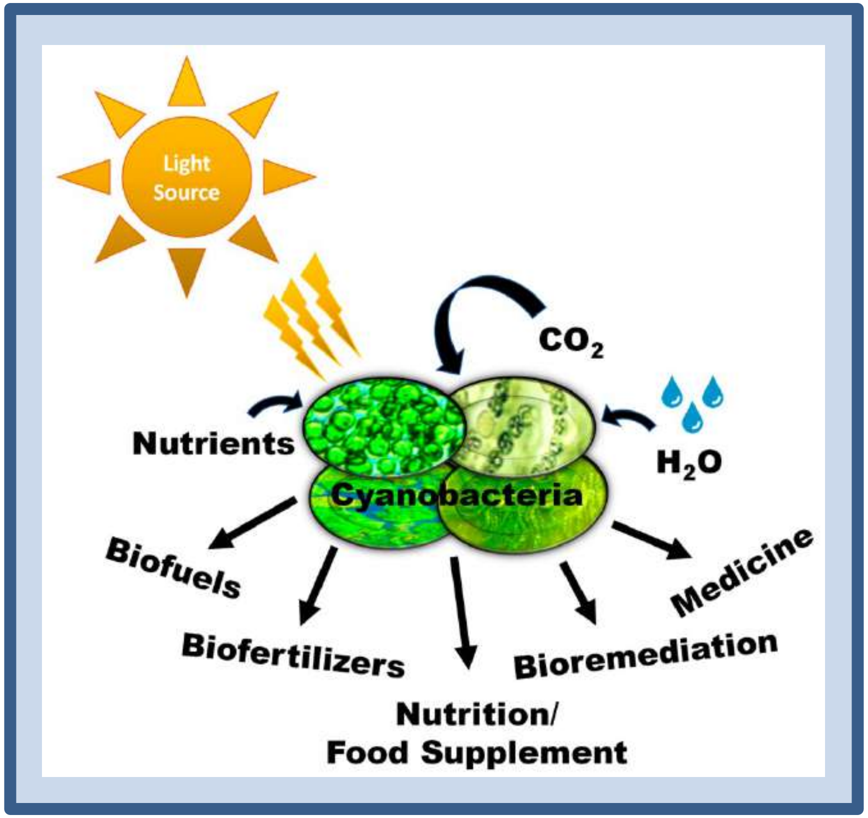
Prochloron

Prochloron is another unicellular prochlorophyte that lives in the interior of ascidians (metazoa-animals).

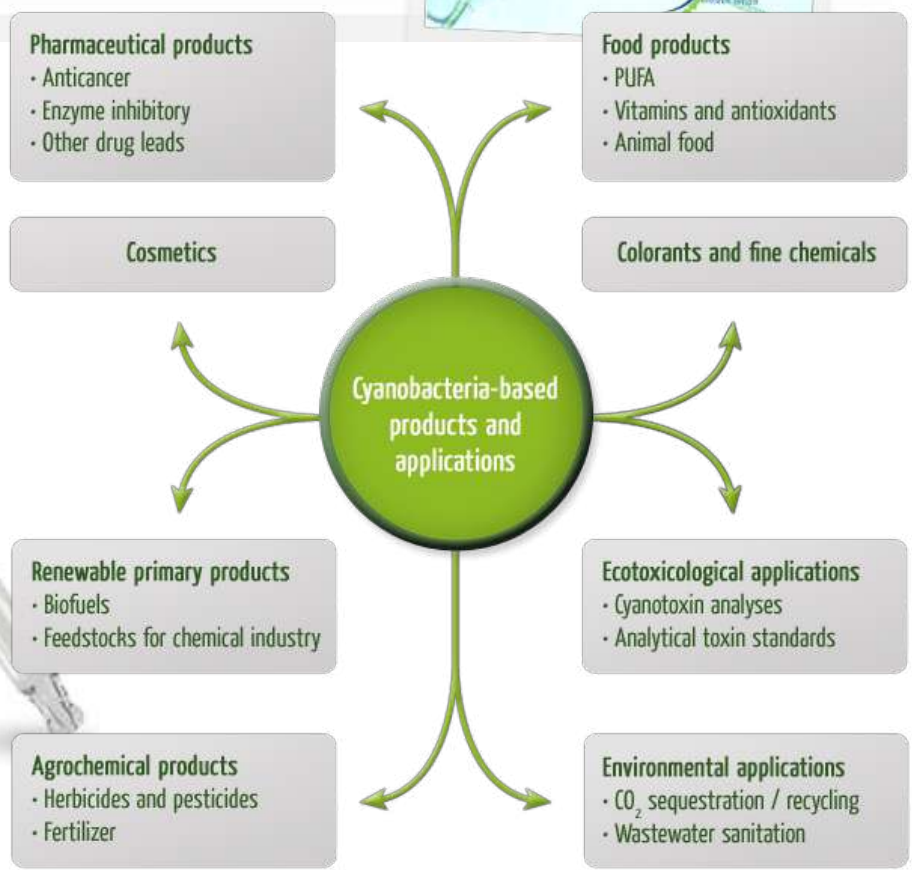


The importance of cyanobacteria

Uses for humans



Uses for humans



Uses for humans

Bioactive Compounds	Microalgae/Cyanobacteria	Potential Activities and Uses in Cosmetics	References
Polysaccharides	*Chlorella*	Moisturizing and thickener agent	Jain et al., 2005
Methanolic extracts of exopolysaccharides	*Arthrospira platensis*	Antioxidant	Raposo et al. 2015
Chrysolaminarin	*Odontella aurita*	Antioxidant	Xia et al., 2014
Sulfated polysacharides	*Porphyridium and Rhodella reticulata*	Antioxidant	Raposo et al., 2015
ß-1,3-Glucan	*Chlorella* *Skeletonema* *Porphyridium* *Nostoc flegelliforme*	Free-radical collector Immune system booster Anti-inflammatory	Spolaore et al., 2006 Koller et al., 2014 Bin et al., 2013 Hamed, 2016
ß-carotenes	*Dunaliella salina*	Antioxidant	Hamed, 2016
Asthaxanthin	*Haematococcus pluvialis*	Antioxidant Sunscreen protection	Hamed, 2016 Koller et al., 2014
Phycocyanobilin phycoerythrobilin	*Spirulina* *Porphyridium*	Antioxidant Pigment for eye-liner and lipsticks	Hamed, 2016

Cyanobacteria species (red boxes: *Arthrospira platensis*, *Nostoc flegelliforme*, *Spirulina*)

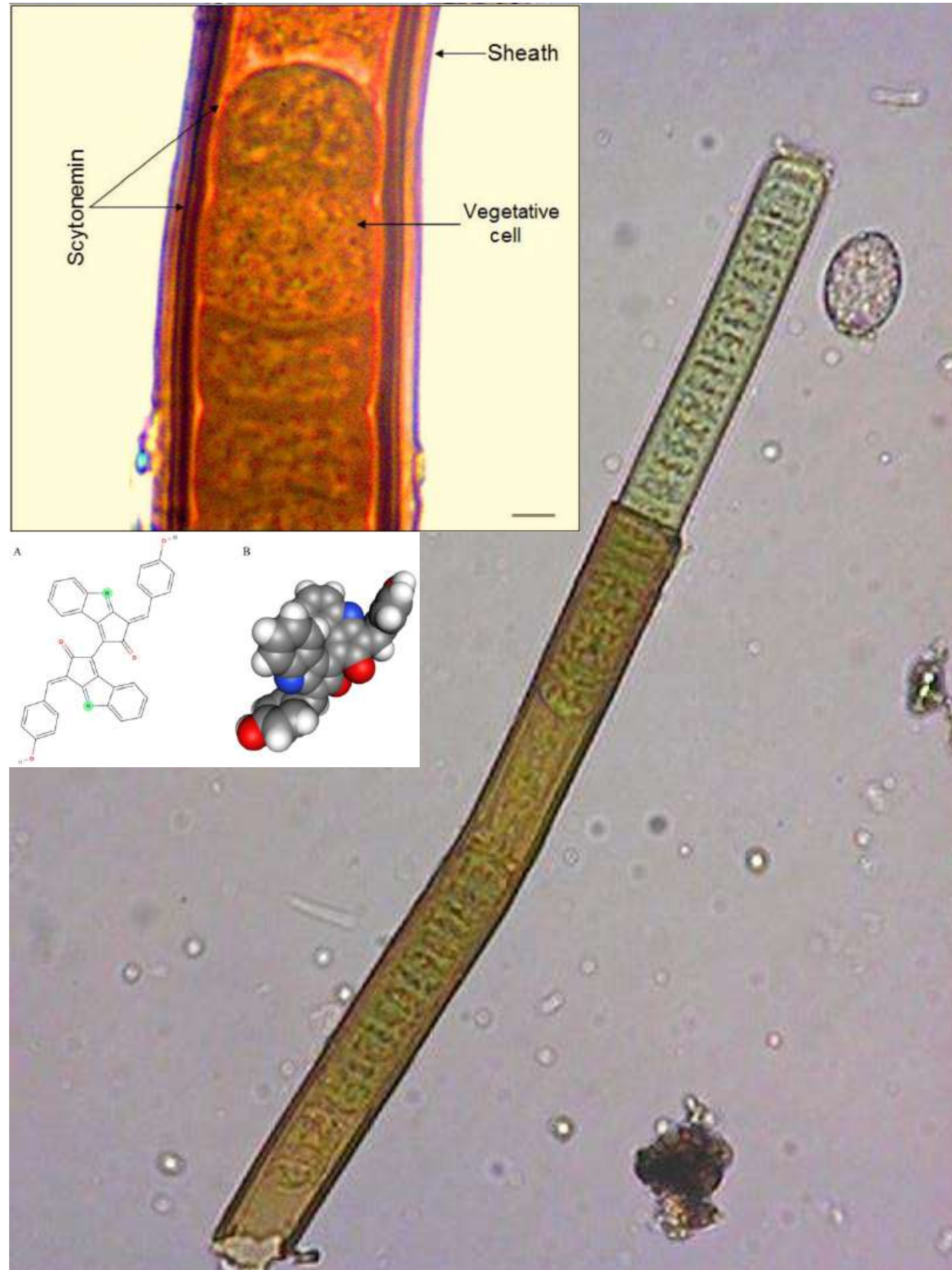
Uses for humans

Some cyanobacteria are used as dietary supplements.

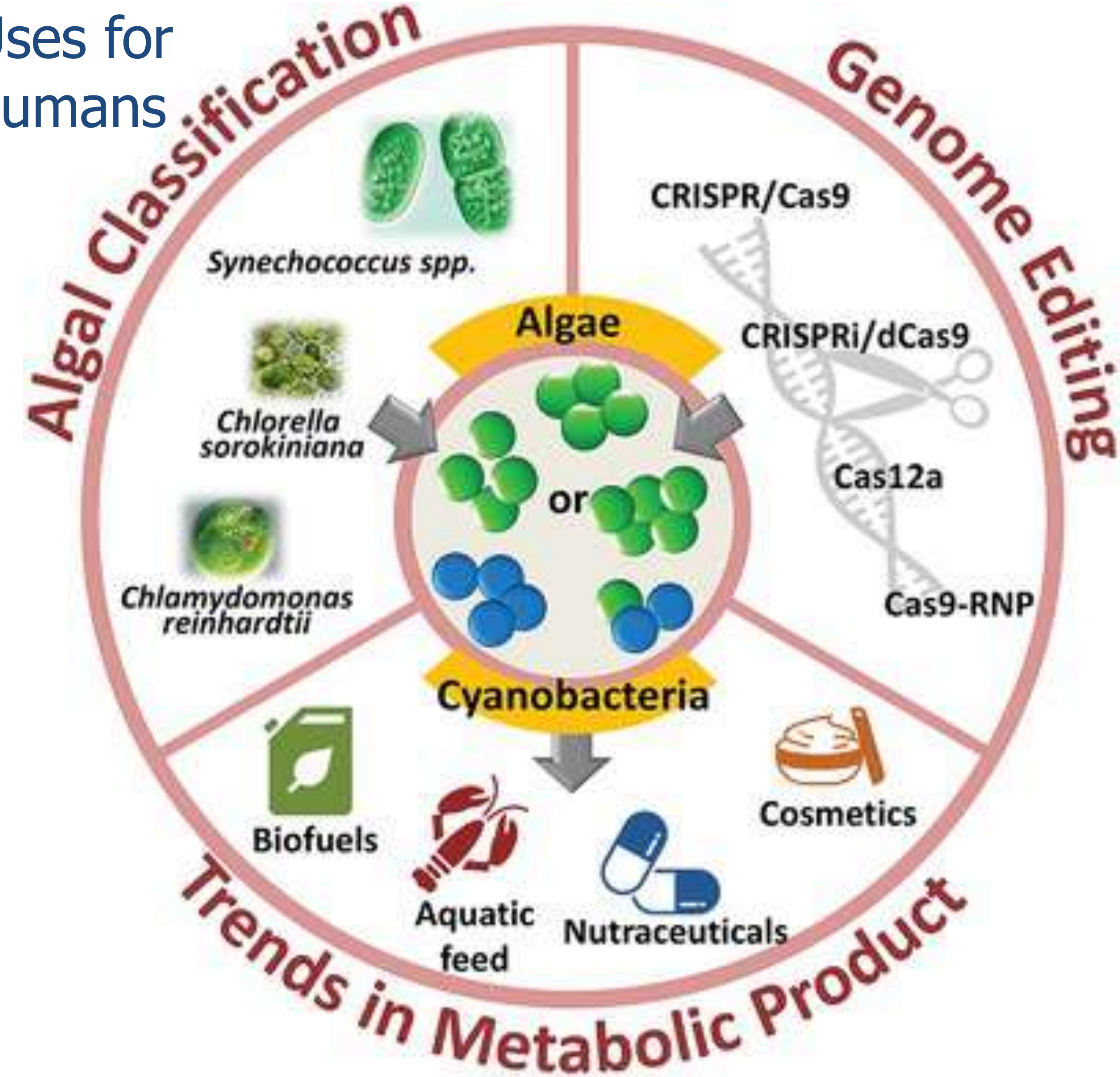
(***Arthrospira platensis*** and ***A. maxima***).

Uses for humans

Scytonemin ("*escitonemina*") is a promising **UV-screen** and **antioxidant** small molecule with commercial value in cosmetics and medicine. It is solely biosynthesised in some cyanobacteria. This compound is located in the exopolysaccharide (EPS) matrix and constitutes the first line of defense against UV penetration and subsequent damage. Scytonemin can absorb the three UV radiations, but mainly the UV-A, and can prevent about 90% of UV-A from entering the cells. It can also provide substantial protection against UV-B and UV-C damage. Medically, scytonemin possesses **anti-inflammatory** and **anti-proliferative** properties (Gao et al. 2021).

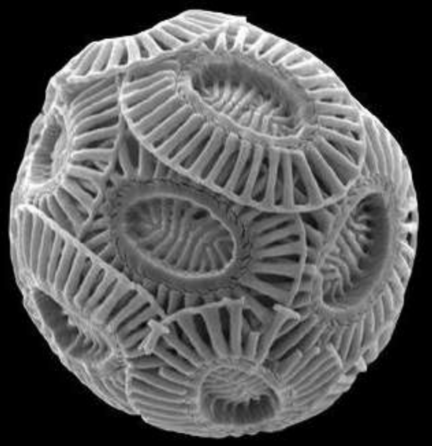


Uses for humans



Cyanobacteria possess relatively small genomes and can grow with minimal nutrient requirement. Engineering cyanobacteria offers an attractive approach to drive carbon flux to the biosynthesis of fuels, chemicals, medicines, plant secondary metabolites, and other value-added products (Gao et al. 2021)

Ng, I. S., Keskin, B. B., & Tan, S. I. (2020). A critical review of genome editing and synthetic biology applications in metabolic engineering of microalgae and cyanobacteria. *Biotechnology Journal*, *15*(8), 1900228.

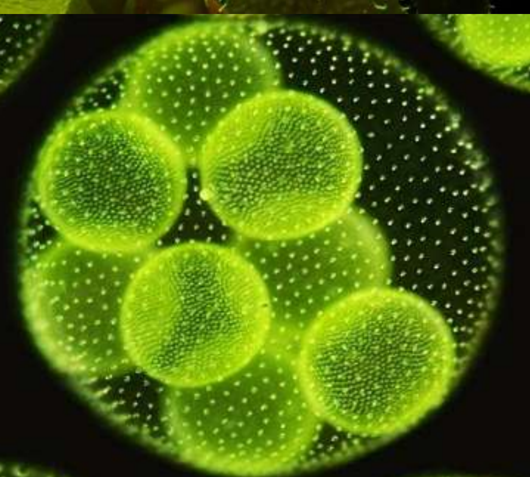
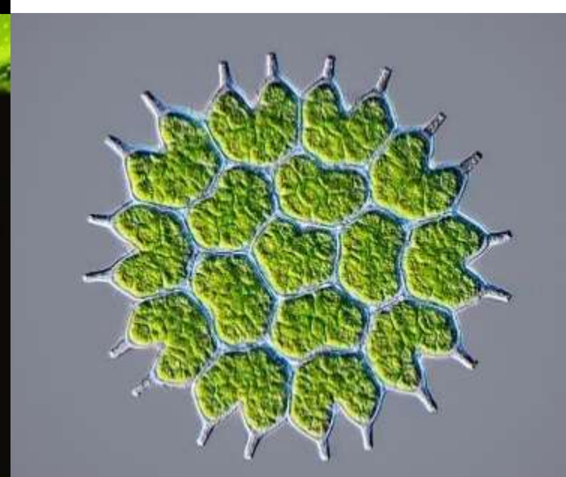




Lecture 06

(Algae II)

Green, red and brown algae
(Domain *Eukarya*, eukaryotes).

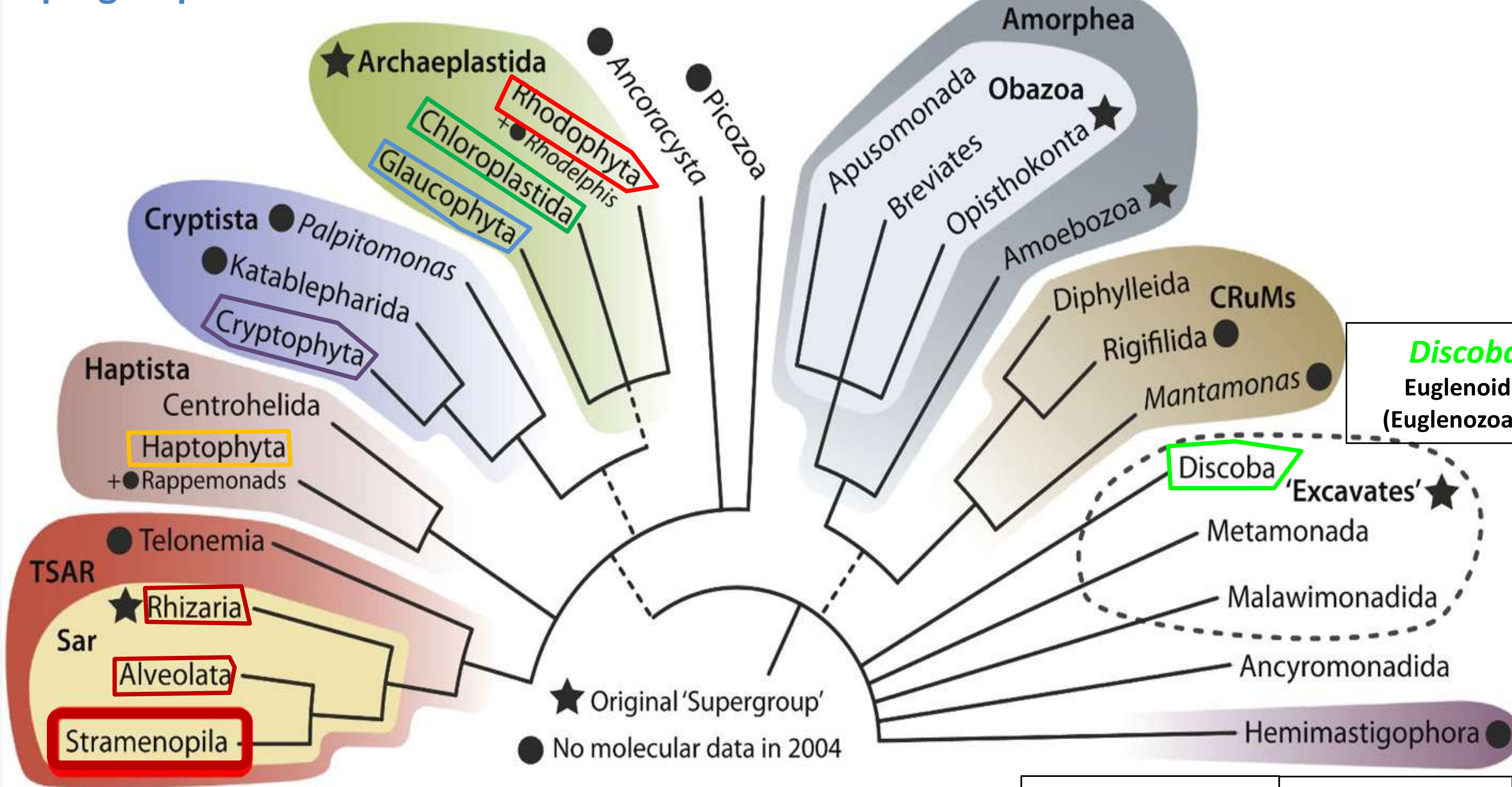

What are ALGAE?

- *def.*: algae are aquatic, photosynthetic organisms with a relatively simple organisation (**thallophytes**) that lack roots, stems and leaves and reproduce by spores and/or gametes.
- In the broadest sense they include both prokaryotes (cyanobacteria) and eukaryotes, and account for almost 75,000 species worldwide. Eukaryotic algae include a wide and diverse range of organisms belonging to different phyla or divisions.

- The universal photosynthetic pigment is **chlorophyll *a***. Accessory pigments are chlorophylls *b* and *c*, phycobilins and carotenoids.

Eukaryotic algae: a heterogenous group of organisms integrated into different supergroups

Burki et al. (2020)



Discoba
Euglenoids (Euglenozoa)

Stramenopila
Diatoms
Xanthophyceans
Phaeophyceans (brown algae)

Alveolata
Dinoflagellates

Rhizaria
Cercozoans
Chlorarachniophytes

Haptophyta
Haptophytes

Cryptophyta
Cryptophytes

Glaucophyta
Glaucophytes

Rhodophyta
Rhodophytes or red algae

Chloroplastida **(green algae)**
Chlorophytes
Charophytes

The role of algae in ecosystems and for humans

- Algae are the main **primary producers** in aquatic ecosystems, constituting the so-called **phytoplankton** in freshwater (lakes, ponds and rivers) and marine habitats. Almost 37,000 marine species have been recognised.

- They provide **ecological services** such as nutrient recycling, purification and habitat generation.

- They are **bioindicator organisms** with industrial, pharmaceutical and biotechnological importance. They are also a source of food for humans. Example: cell wall **phycocolloids** (agar, carrageenans, alginates = alginic acid).

- In marine ecosystems, some species establish **symbioses** with invertebrates (dinoflagellates + cnidaria); in terrestrial ecosystems, some species establish **symbioses** with fungi, giving rise to lichens**.**

Algae as bioindicators

Foto: Isaac GB

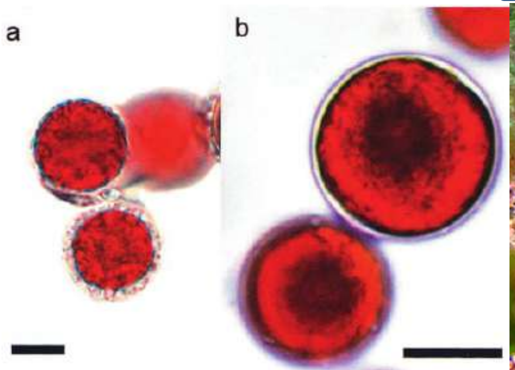
Algae as bioindicators

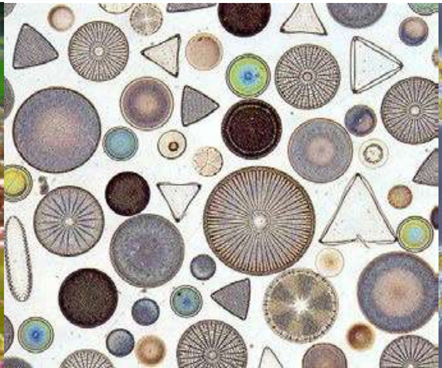
Foto: Isaac GB

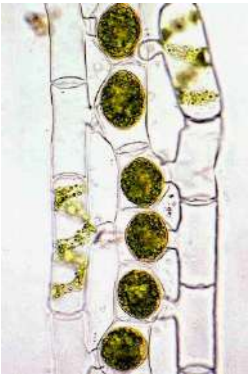
“Watermelon snow”: *Chlamydomonas nivalis*

Trentepohlia sp. in the walls of churches and pine bark

Classification of algae	Brown algae
Red algae	Green algae

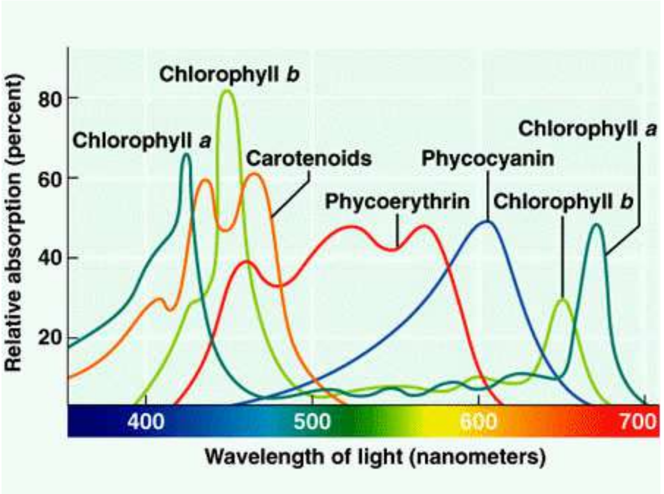


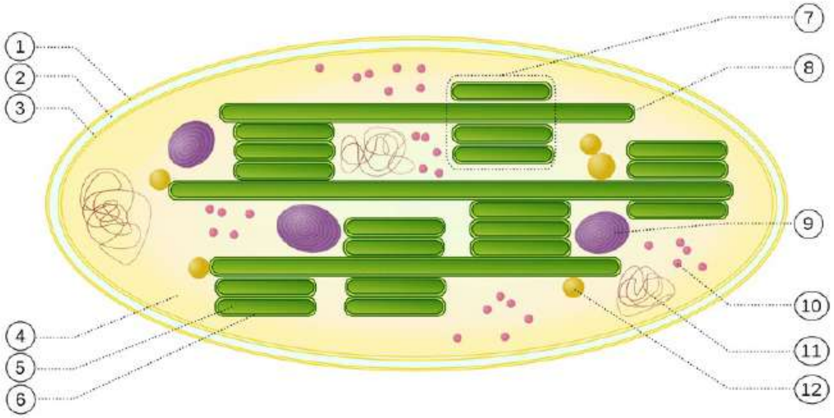


Eukaryotic algae can be divided into different groups based on:

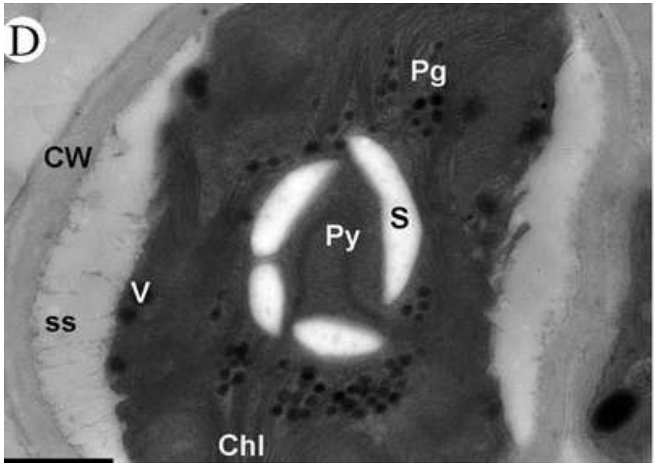
- **Type of chlorophyll and accessory pigments (the "colour")**



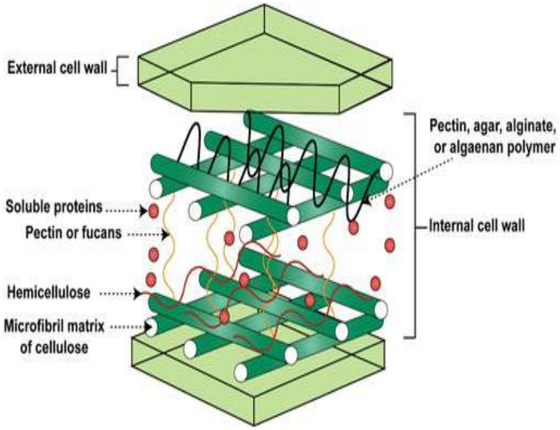
- **Ultrastructure of plastids and their different endosymbiotic origin**



- **Food-storage material**



- **Cell-wall composition**

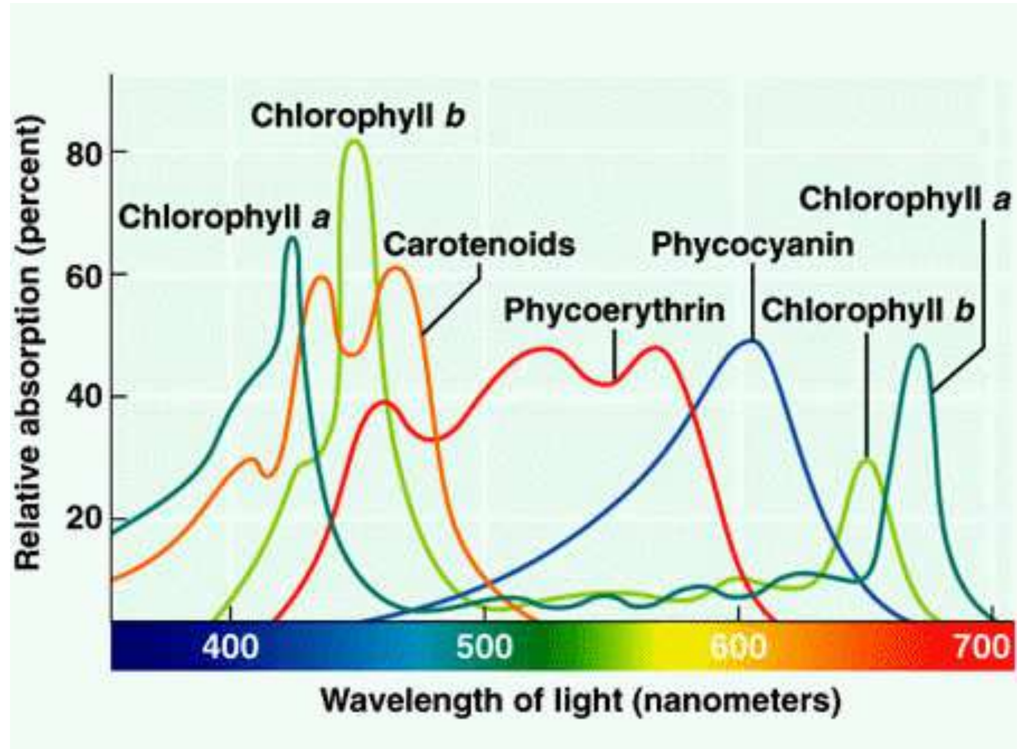


- **Presence or absence of flagella; in addition, flagellar types are important**

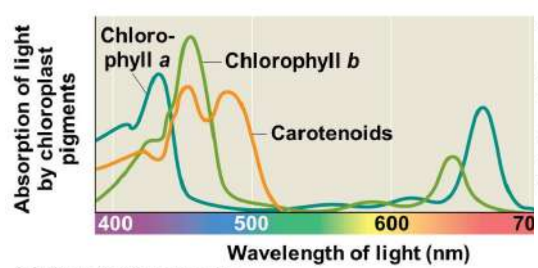
Type of chlorophyll and accessory pigments (~colour)

- **Universal pigments**. All algae contain **chlorophyll *a***.

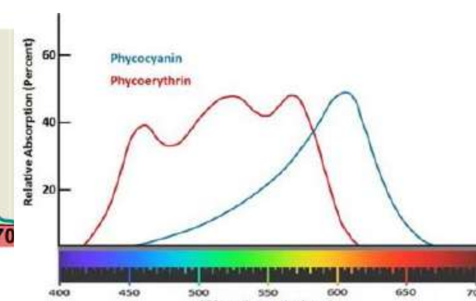
- **Accessory pigments**:
  - **Chlorophylls *b*** and ***c***.
  - **Phycobiliproteins** (phycocyanin and phycoerythrin).
  - **Xanthophylls**. Fucoxanthin. Siphonoxanthin and siphonein in the green algae *Caulerpales* (500-560 nm).
  - **Carotenoids**.



Algal group	Pigments
Chlorophyta and *Charophyta* (**green algae**)	Chlorophylls *a* and *b*
Rhodophyta (**red algae**)	Mainly chlorophyll *a*, phycoerythrin and phycocyanin
Phaeophyceae (**brown algae**)	Chlorophylls *a* and *c*, and fucoxanthin

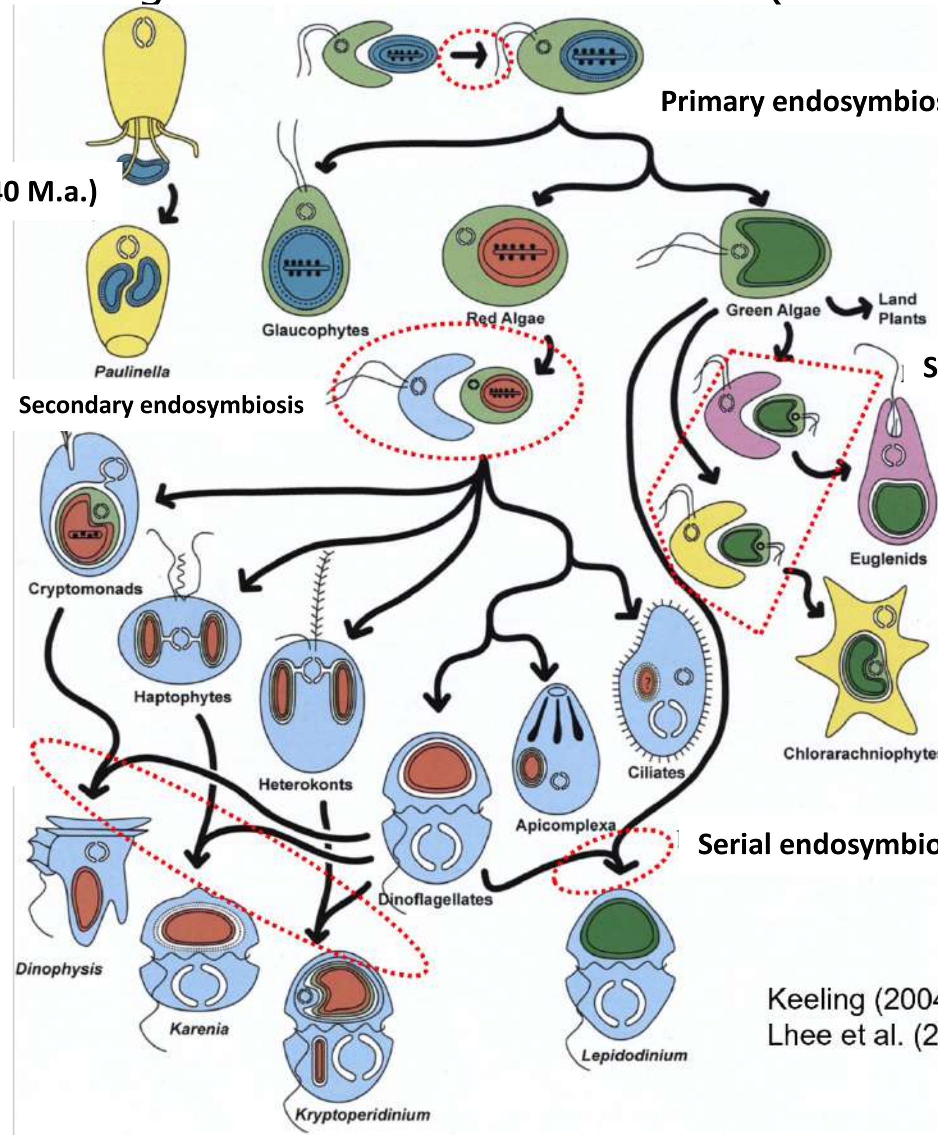


(a) Absorption spectra



Ultrastructure of plastids and their different endosymbiotic origins

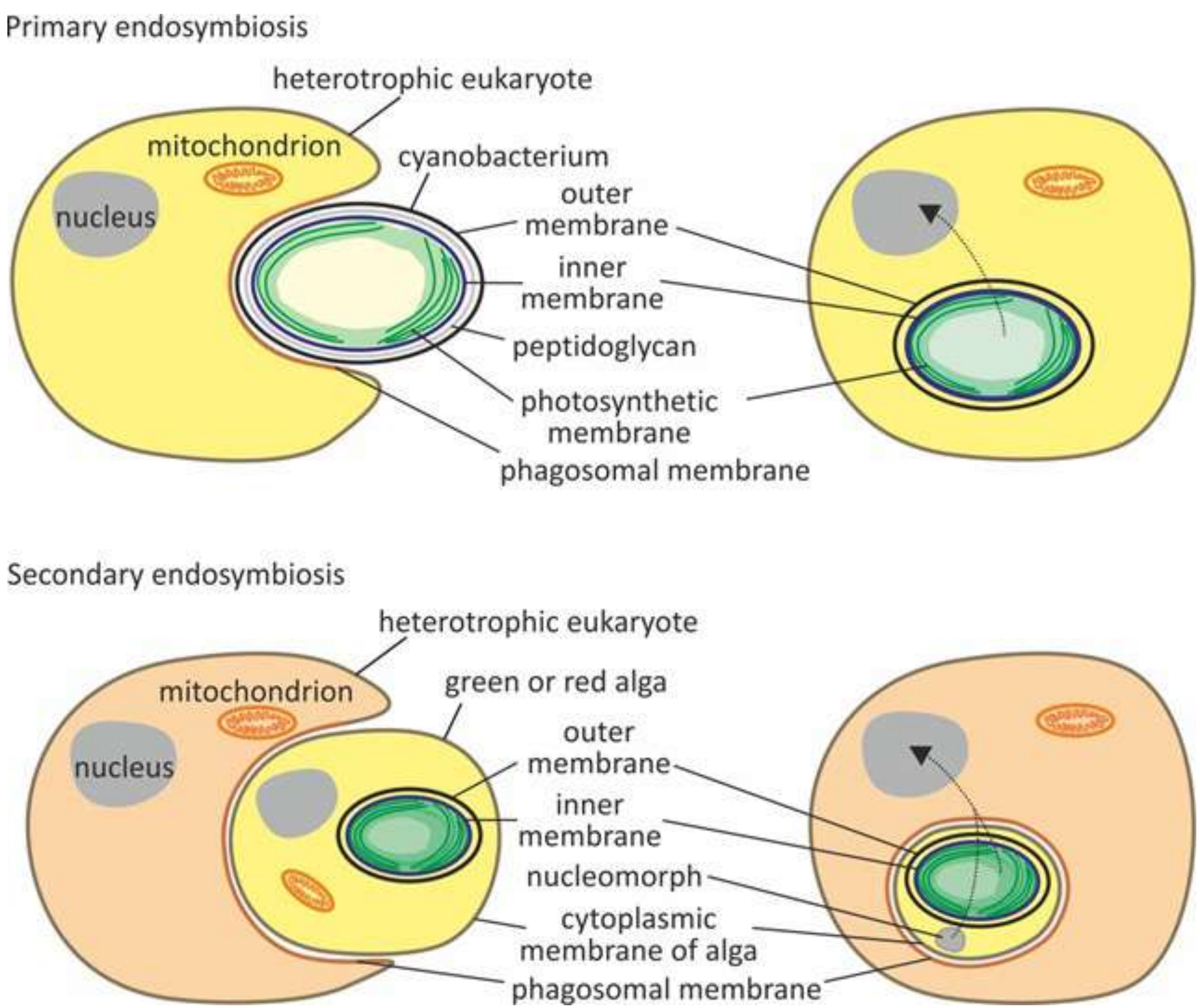
The origin of the plastids is found in cyanobacteria incorporated as endosymbionts. These cyanobacteria belong to the Domain *Bacteria* (Gram -) and are therefore prokaryotes.



The different groups originated through various processes involving **primary**, **secondary** and **tertiary endosymbioses**.

Keeling (2004, *American Journal of Botany* 91)
Lhee et al. (2019, *Scientific Reports* 9: 2560)

Ultrastructure of plastids and their different endosymbiotic origins



The various groups originated through different processes involving **primary**, **secondary** and **tertiary endosymbioses**. Please review Lecture 02

Ultrastructure of plastids and their different endosymbiotic origins

Algal plastids are remarkably diverse in terms of morphology, arrangement, ultrastructure and pigment composition.

Secondary plastids

***Phaeophyceae* (brown algae) and related groups**

- Four membranes (2+2 additional membranes).
- Thylakoids are usually found in bundles of three.
- Eccentric intraplastidial pyrenoids.

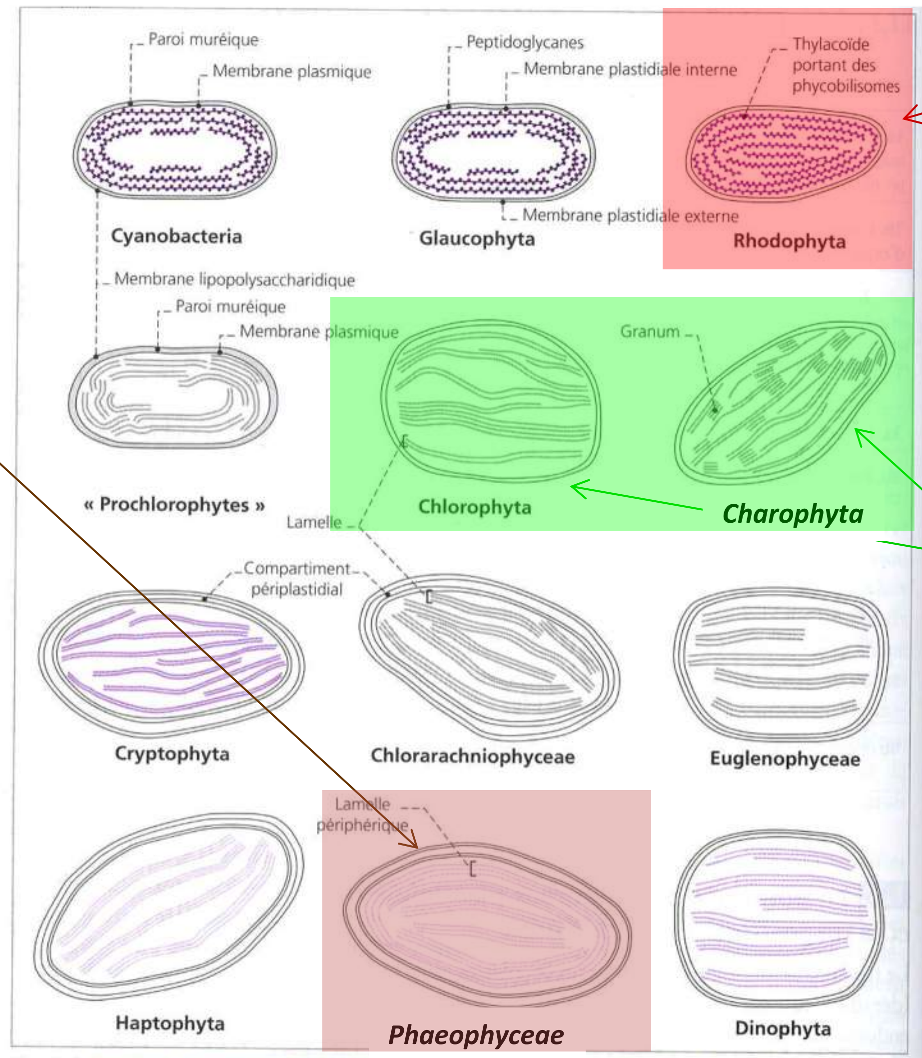


Fig. 3.9. Nombre de membranes plastidiales et disposition des thylacoïdes chez les cyanobactéries et dans les plastes des diverses lignées d'algues.

Primary plastids

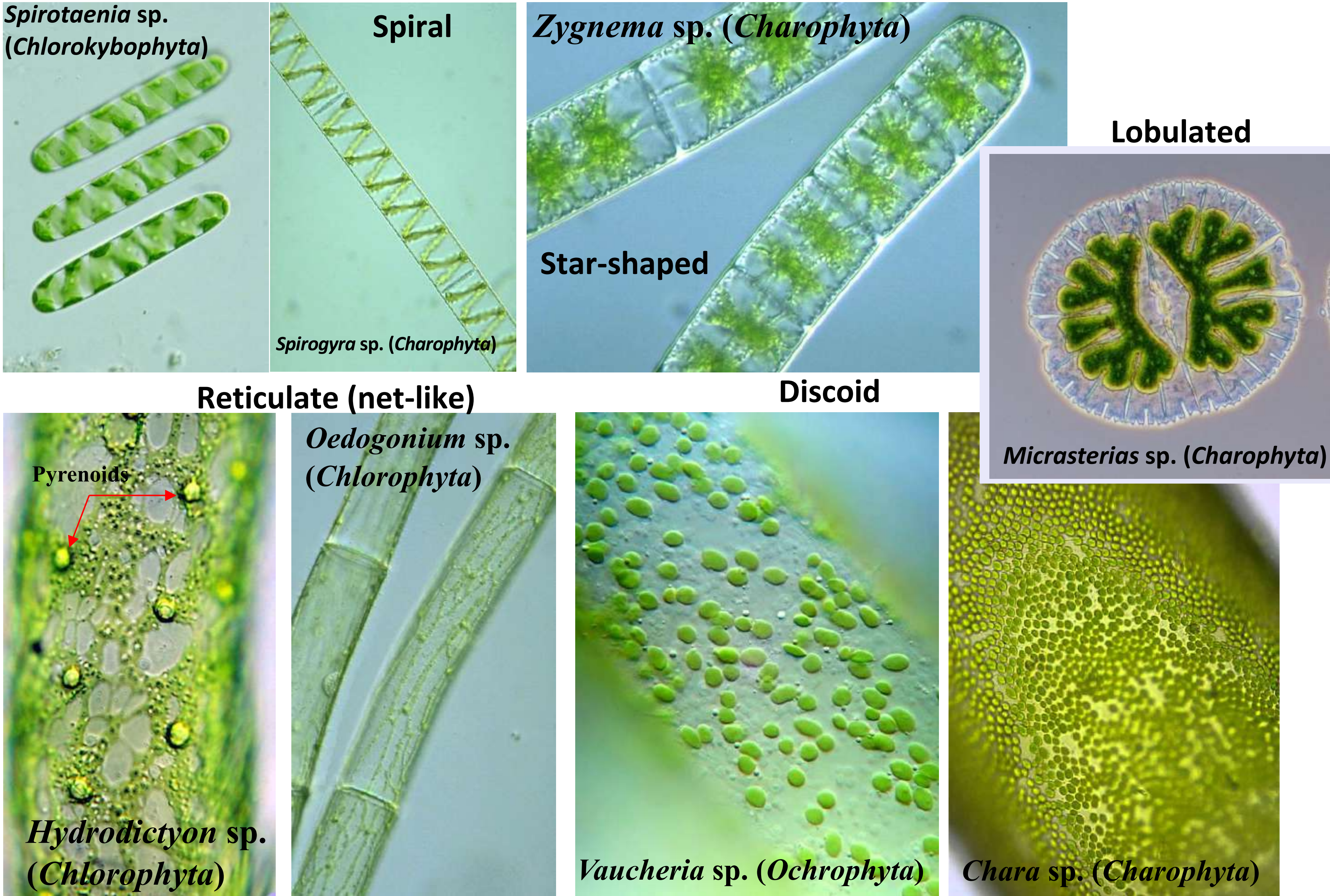
***Rhodophyta* (red algae)**

- 2 membranes and simple thylakoids (isolated).
- Phycobilisomes on thylakoid surfaces.
- Pyrenoids are rare.

***Chlorophyta Charophyta* (green algae)**

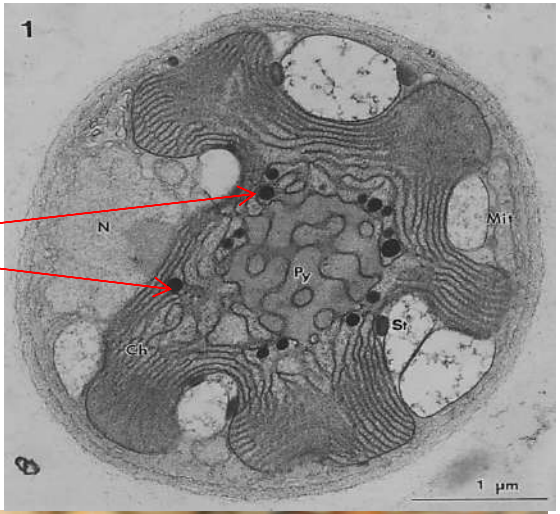
- 2 membranes and thylakoids in packages of 2-6 grana (in *Charophyta*).
- Thylakoids without phycobilisomes.
- Frequent pyrenoids.

The morphological diversity in the plastids of algae is remarkable

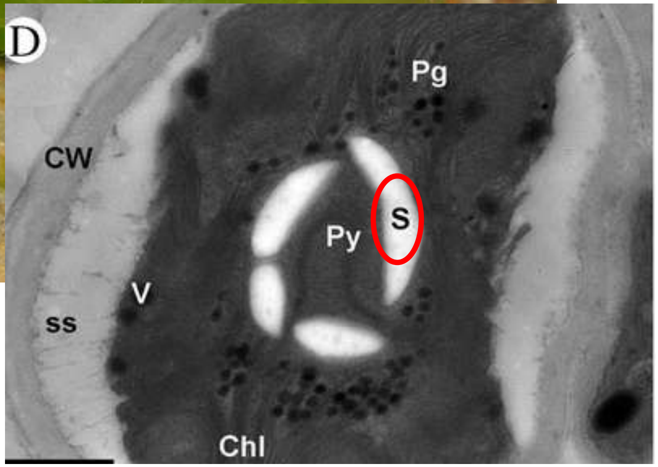


Food-storage material

- RED ALGAE: floridean starch (stored in the cytoplasm)



- BROWN ALGAE: the carbohydrate laminarin, which is stored in cytoplasmic vacuoles

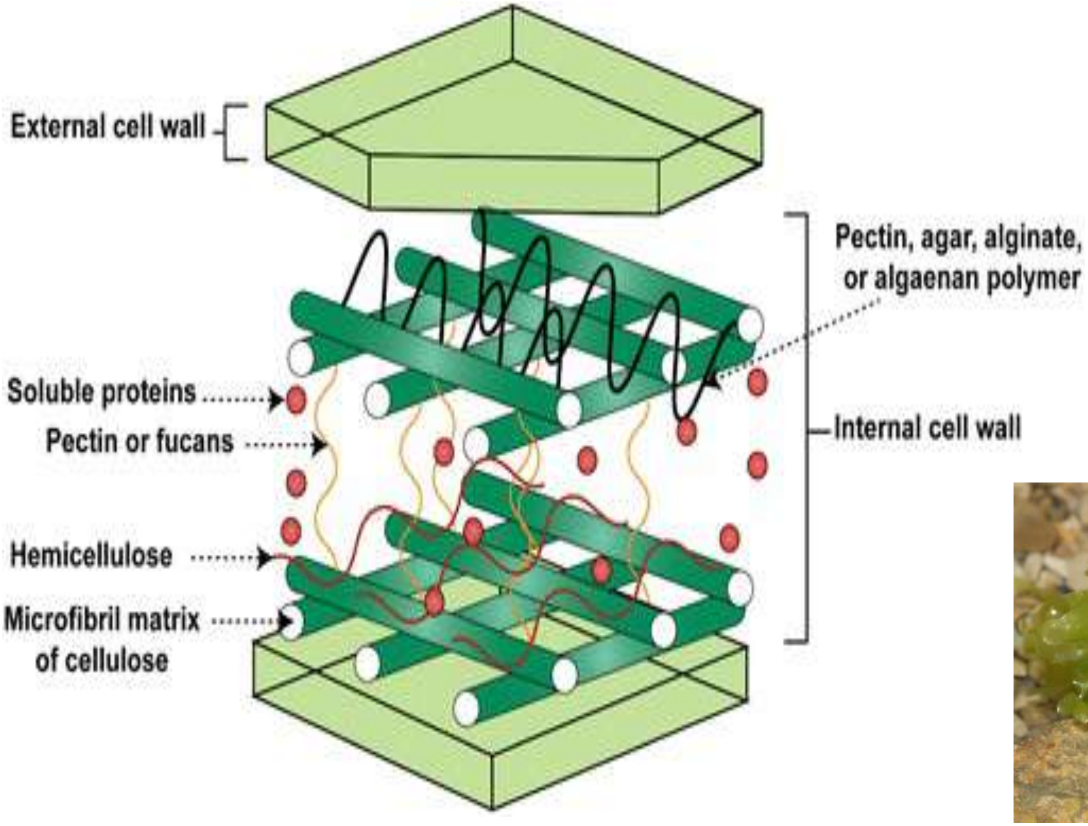


- GREEN ALGAE: starch stored in the plastids

Cell-wall composition

- **fibrillar component** of cellulose microfibrils, xylans, mannans, etc.
- **amorphous component** of agar and carrageenan (phycocolloids of red algae), or alginates and fucoidin (in brown algae)
- there may be deposits of **calcium carbonate** (red algae).

- **BROWN ALGAE: cell walls with cellulose and an amorphous fraction of salts of alginic acid (= alginates) (35% dry weight).**

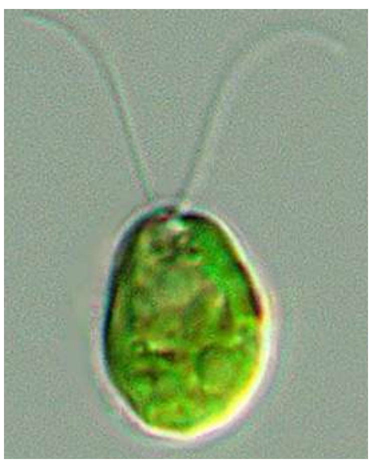


- **RED ALGAE: cell wall formed by a matrix of cellulose microfibrils associated with phycocolloids (agar, carrageenan). In *Corallinales*, impregnated with calcium carbonate.**

- **GREEN ALGAE: cell walls with cellulose, hemicelluloses and pectic substances.**

Presence or absence of flagella and flagellar types

- The number of flagella and their arrangement in reproductive (gametes or spores) or vegetative cells is variable across the different phyla of eukaryotic algae.
- Flagella may be **absent** (red algae) or **present** (green and brown algae); when present, they can be isokont, anisokont, heterokont or stephanokont.



Isokont flagella in a chlorophycean (green alga).

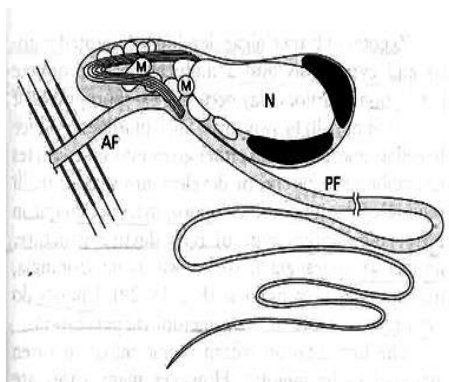


Figure 15–27 Diagrammatic representation of a laminarialean sperm cell, showing lateral emergence of heterokont flagella. AF=anterior flagellum, M=mitochondrion, N=nucleus, P=plastid, PF=posterior flagellum. (From Henry and Cole, 1982b by permission of the *Journal of Phycology*)

Heterokont flagella in a phaeophycean (brown alga).

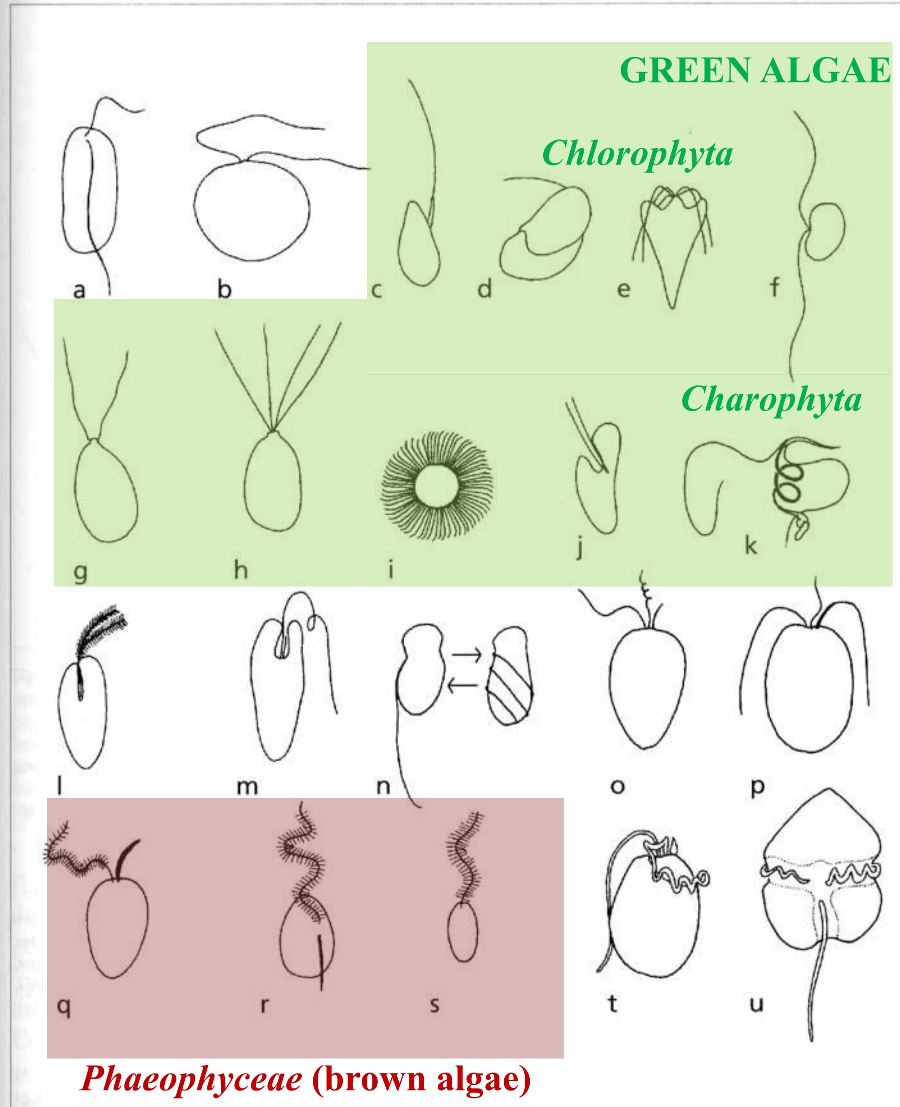
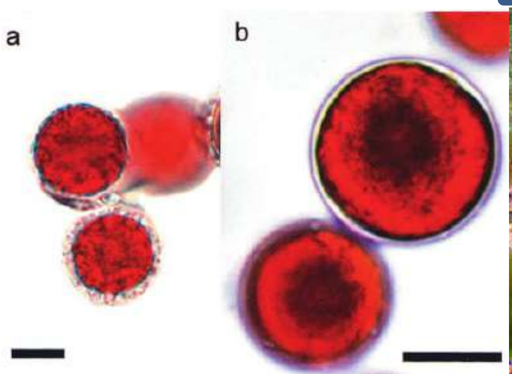
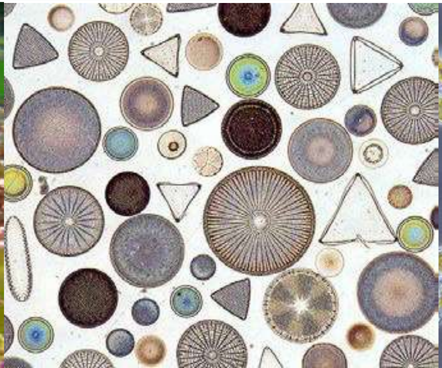
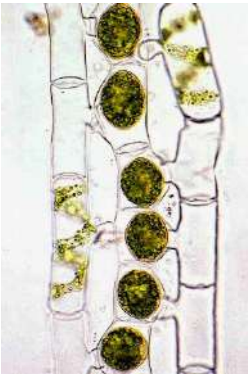


Fig. 3.13. Représentation schématique des divers types de cellules flagellées chez diverses lignées d'algues. **a.** Monade de *Cyanophora* (Glaucophyta). **b.** Zoospore de *Gloeochaete* (Glaucophyta). **c-f.** Exemples de configuration observées chez des monades de Prasinophyceae (voir aussi tome 2). **g.** Monade, gamète ou zoospore isocontée de Chlorophyta (configuration la plus fréquente). **h.** Monade ou zoospore isocontée de Chlorophyta (configuration très fréquente, en particulier pour les zoospores). **i.** Zoospore stéphanocontée de Chlorophyta (Oedogoniales et Bryopsidales). **j.** *Mesostigma viride* (seul organisme monadoïde connu chez les Streptophyta). **k.** Spermatozoïde de Charale. **l.** Monade de Cryptophyta. **m.** Monade d'Euglenophyceae. **n.** Zoospore ou monade de Chlorarachniophyceae. **o.** Monade de Pavlovophyceae (anisocontée + haptonème). **p.** Monade de Prymnesiophyceae (isocontée + haptonème). **q-s.** Monades hétérocontées de Stramenopiles (ou Heterokonta; voir aussi tome 2). **q.** Insertion apicale des deux flagelles (cas général). **r.** Insertion latérale des deux flagelles (Phaeophyceae, Chrysomerophyceae). **s.** Un seul flagelle pourvu de mastigonèmes tubulaires tripartites. **t.** Monade de dinophyte desmocontée. **u.** Monade, zoospore ou gamète de dinophyte, dinocontée (cas le plus fréquent).

Classification of algae	Brown algae
Red algae	Green algae





Group SAR, Stramenopila, Phylum *Ochrophyta*, class *Phaeophyceae* (brown algae)

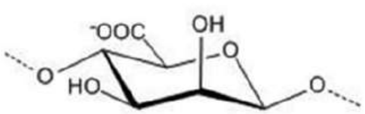
- Brown algae are mainly marine, with around 2,000 known species. There are only 5 freshwater genera.
- These are abundant on the rocky coasts of cold and temperate seas (*Fucus*, *Laminaria*).
- Some important genera are found in the tropics (*Sargassum*).
- Phaeophyceans have a remarkable morphological variability.

- They are economically important, being widely used as a food – *Laminaria* (kombu) and *Undaria* (wakame) – or as a source of alginates (*Laminaria*, *Macrocystis*).

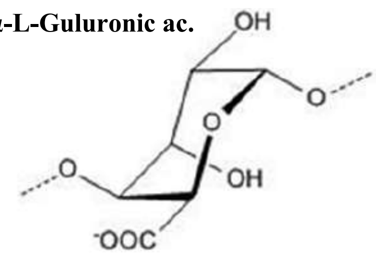
Main traits of brown algae (class *Phaeophyceae*)

- **Thallophytes** (filamentous and (pseudo)-parenchymatous)
- Cell walls with cellulose and an amorphous fraction of salts of alginic acid (**alginates**) (35% dry weight)

β-D-Manuronic ac.



α-L-Guluronic ac.



- **Spores** and **gametes** usually flagellate, heterokonts.

Generally pyriform and provided with two flagella inserted laterally or subapically: one directed towards the posterior pole, which is acronematic (= ending in a thin filament) and smooth, and the other directed towards the anterior pole, which is covered with mastigonemes arranged in two rows.

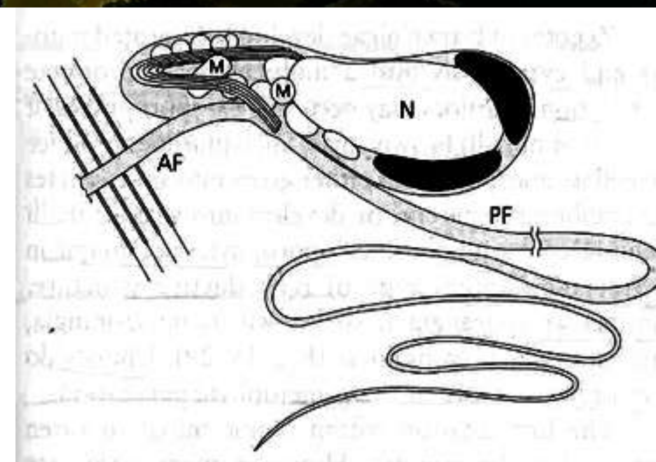
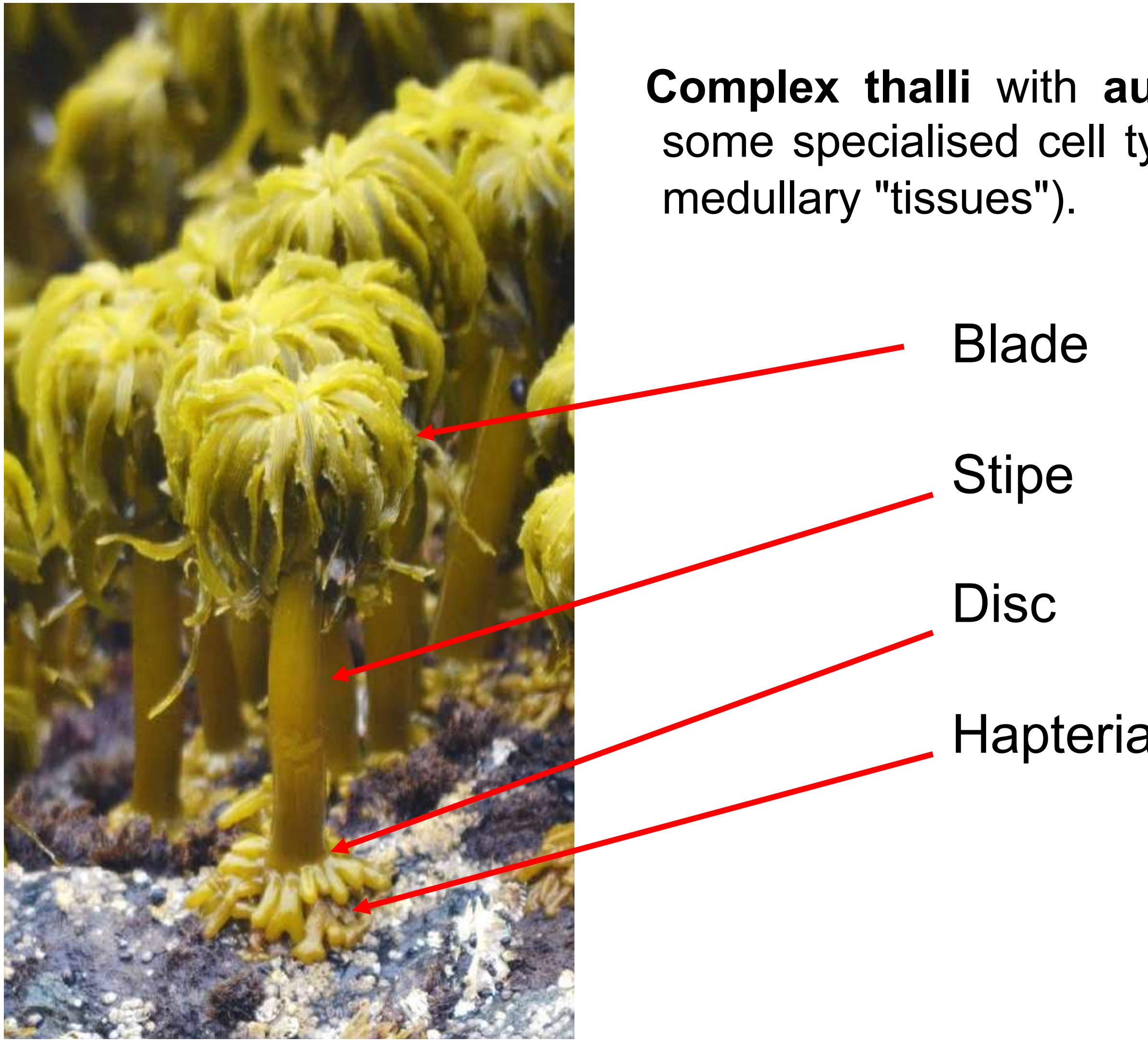


Figure 15–27 Diagrammatic representation of a laminarialean sperm cell, showing lateral emergence of heterokont flagella. AF=anterior flagellum, M=mitochondrion, N=nucleus, P=plastid, PF=posterior flagellum. (From Henry and Cole, 1982b by permission of the *Journal of Phycology*)

- Numerous discoid or elongated plastids, with **4 membranes** and thylakoids in bundles of three. Their brown colour is due to **fucoxanthin**. They also have **chlorophyll *a*** and c. Storage material: **laminarin**.

Main traits of brown algae (class *Phaeophyceae*)

Complex thalli with **authentic tissues**, displaying some specialised cell types (insulating, cortical and medullary "tissues").



These thalli often show more complex structures that can be observed by the naked eye.

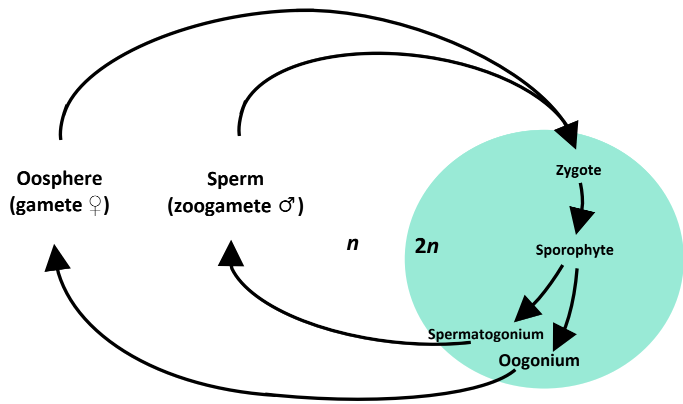
Postelsia palmaeformis (*Phaeophyceae*, brown alga)

Brown algae: life cycles

The three types of known life cycles in brown algae are:

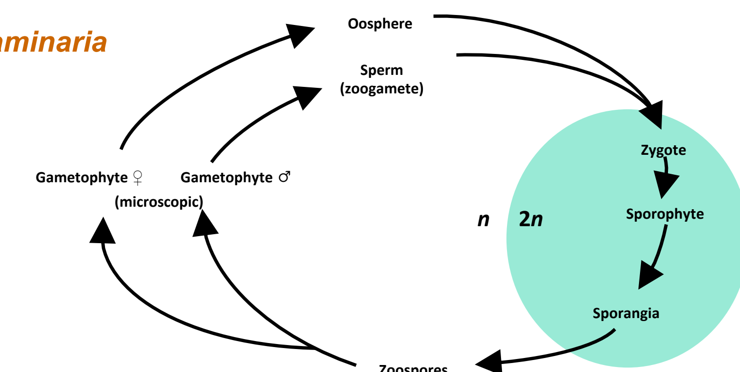
- **Monogenetic diploid** (gametic R!).
- **Digenetic haplo-diploid and isomorphic** (sporic R!).
- **Digenetic haplo-diploid and heteromorphic** (sporic R!).

Ex. ***Fucus***



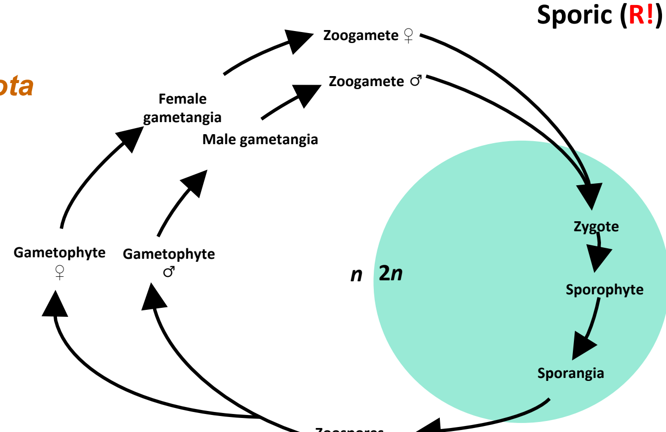
Gametic (R!) meiosis

Ex. ***Laminaria***



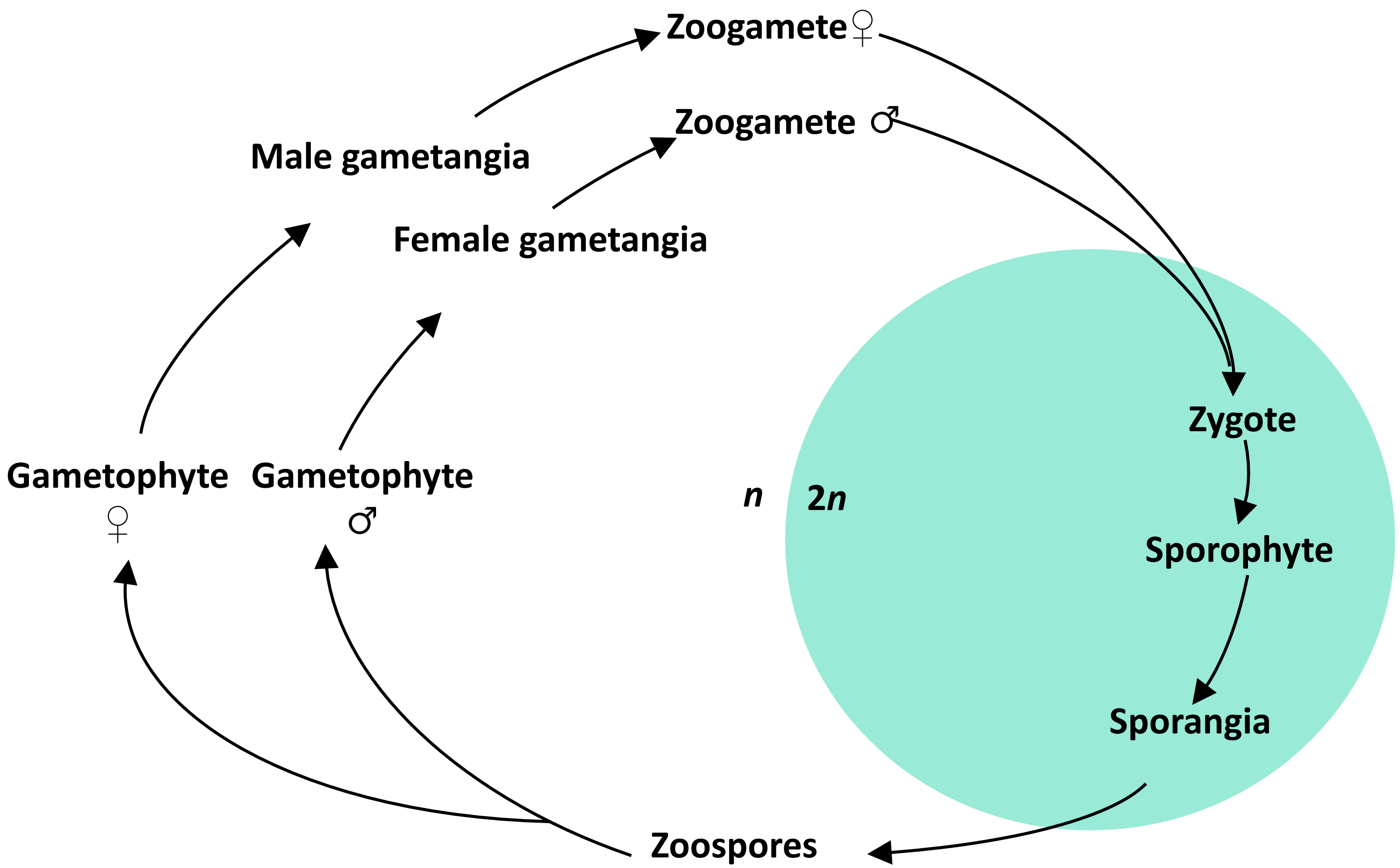
Sporic (R!) meiosis

Ex. ***Dictyota***



Sporic (R!) meiosis

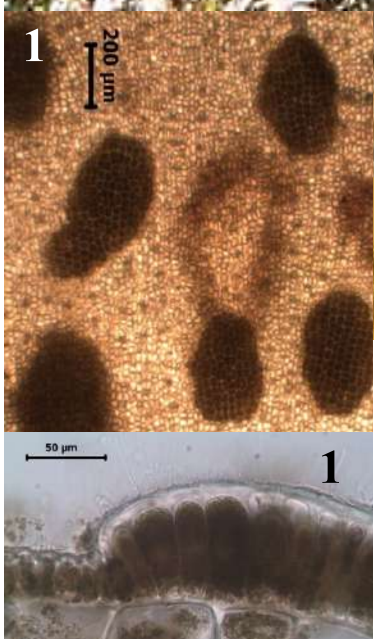
Digenetic haplodiploid and isomorphic life cycle

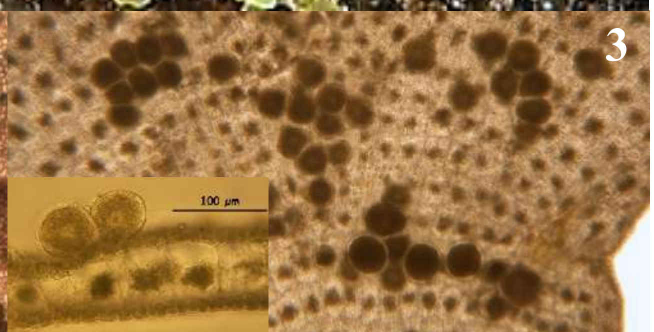


Sporic meiosis (R!)

Ex. ***Dictyota dichotoma***

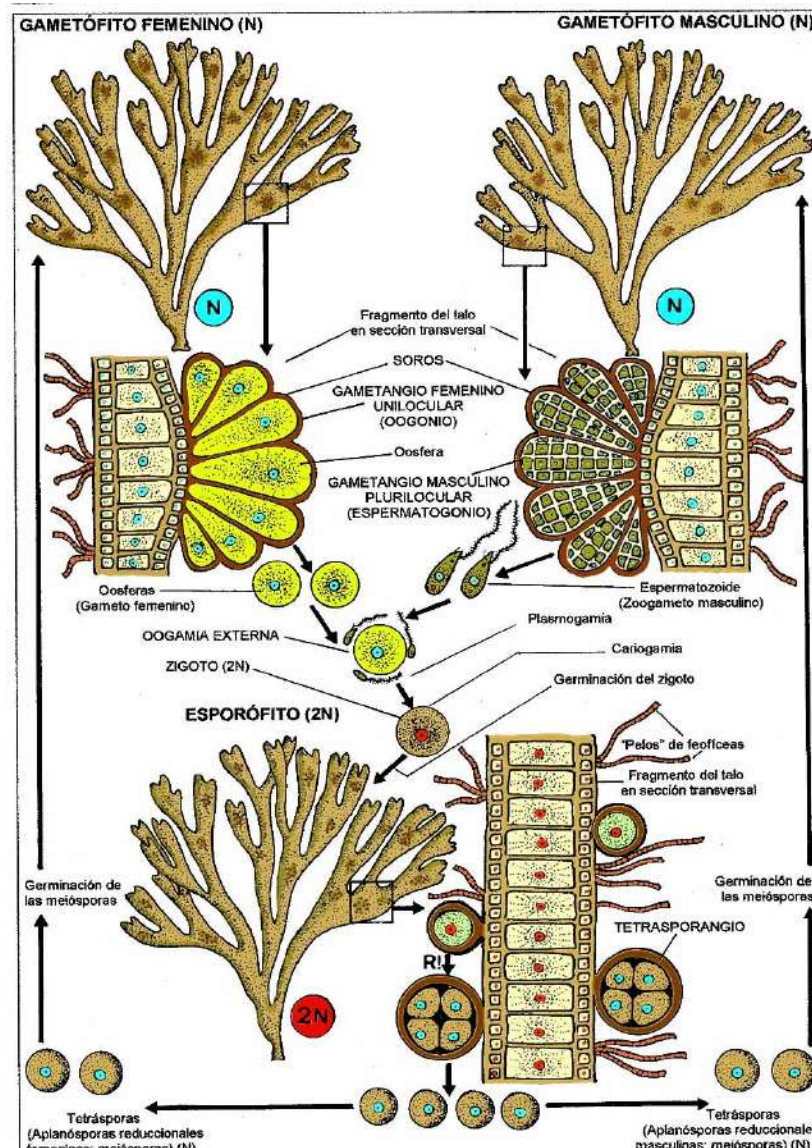
Example of digenetic haplodiploid and isomorphic life cycle: *Dictyota dichotoma*





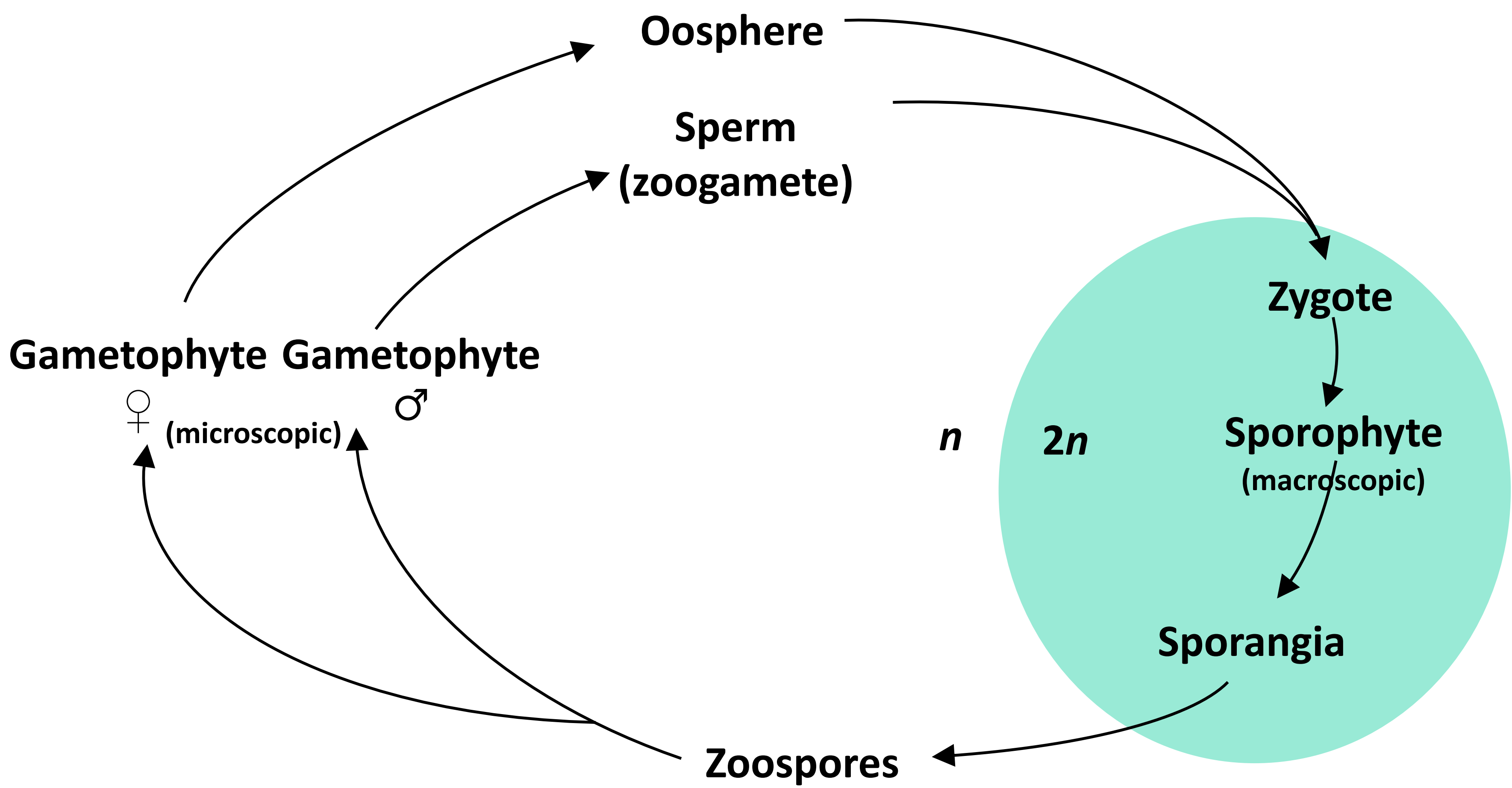
Structures involved in reproduction:

1. Oogonia
2. Spermatogonia
3. Sporangia



Díaz-González *et al*. (2004)

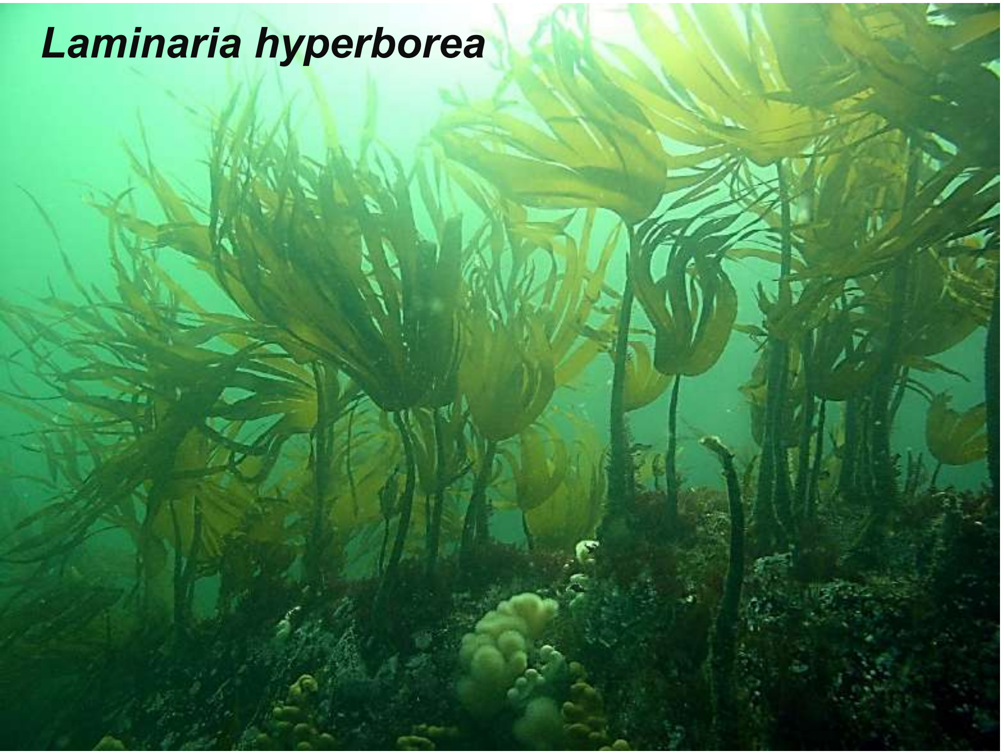
Digenetic haplo-diploid and heteromorphic life cycle



Sporic (R!) meiosis

Ex. ***Laminaria* spp.**

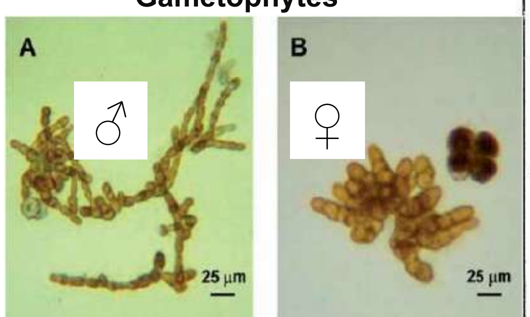
Example of digenetic haplodiploid and heteromorphic life cycle: *Laminaria* spp.

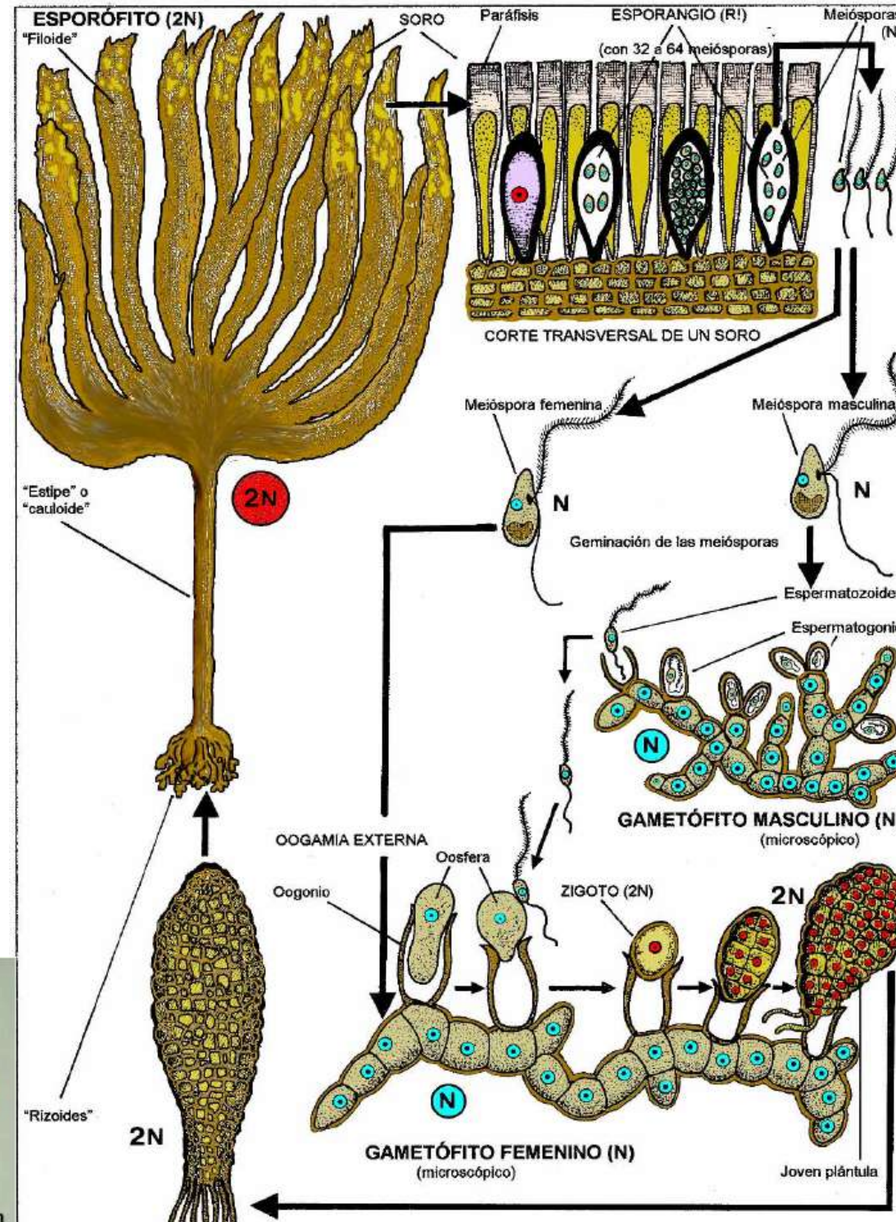


Involvement of:

- Sporangia (R!)
- Oogonia
- Anteridia/Spermatogonia

Gametophytes





Díaz-González *et al.* (2004)

Brown algae from the Pacific Ocean

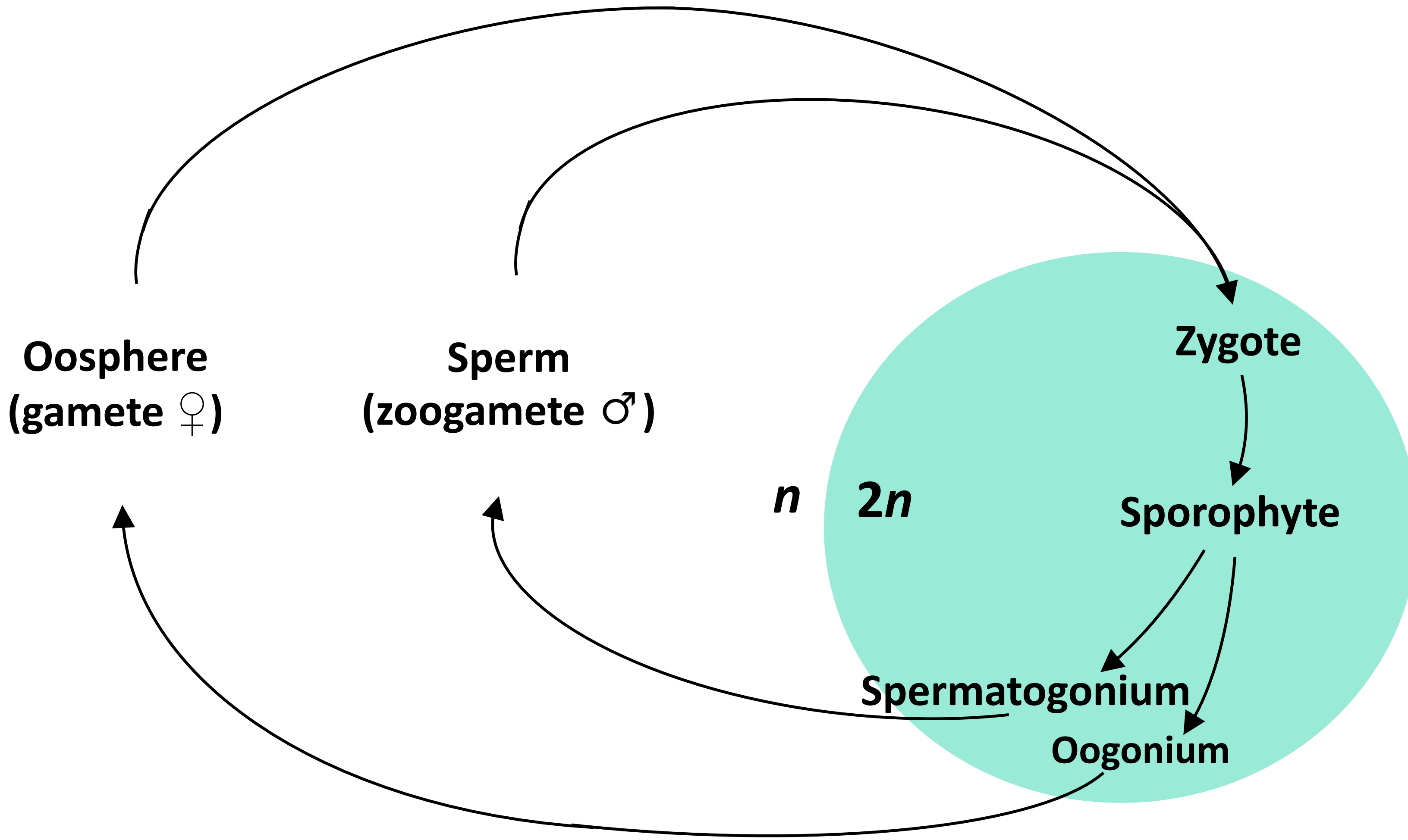
Laminarean brown algae present greater dimensions and histological complexity.

Brown algae from the Pacific Ocean

Macrocystis spp.

These algae can exceed 60 m in length.

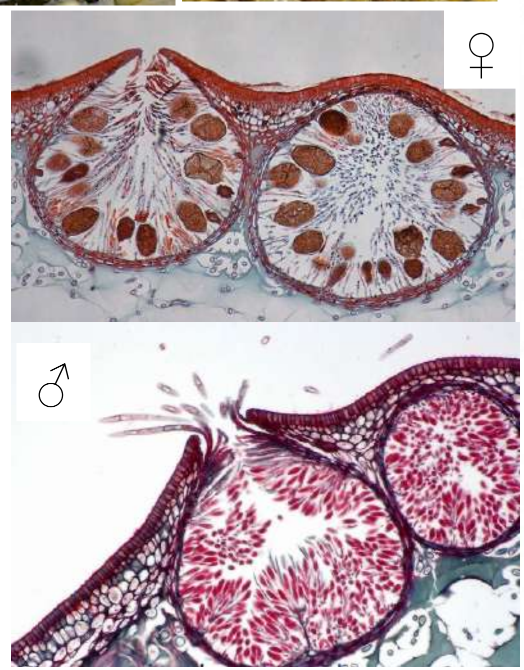
Monogenetic diploid life cycle

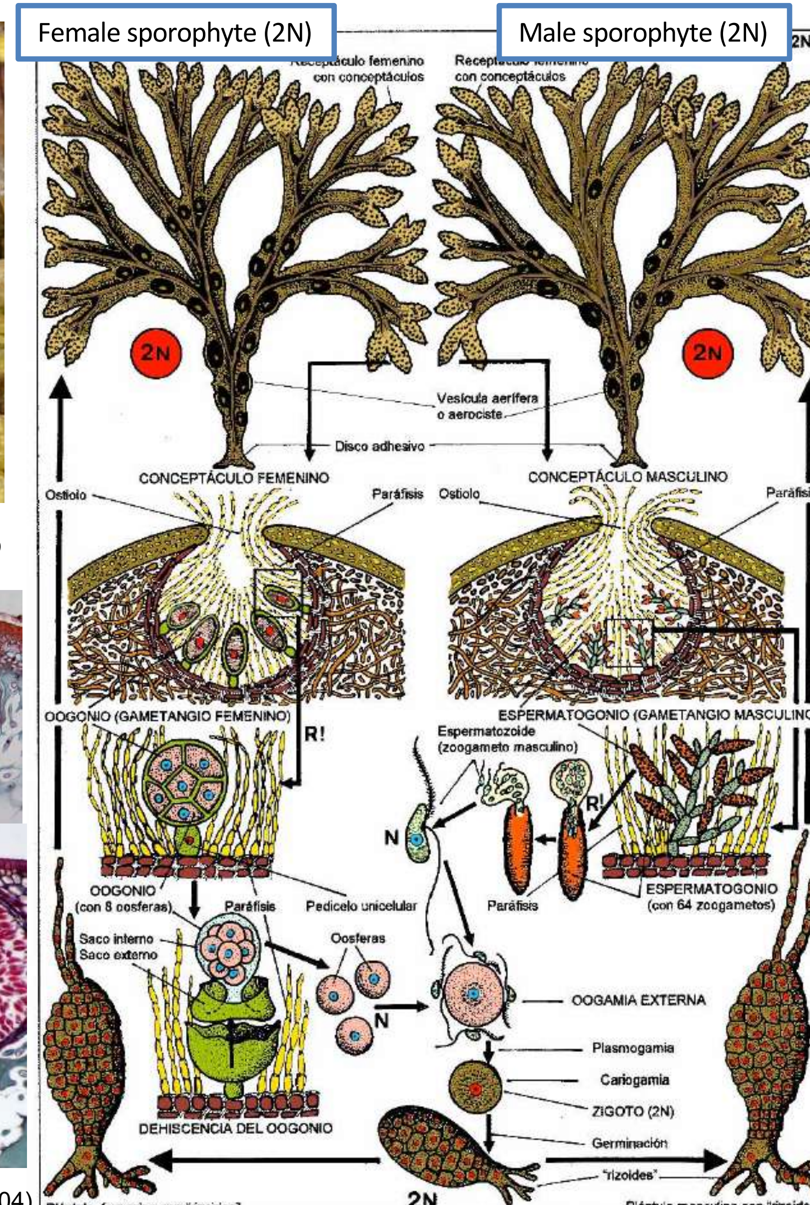


Gametic (R!) meiosis

Ex. ***Fucus* spp.**

Example of monogenetic diploid life cycle: *Fucus* spp.





Díaz-González *et al*. (2004)

Involvement of:

- Receptacles
- Conceptacles
- Oogonia
- Spermatogonia/Anteridia

Uses of brown algae for humans

Laminaria japonica

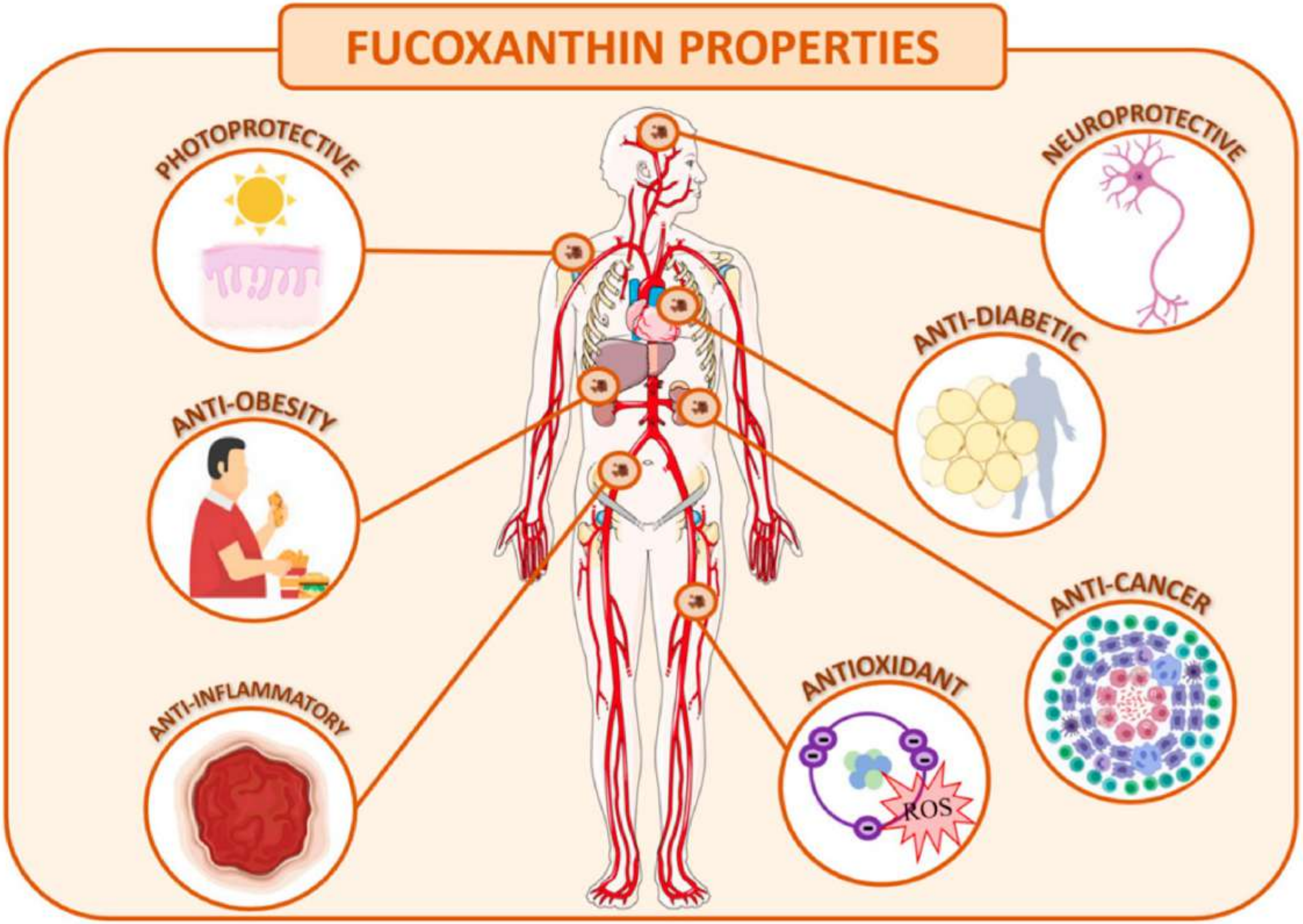
Wakame

Undaria pinnatifida

Kombu

in dishes, kombu (***Laminaria japonica***) has a unique taste called "**umami**".

Uses of brown algae for humans

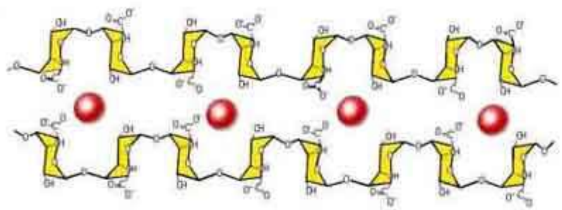


The scientific community has corroborated the numerous beneficial activities of fucoxanthin, such as its antioxidant, anti-inflammatory, anticancer and neuroprotective effects. These properties have attracted the attention of the nutraceutical, cosmetic and pharmacological industries, giving rise to numerous applications (Lourenço-Lopes et al. 2020).

Uses of brown algae for humans

Gelling properties of <u>alginates</u>. Gels are formed “at low temperatures” in the presence of Ca^{+2}.

In the presence of calcium, alginate forms a structure known as an "egg crate". In this structure, calcium ions are placed as bridges between the negatively charged groups of guluronic acid.



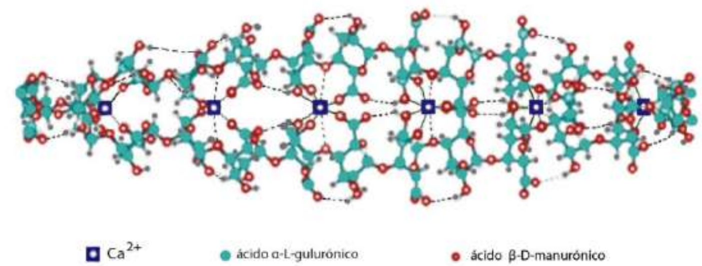
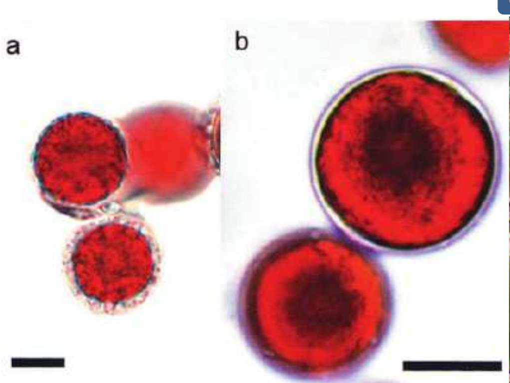
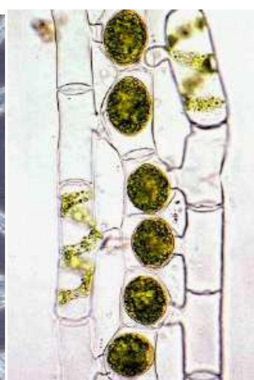


Fig. 1. Modelo “caja de huevo” que describe la estructura del alginato. (Adaptada de Reddy y Reddy 2010).

The gelling properties of alginates are used in avant-garde cooking preparations (**spherification**), whereby a liquid is encapsulated inside a calcium alginate sphere.

Classification of algae	Brown algae
Red algae	Green algae



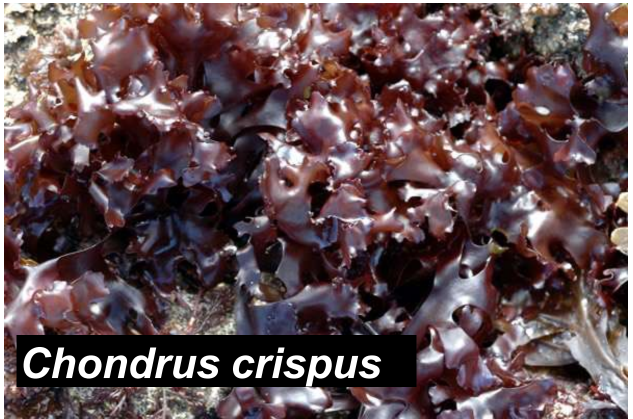


Main traits of red algae (phylum *Rhodophyta*)

- Most of the 6,000 recognised species are marine and distributed in 500-600 genera.
- They are frequently found in tropical/subtropical waters. Calcified encrusting rhodophyceans are important on **reefs** in tropical regions.
- They **lack flagellated cells** at every stage of their life cycles.
- Pigments: **chlorophyll *a***, **phycoerythrin**, **phycocyanin** and **carotenoids**.
- Their walls consist of a matrix of **cellulose** microfibrils associated with phycocolloids (**agar** and **carrageenans**). In *Corallinales*, they are impregnated with calcium carbonate.
- The economic importance of these phycocolloids is associated with their use as food: *Porphyra* (nori) in Japan and Korea.


Halymenia floresii

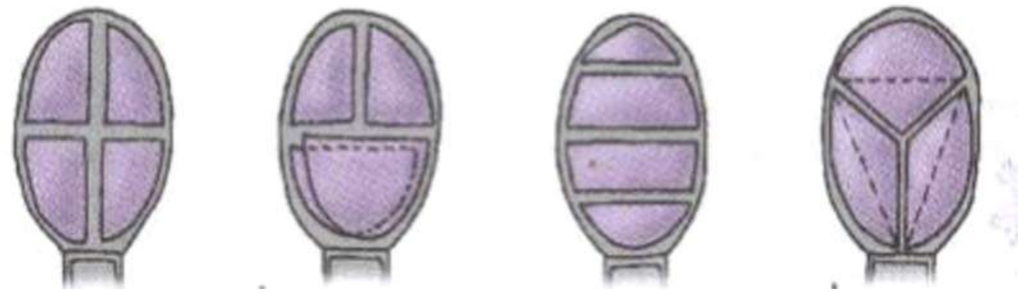
Lithophyllum incrustans


Chondrus crispus

Reproduction in red algae

- Their life cycles are typically **trigenetic haplo-diploid**, with **gametophytes**, **tetrasporophytes** and **carposporophytes**.

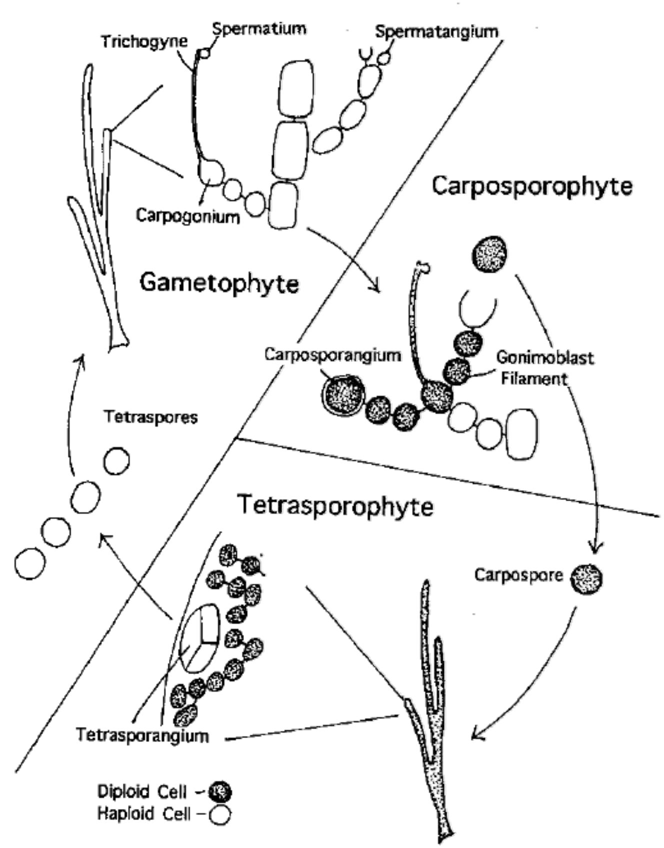
Feldmann (1963)



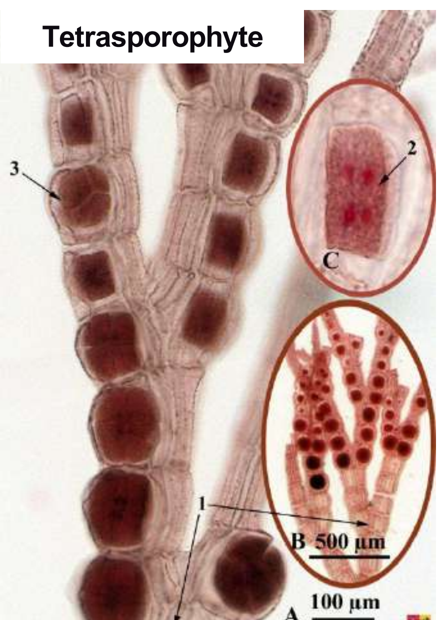
- **Tetrasporophytes** form **tetrasporangia** (meiosporangia) and tetraspores.
- Morphological types: cruciate, decusate, tetrahedral, zonate.

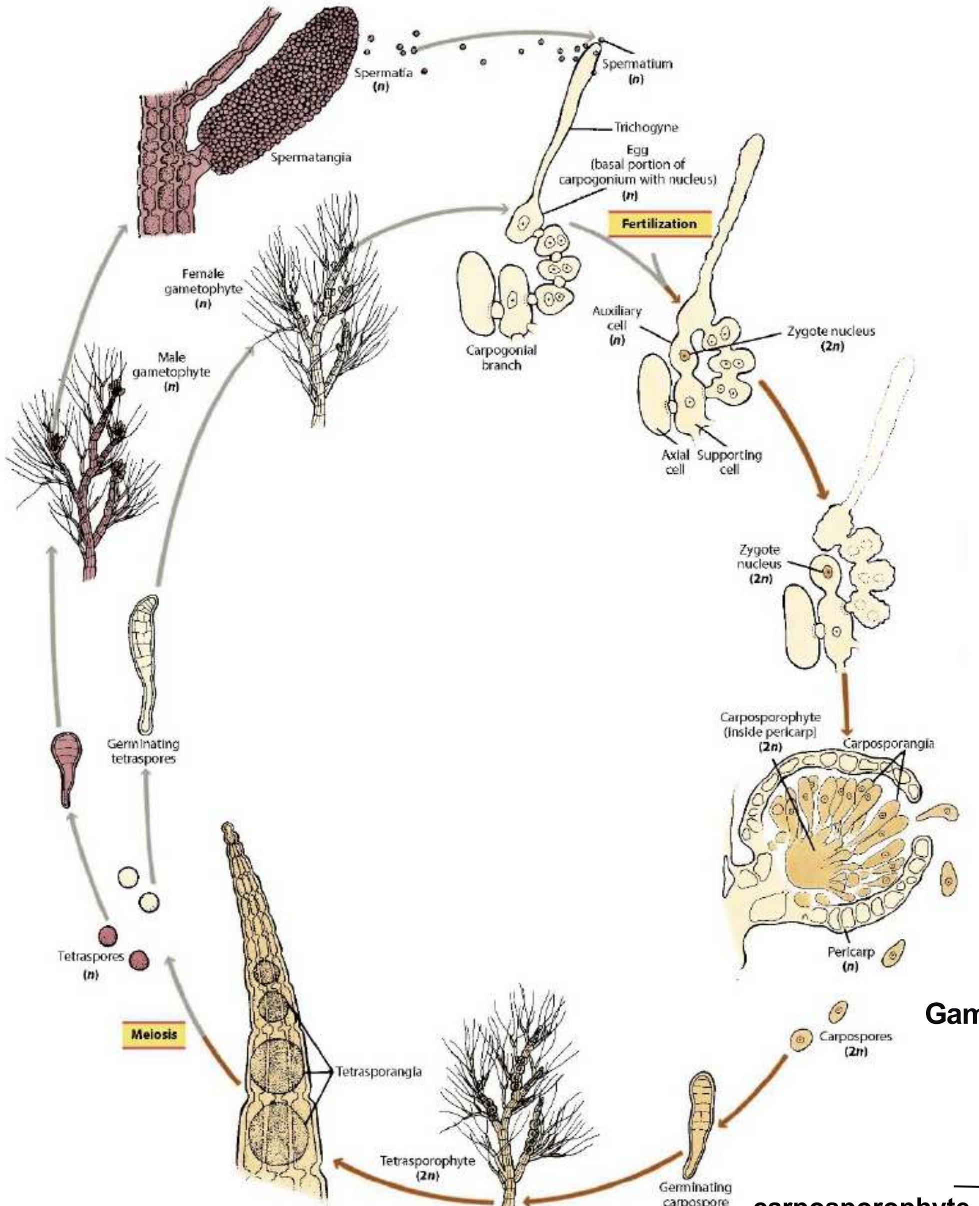
Sexual reproduction:

- **Trichogamy** (a kind of oogamy), which involves the fusion of a **spermatium** (male gamete) with a **carpogonium** (oogonium or female gametangium); **non-flagellated gametes**, with the female being the larger.
- A **carposporophyte (2N)** develops as a result of this fusion.

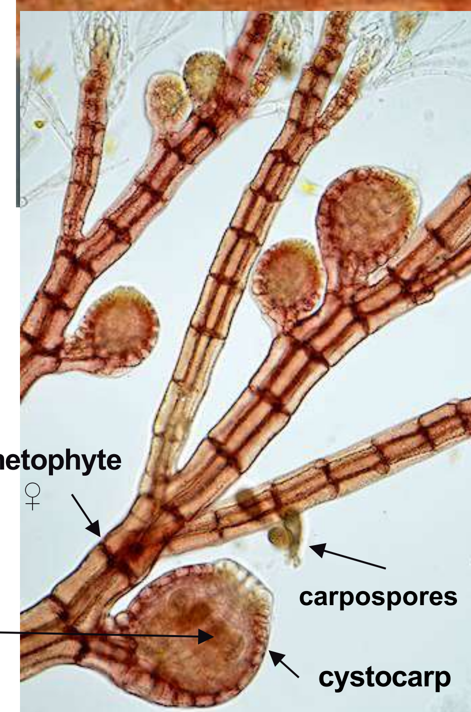


Life cycle of *Polysiphonia*: trigenetic haplo-diploid isomorphic

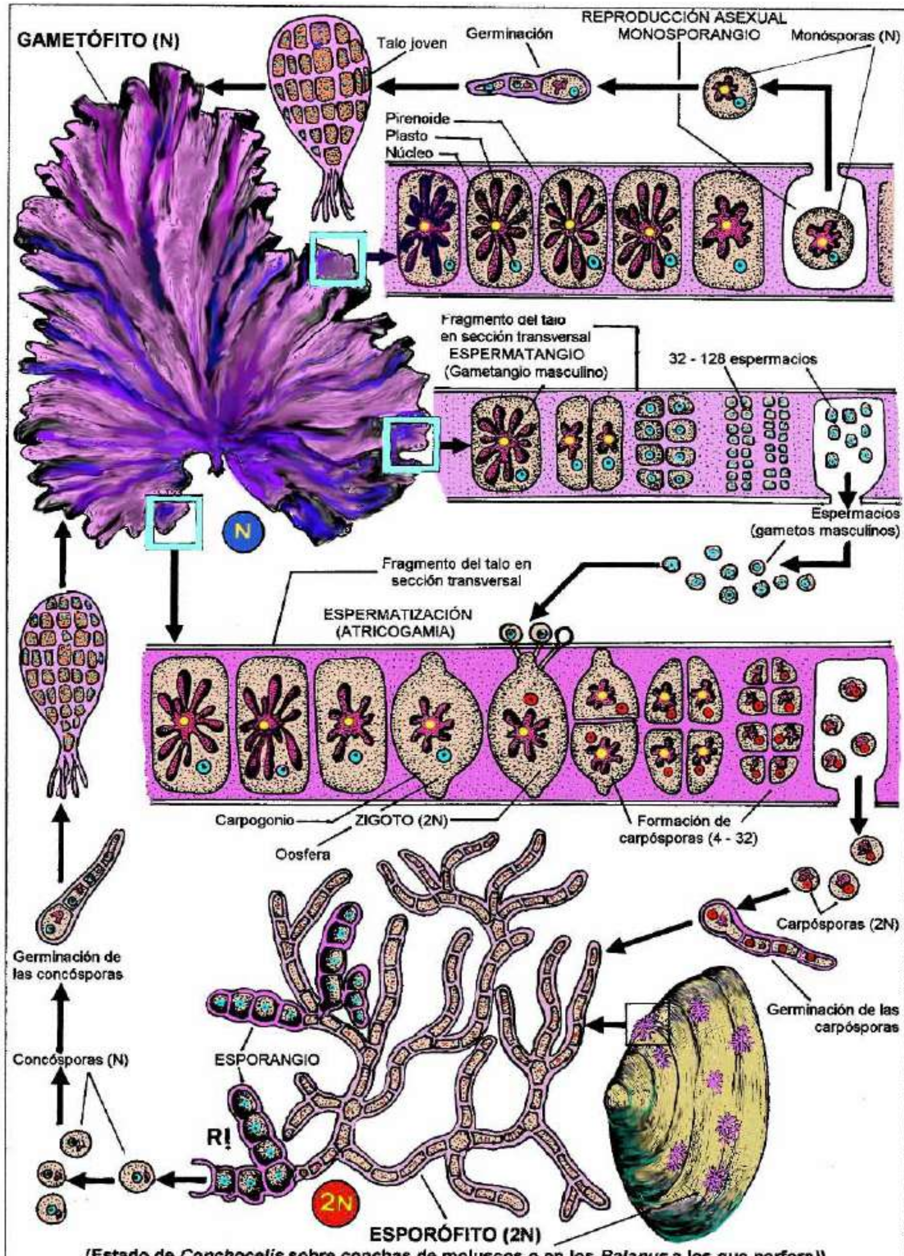


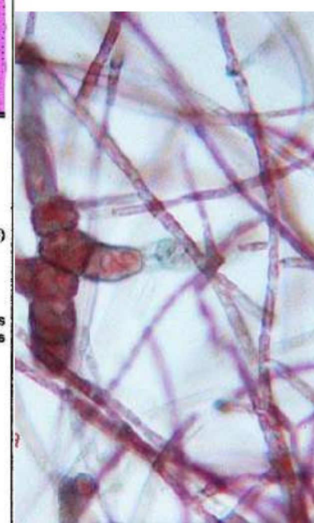


Adapted from Evert & Eichhorn (2013)



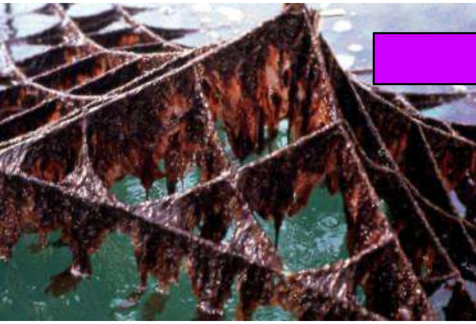
Life cycle of nori (*Porphyra*, class *Bangiophyceae*)



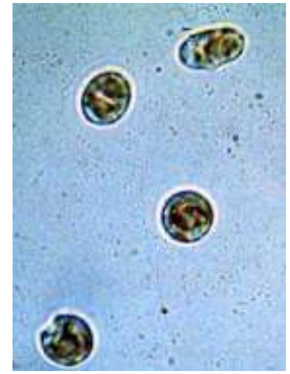


Cultivation of *Porphyra* (nori)

Gametophyte



Harvest



Carpospores

Conchocelis phase

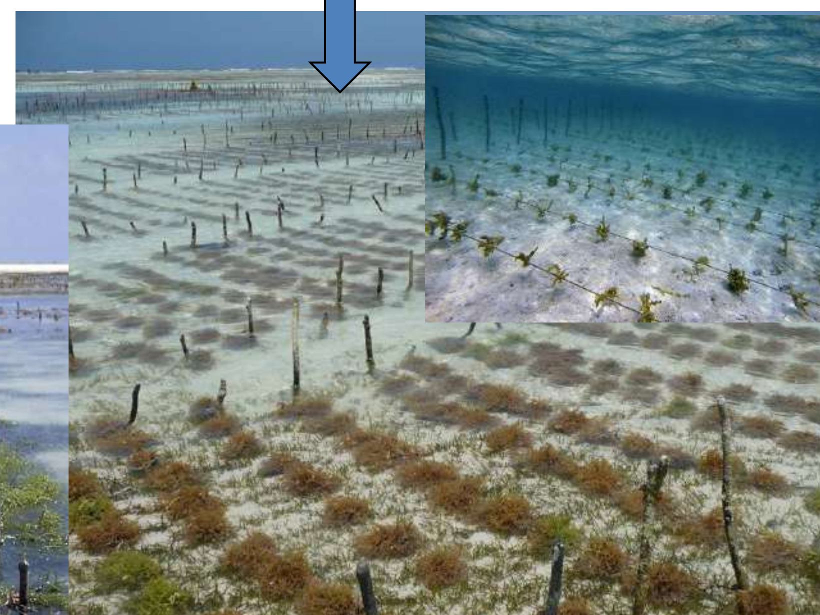
Insemination of nets with conchospores

conchosporangia

See www.seaweed.ie

Diversity of red algae: class *Florideophyceae*, order *Gigartinales*

Carrageenophytes. Source of carrageenans (sulfated polysaccharides). *Chondrus crispus* is the Irish “moss”, though other producing species are cultivated in tropical countries: ***Eucheuma denticulatum*** and ***Kappaphycus alvarezii***. They are used for making foods such as ice cream, jellies, syrups and bread, as well as for making lotions, toothpaste and pharmaceutical jellies.

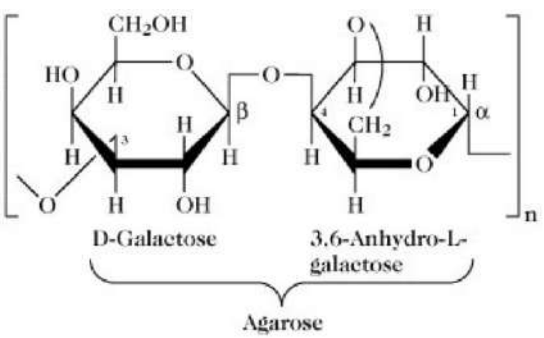


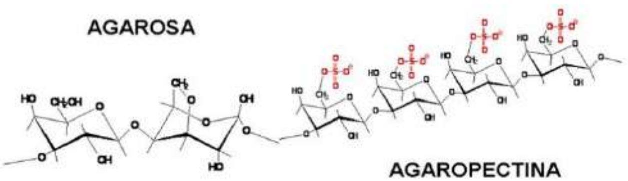
Diversity of red algae: class *Florideophyceae*, order *Gigartinales*

Agarophytes.

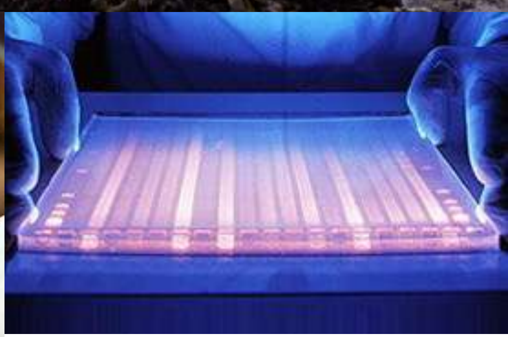
Agar sources.

Agar is a polymer of galactose subunits, a heterogeneous mixture of two classes of polysaccharides: agaropectin and agarose .



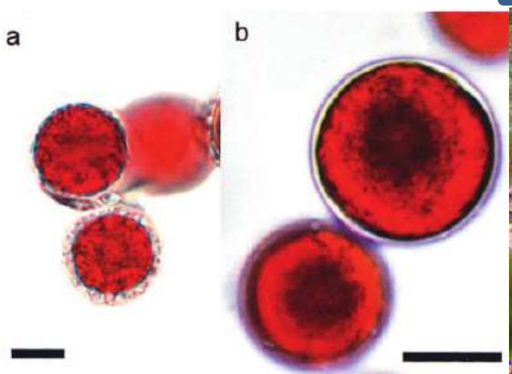


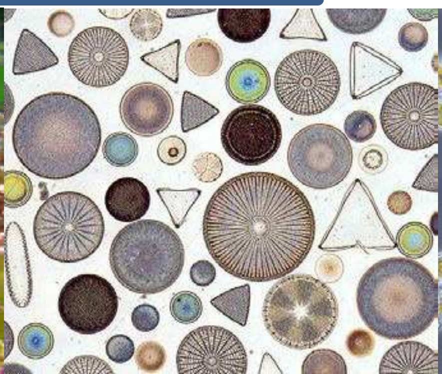
Gelidium corneum



Agarose is used for DNA electrophoresis.

Classification of algae	Brown algae
Red algae	Green algae

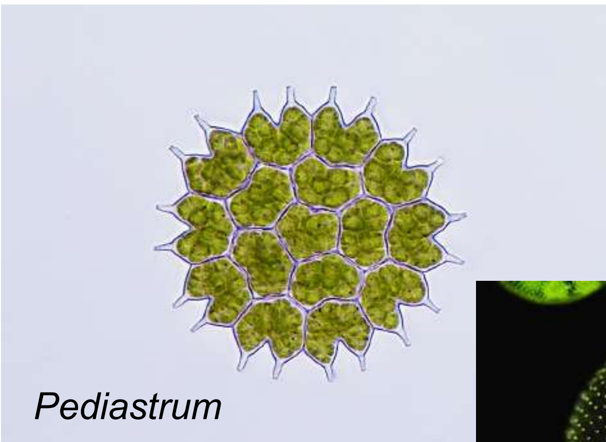


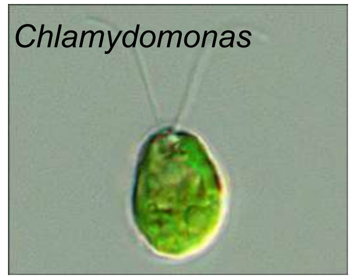



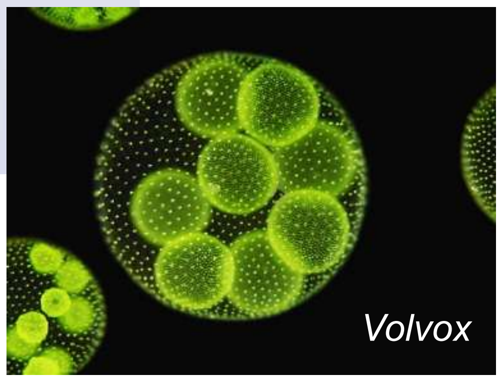
Green algae: phyla *Chlorophyta* and *Charophyta*

Chlorophyta includes marine green algae and many freshwater algae, while ***Charophyta*** includes other freshwater and subaerial algae.

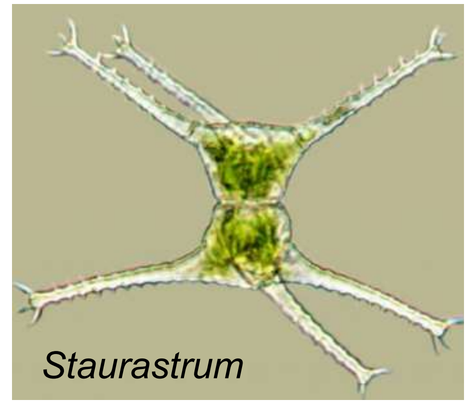
Chlorophyta

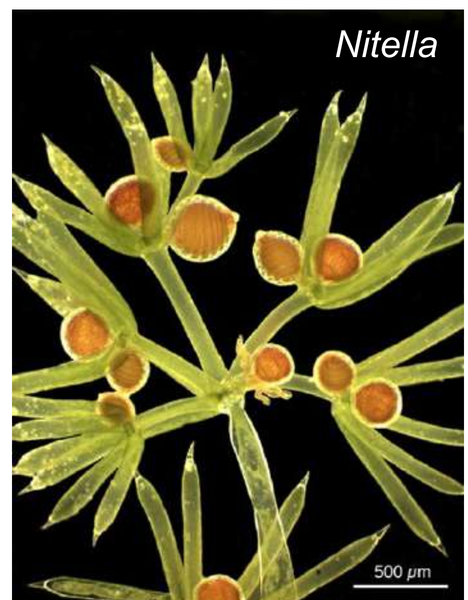






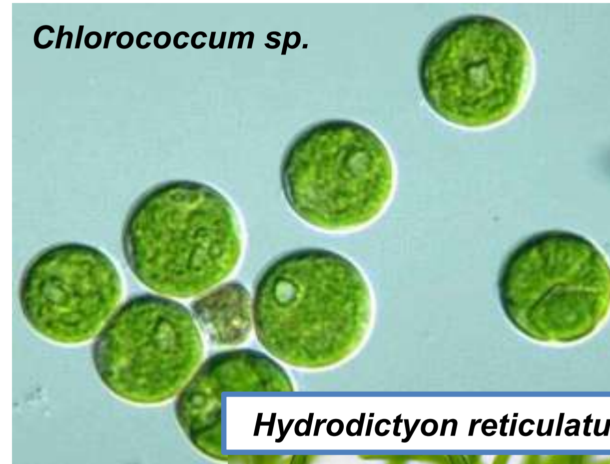
Charophyta

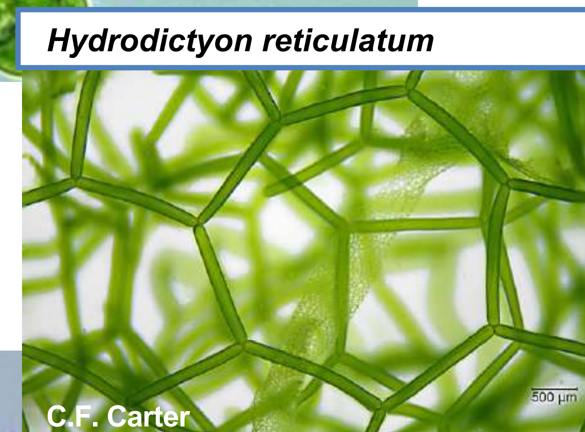


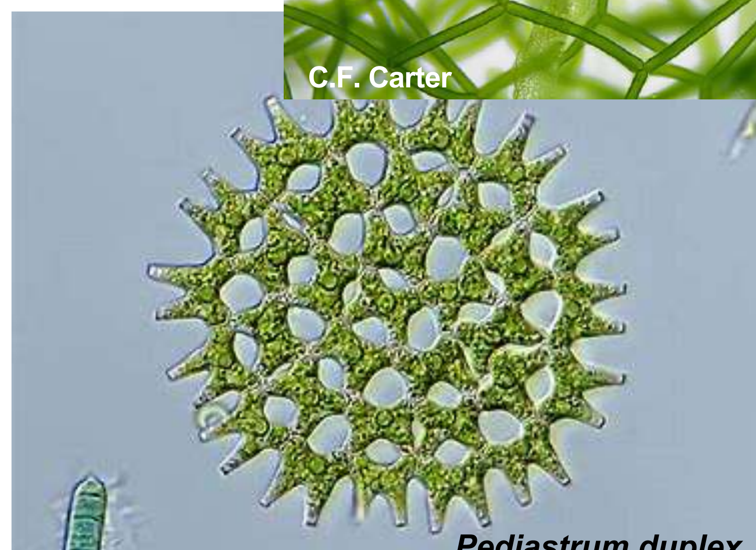


The main characteristics of green algae

- High biodiversity.
- They include some **500 genera** and **18,000 spp**.
- High **morphological diversity**: unicellular, flagellate or non- flagellate, colonials, coenobial, simple and branched filaments, blades and siphonous thalli.
- They colonise both fresh (90%) and marine (10%) waters.







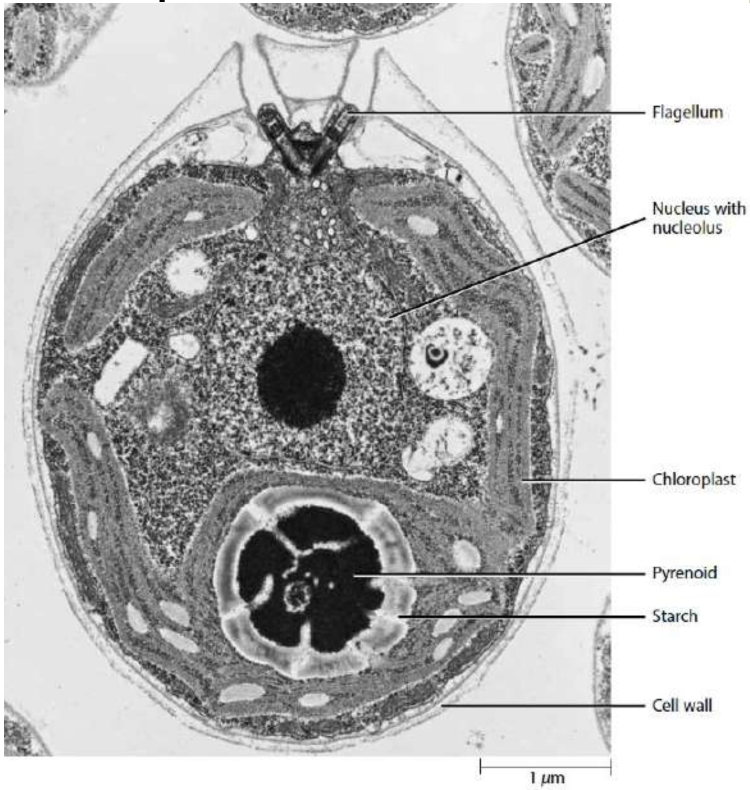
The main characteristics of green algae

- Their **cell walls** contain **cellulose**, **hemicellulose** and **pectic substances.**

- Chloroplasts have a **double membrane** and **thylakoids that are simple** or **grouped** in **grana**. Intraplastidial **pyrenoids**.

- **Photosynthetic pigments**: chlorophylls *a* y *b*, *β*-carotens, diverse xanthophylles.

- **Intraplastidial starch**.



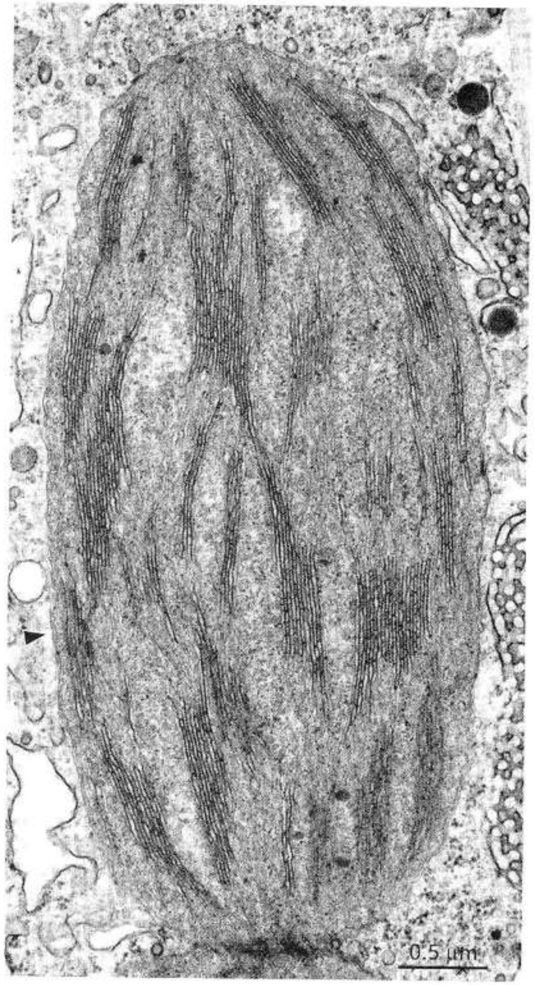
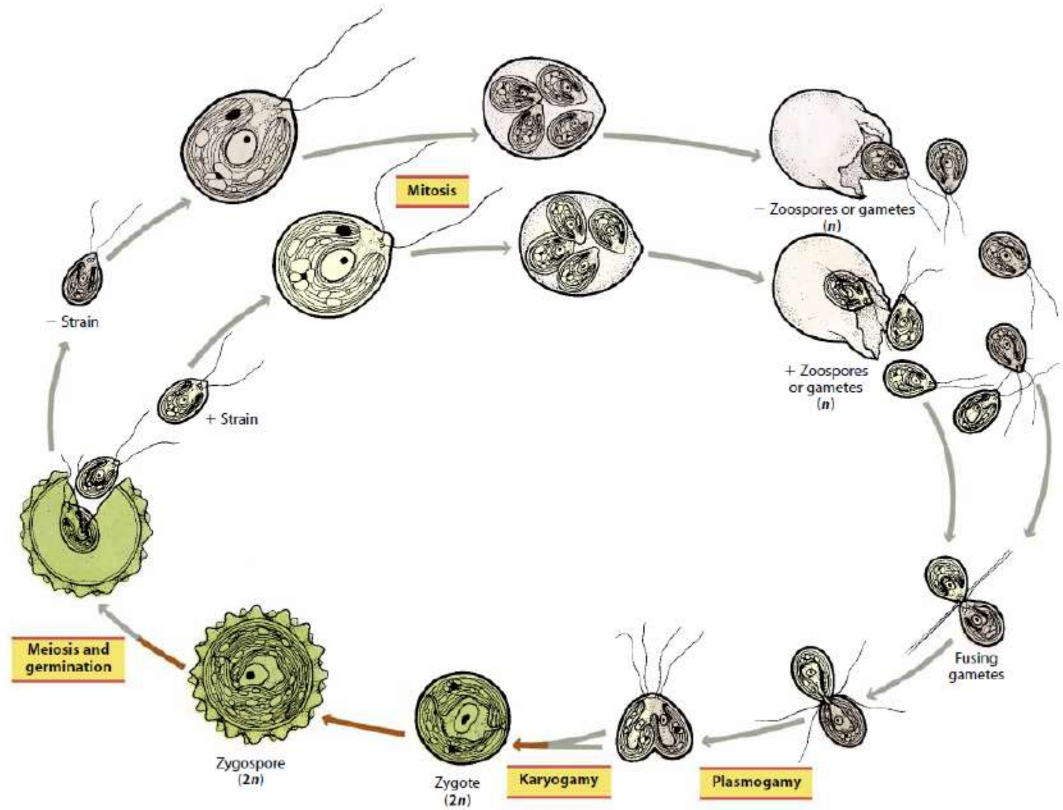


Figure 17–9 TEM view of a plastid of *Chara zeylanica*, illustrating the characteristic arrangement of thylakoids into granalike stacks and the double membrane envelope (arrowhead). Note the absence of a periplastidal endoplasmic reticulum such as that surrounding the plastids of ochrophytes and some other algae. Another characteristic of green algae is intraplastidal starch (see Fig. 19–8, for example). (Reprinted with permission from Graham, L. E., and Y. Kaneko. 1991. Subcellular structures of land plants [Embryophytes] from green algae. *CRC Critical Reviews in Plant Science* 10:323–340 ©CRC Press, Boca Raton, FL)

Reproduction in green algae

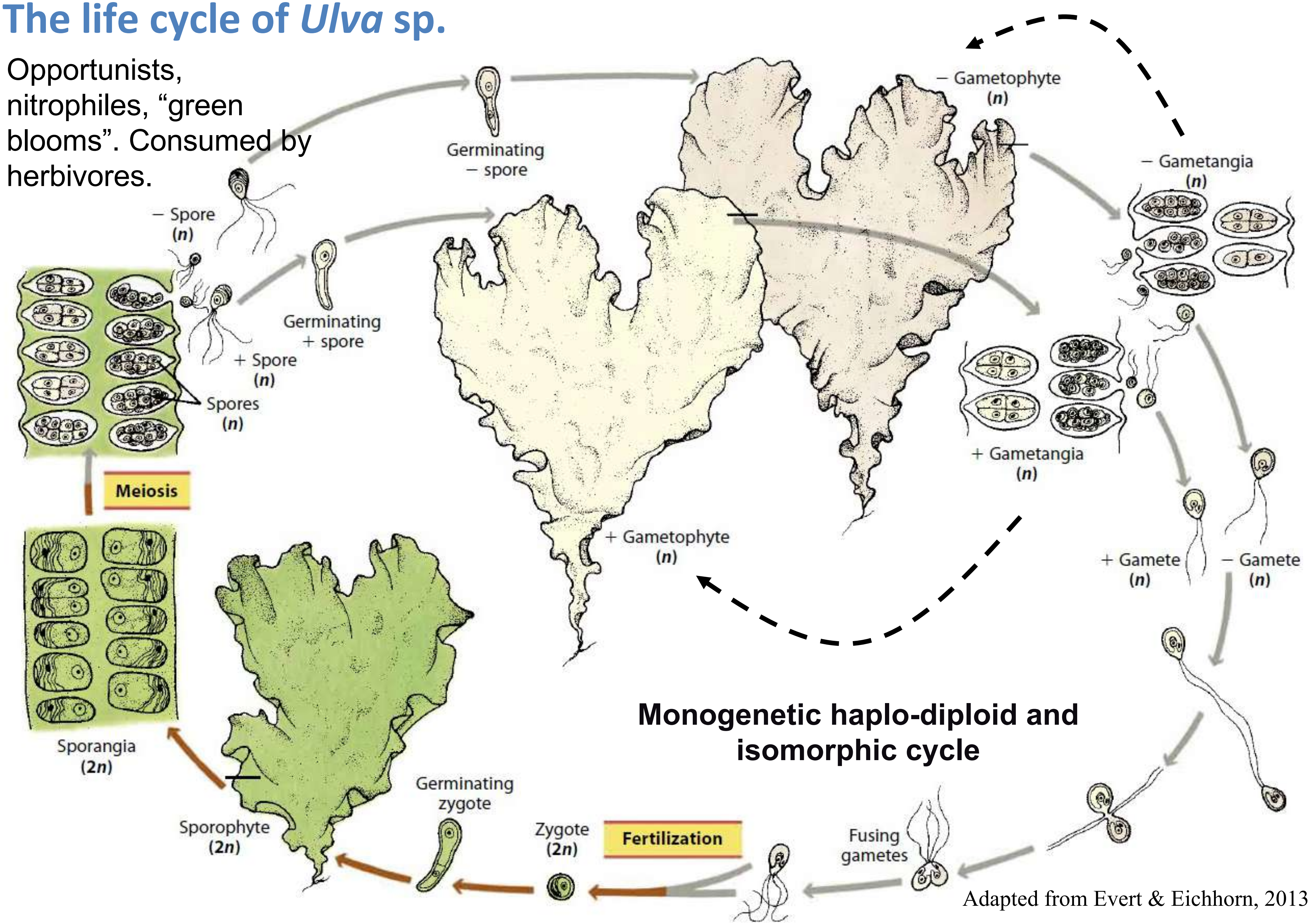
- **Asexual**. Through zoospores, aplanospores or autospores.
- **Sexual**. Isogamy, anisogamy or oogamy, often induced by changes in environmental factors.
- There are three kinds of life cycles:
    - **Monogenetic haploid** (U, T, C and CH), with **zygotic meiosis**.
    - **Monogenetic diploid** with **gametic meiosis** in siphonous marine algae (U).
    - **Digenetic haplo-diploid** in U, with alternating gametophytes and sporophytes, and **sporic meiosis**.



Life cycle of ***Chlamydomonas* sp.** **Monogenetic haploid** with **zygotic meiosis.**

The life cycle of *Ulva* sp.

Opportunists, nitrophiles, “green blooms”. Consumed by herbivores.



Monogenetic haplo-diploid and isomorphic cycle

Adapted from Evert & Eichhorn, 2013

Main groups of green algae

Green algae comprise six large monophyletic groups:

Prasinophyceae (polyphyletic)

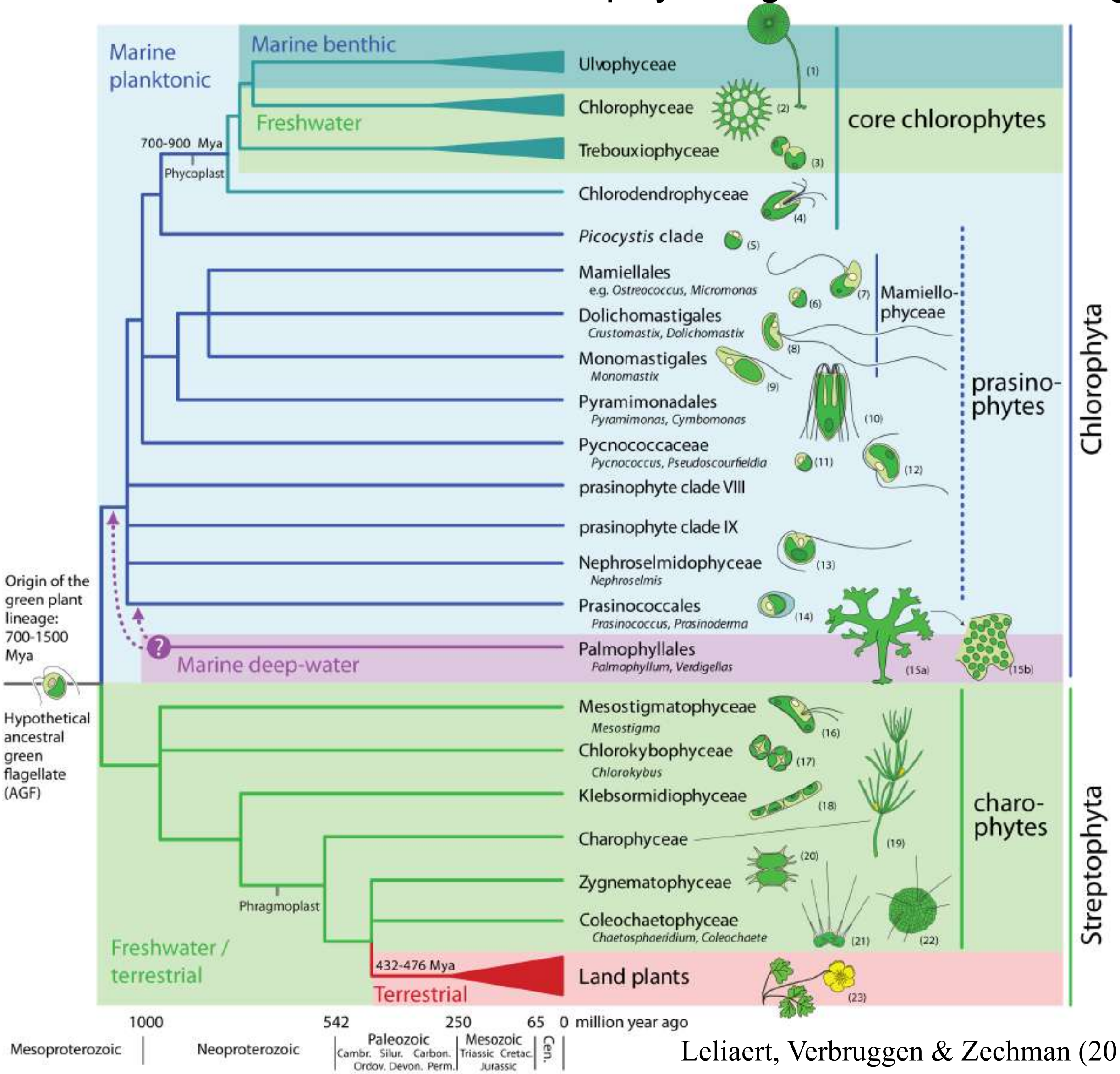
Ulvophyceae (U)
Trebouxiophyceae (T)
Chlorophyceae (C)
} **Ph. *Chlorophyta***

Charophyceae (CH)
Zygnematophyceae
Coleochaetophyceae
} **Ph. *Charophyta* (Streptophyta)**

Systematics in green algae is based on ultrastructural and molecular data

Phylogeny of green algae (and land plants)

VERY IMPORTANT: Charophyte algae are the sister group of all land plants.



Leliaert, Verbruggen & Zechman (2011). *BioEssays* 33: 683-692.

Chlorophyta

Ulvophyceae

Chlorophyceae

Trebouxiophyceae

Prasinophyceae (polifilético)

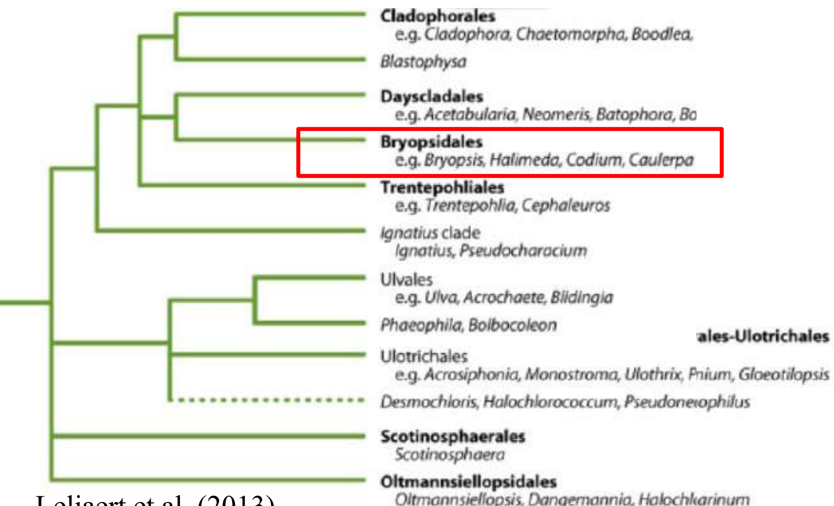
Charophyta

Charophyceae

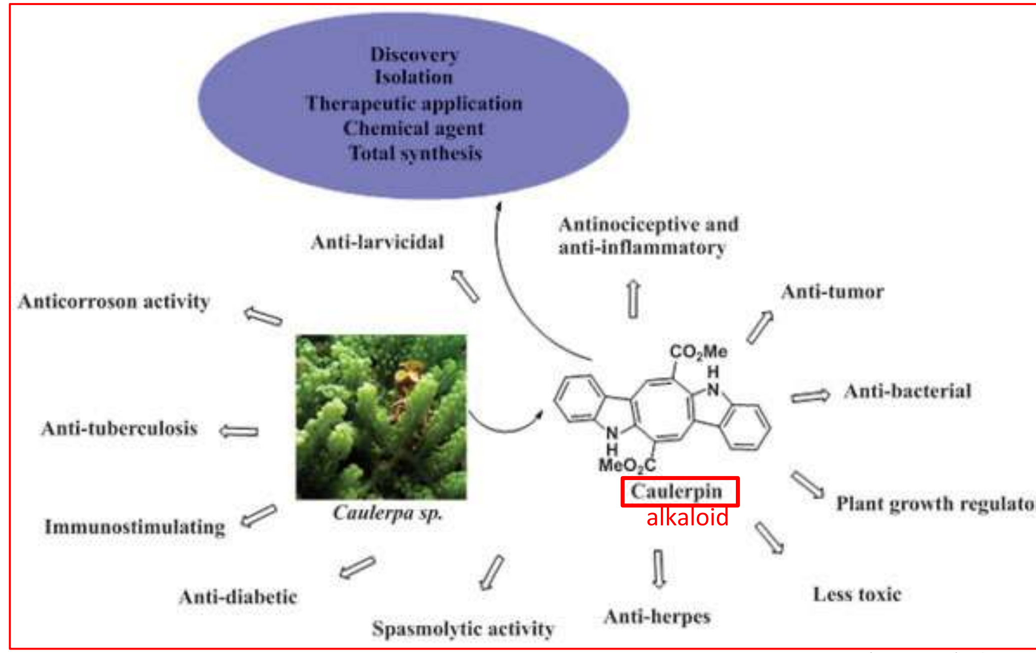
Zygnematophyceae

Coleochaetophyceae

Diversity of green algae and their uses: phylum *Chlorophyta*, class *Ulvophyceae* (I)



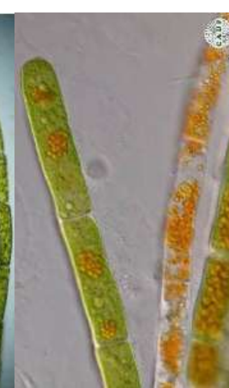
Leliaert et al. (2013)



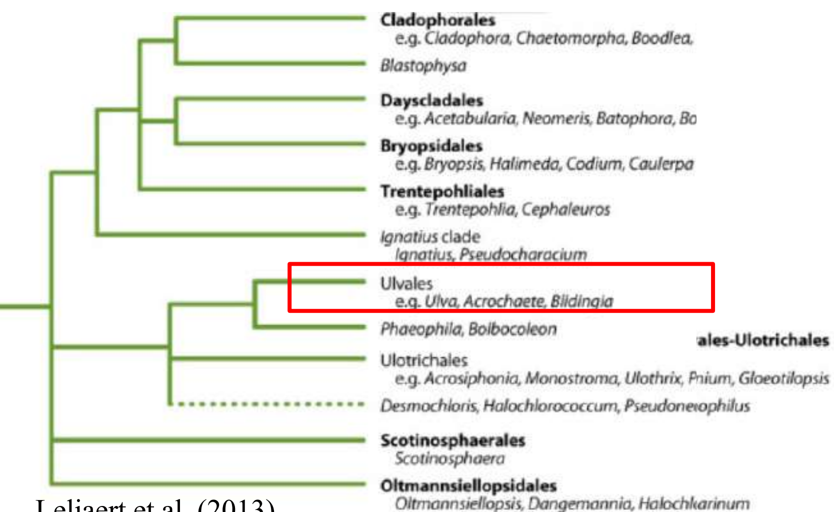
Lunagariya et al. (2019)

- Mainly marine; some groups siphonous (ex. *Caulerpa*), mono- and digenetic cycles; ecological importance and invasive species.



Diversity of green algae and their uses: phylum *Chlorophyta*, class *Ulvophyceae* (II)



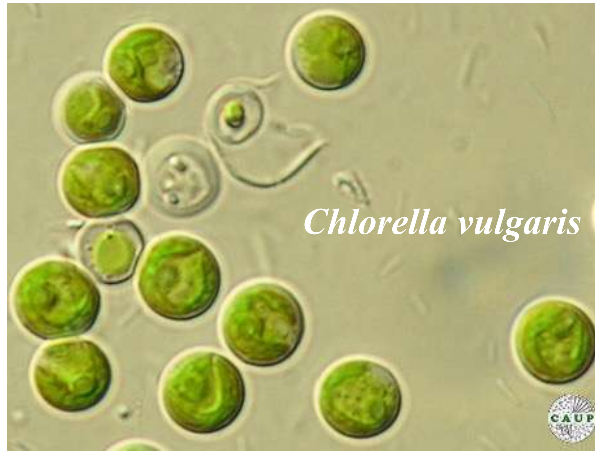
Leliaert et al. (2013)

As a food for humans, sea lettuce (*aosa*) is consumed raw, in salads, or cooked in soups. It is rich in proteins, soluble dietary fibre, vitamins and minerals (mainly iron).

- Mainly marine; some groups siphonous (ex. *Caulerpa*), mono- and digenetic cycles; ecological importance and invasive species.

Diversity of green algae and their uses: phylum *Chlorophyta*, class *Trebouxiophyceae*

Photobioreactors of *Chlorella*. Banco Español de Algas



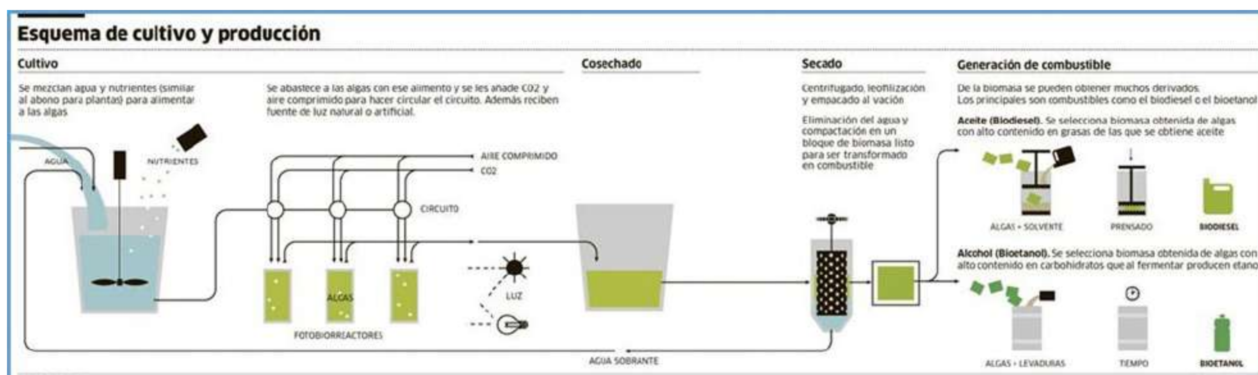
Spherical or ellipsoidal, 2-12 µm in diameter. Parietal chloroplast.

Yields (Gallons of oil per acre per year)

Corn	18
Soybeans	48
Safflower	83
Sunflower	102
Rapeseed	127
Oil Palm	635
Micro Algae	5000-15000

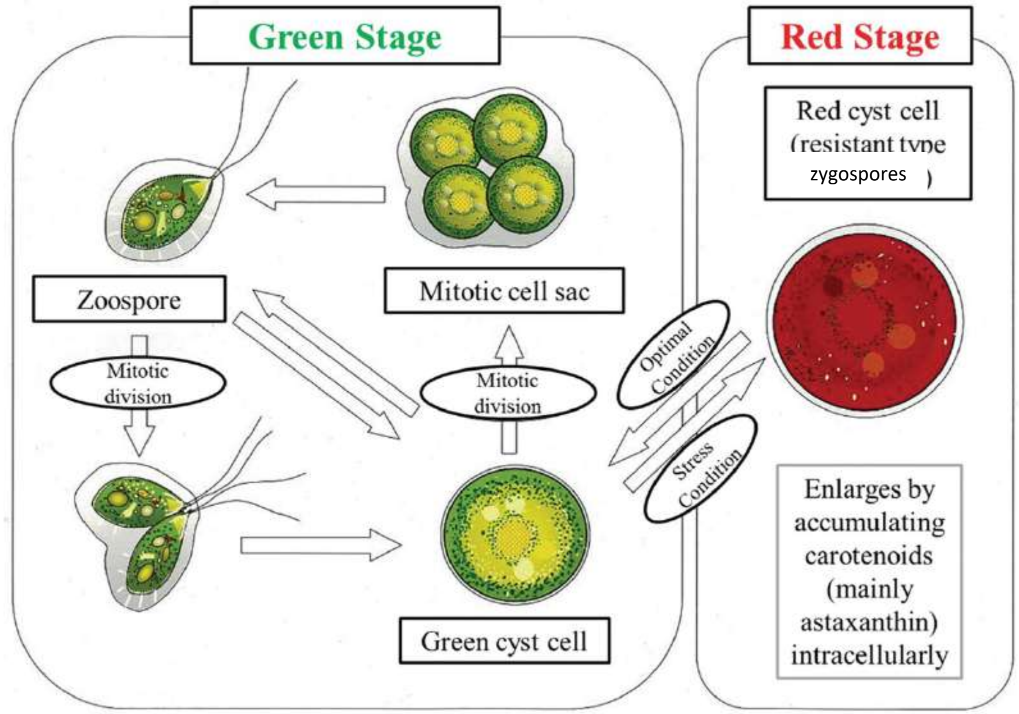
Wacker's photobioreactors. With a capacity of 1000 l, they produce 130 kg of seaweed in 200 days of production.

Biotechnological interest

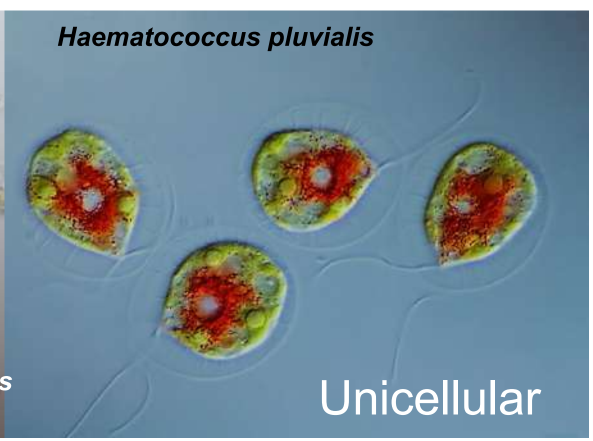


https://elodiebrans.wordpress.com/2013/09/04/biocombustibles-de-microalgas-ii/

Diversity of green algae and their uses: phylum *Chlorophyta*, class *Chlorophyceae*




Zygospores from *Haematococcus pluvialis* with astaxanthin

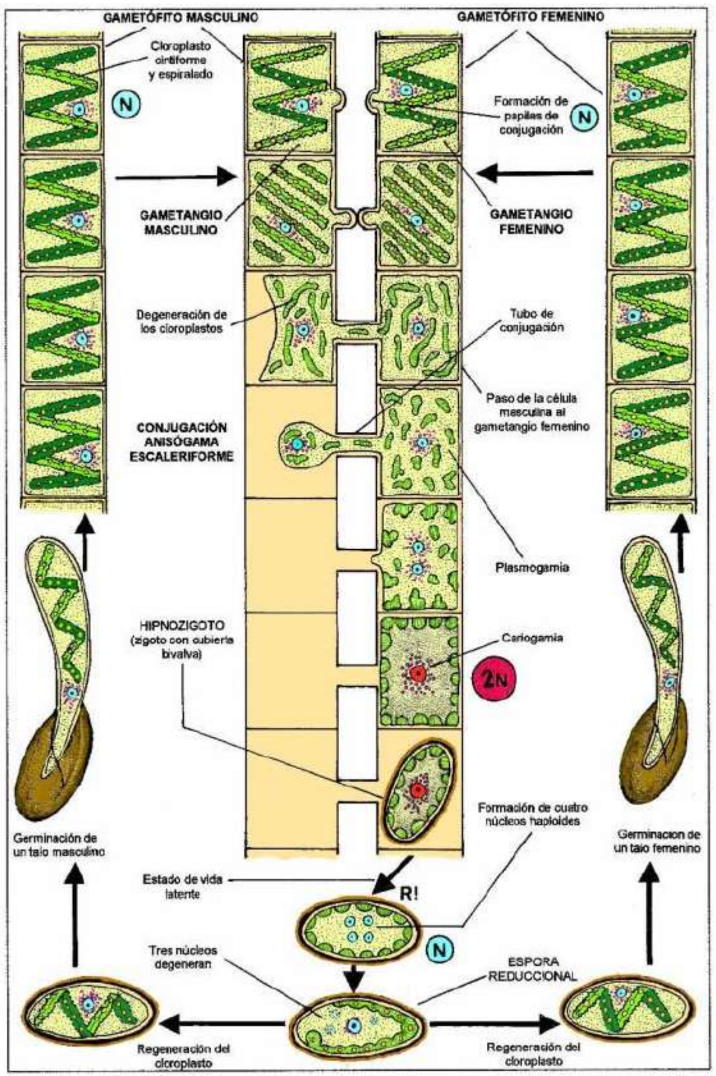

Haematococcus pluvialis

Unicellular

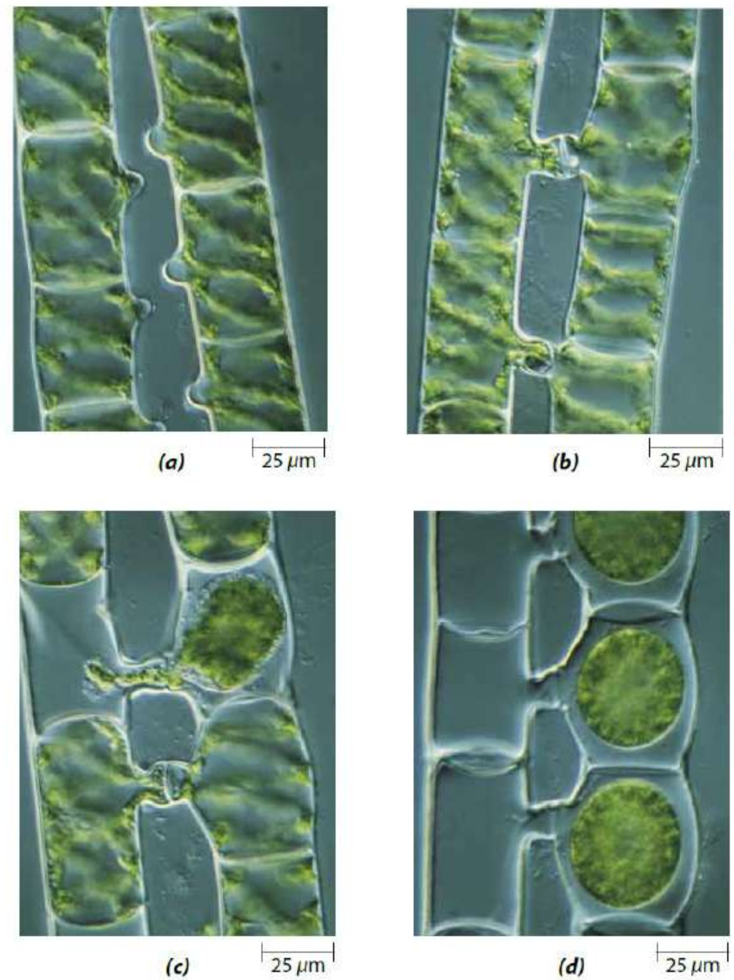
Diversity of green algae: phylum *Charophyta*, class *Zygnematophyceae* (“conjugates”)

Life cycle of *Spirogyra* (filamentous thalli)

Monogenetic haplo-diploid, with zygotic meiosis



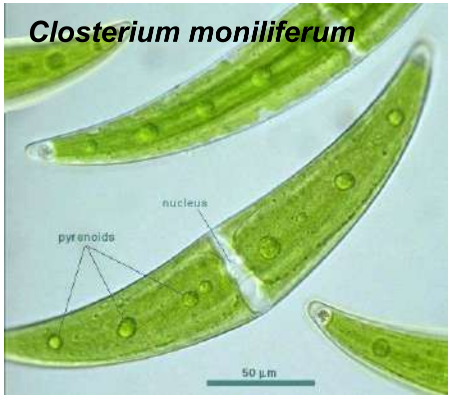
Díaz-González *et al*. (2004)



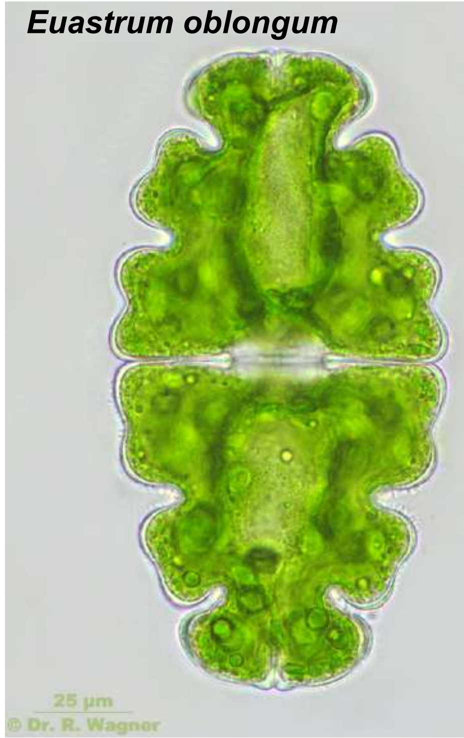
15–46 Sexual reproduction in *Spirogyra* ***(a), (b)*** The formation of conjugation tubes between the cells of adjacent filaments. ***(c)*** The contents of the cells of the – strain (on the left) pass through these tubes into the cells of the + strain. ***(d)*** Fertilization occurs within these cells. The resulting zygote develops a thick, resistant cell wall and is termed a zygospore. The vegetative filaments of *Spirogyra* are haploid, and meiosis occurs during germination of the zygospores, as it does in all Charophyceae.

Evert & Eichhorn (2013)

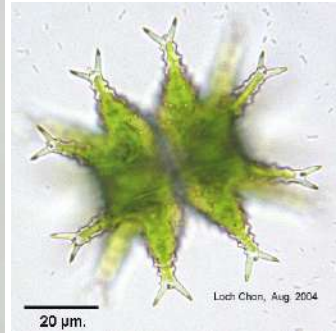
Phylum *Charophyta*: class *Zygnematophyceae*, order *Desmidiales*



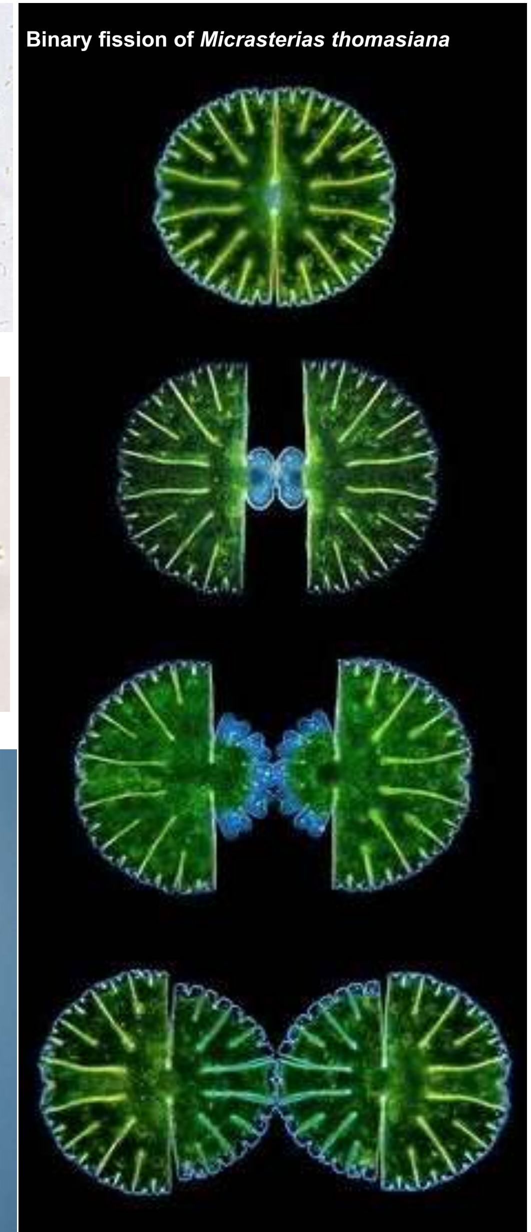
Closterium moniliferum



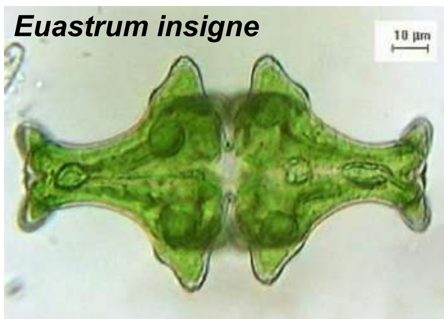
Euastrum oblongum



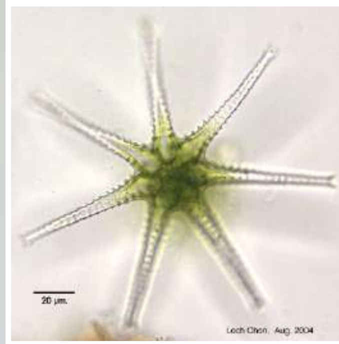
Staurastrum armigerum



Binary fission of *Micrasterias thomasiana*



Euastrum insigne



Staurastrum ophiura

Cosmarium nymannianum

Micrasterias furcata

***Micrasterias papillifera* zygote**

Phylum *Charophyta*: class *Charophyceae*, order *Charales* (charophyceans)

- Ancient group (fossils from the Silurian, 450 Mya.).
- Fresh and brackish water.
- This alga stands out for its greater morphological and reproductive complexity.
- Erect axes are organised in "**nodes**" and "**internodes**". **Siphonous** internodal cells are of remarkable size. **Cytoplasmic streaming**.

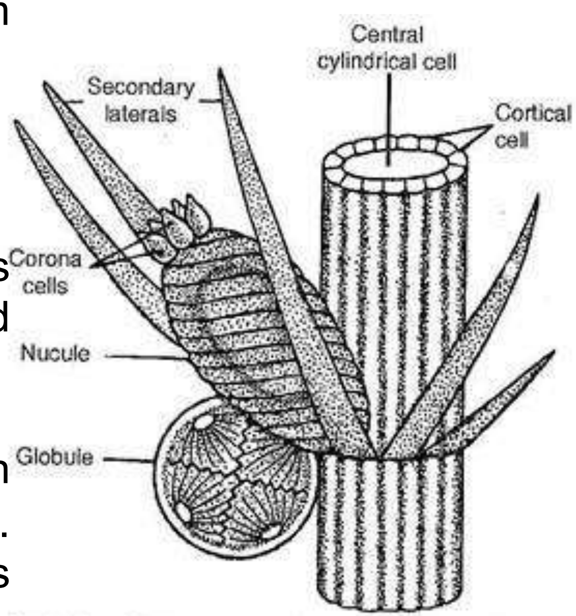
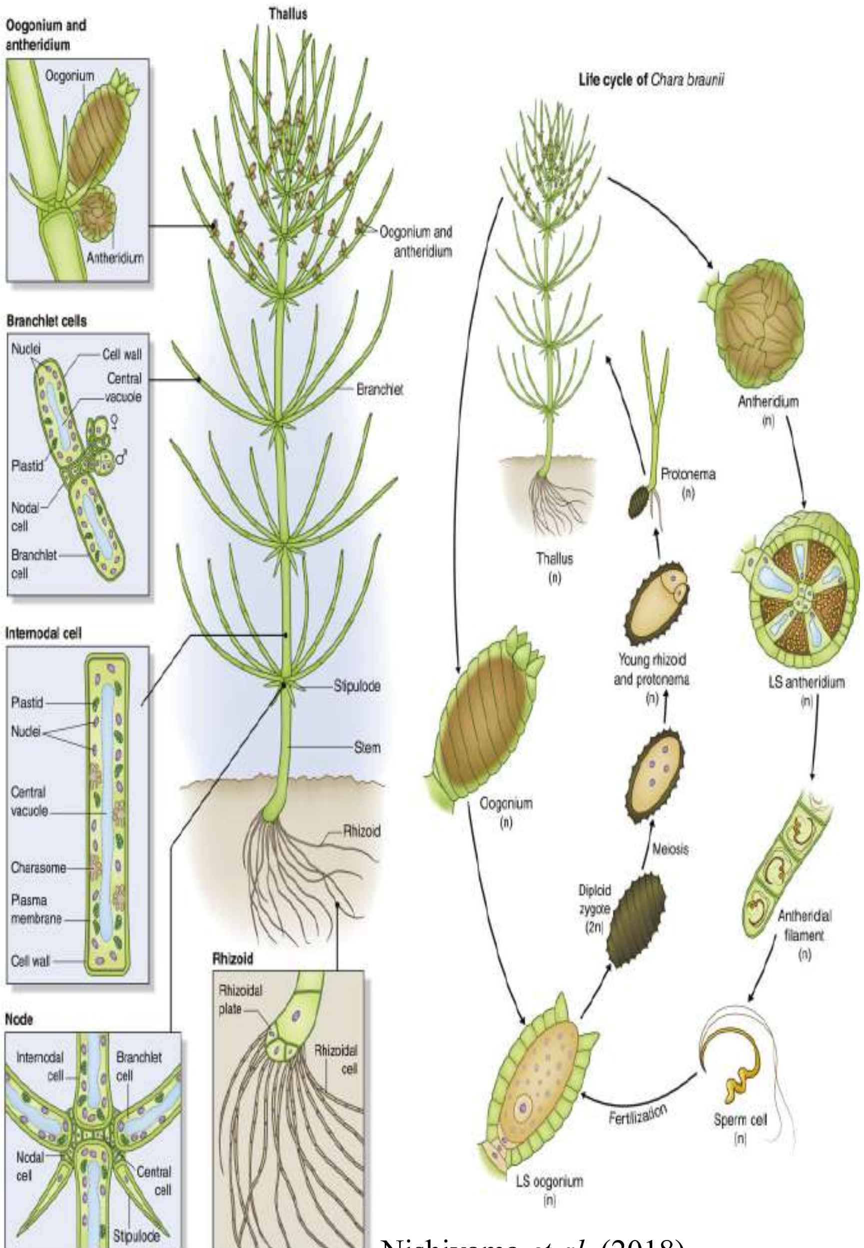


Fig. 3.94 : *Chara* sp. : A portion of the branch of limited growth showing attachment of nucule, globule and secondary laterals at the node

- **Monogenetic haploid** life cycle.
- **Nucules** (female gametangia or oogonia) with cortex.
- Specialised **globules** (male gametangia or anteridia). Biflagellate male gametes.
- Six genera: *Chara*, *Nitella*, *Tolypella*, *Lamprothamnium*, etc.

Phylum *Charophyta*: class *Charophyceae*, order *Charales* (charophytes)

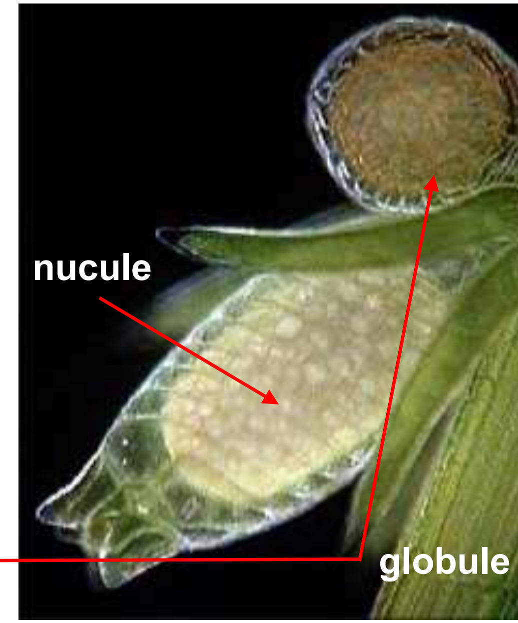


Nishiyama *et al*. (2018)

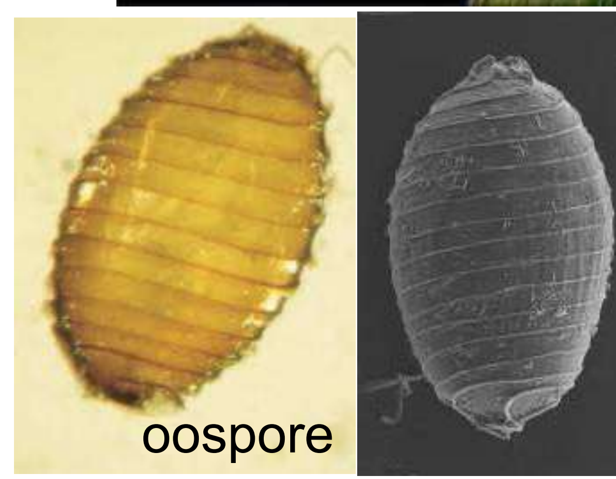
Life cycle of *Chara* sp.

Monogenetic haploid with zygotic meiosis

Nucules (oogonia) and globules (anteridia) with cortex.

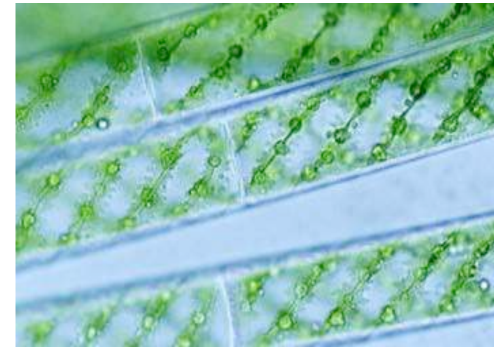


Resistant zygotes. Zygospores / oospores.

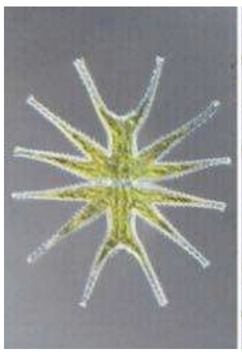


Homologies between charophytes (cl. *Charophyceae*) and land plants

-Chloroplasts (chlorophylls *a* and *b*, double membrane).
-Flagella with asymmetric roots.
-Cell wall: multi-layered structure with cellulose + pectin.
-Open mitosis, with a non-persistent nuclear membrane.
-Glycolate oxidase and catalase in peroxisomes.
-Cell division, cytokinesis, in some with cell plate and phragmoplast.
-DNA sequence similarities.



Spirogyra sp.

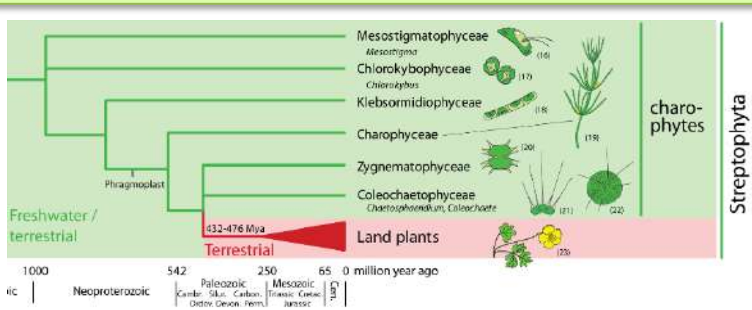


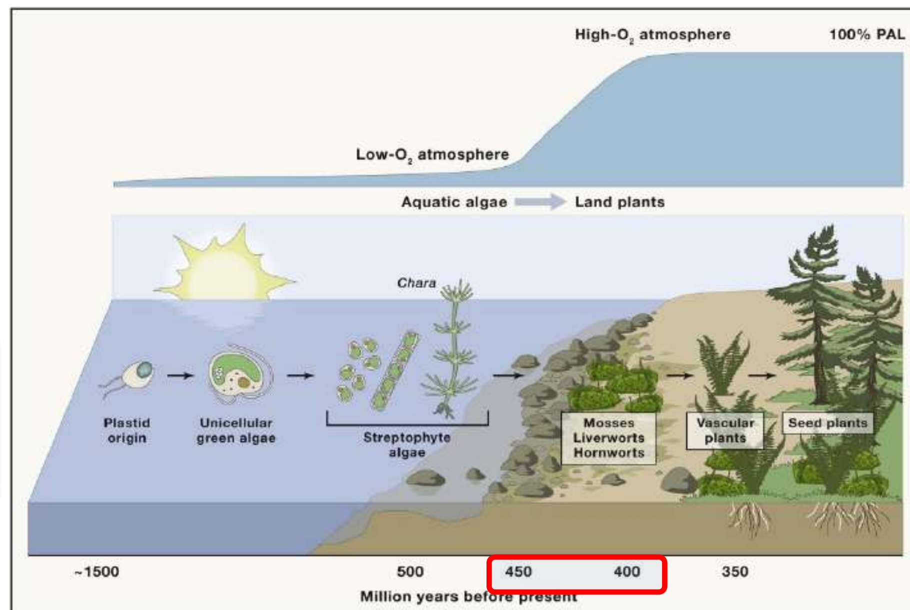
Micrasterias sp.

Coleochaete orbicularis

Chara sp.

The charophytes form a monophyletic clade with land plants, which indicates that they share a common ancestor.





Adapted from Martin & Allen (2018)







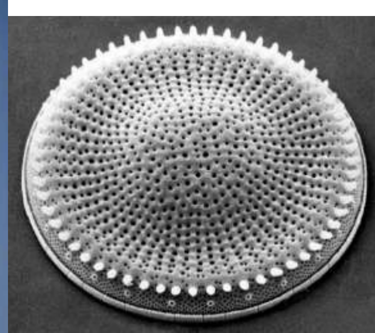
Lecture 06

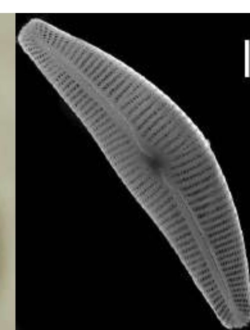
Algae II

Eukaryotic algae

(Bonus lecture)

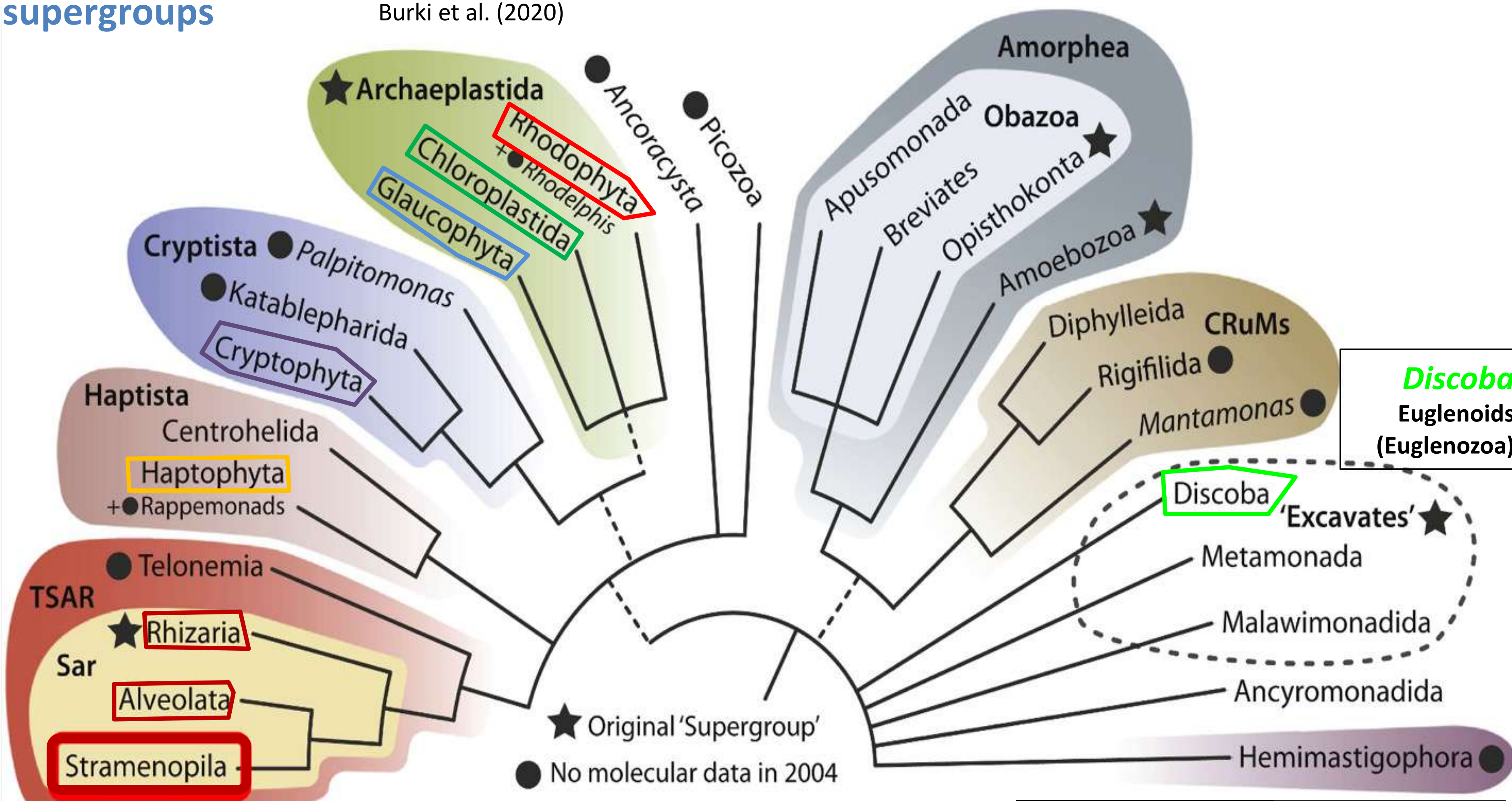






Eukaryotic “algae”: a heterogenous group of organisms integrated into different supergroups

Burki et al. (2020)



Discoba
Euglenoids
(Euglenozoa)

Stramenopila
Diatoms
Xanthophyceans
Phaeophyceans (brown algae)

Alveolata
Dinoflagellates

Rhizaria
Cercozoans
Chlorarachniophytes

Haptophyta
Haptophytes

Cryptophyta
Cryptophytes

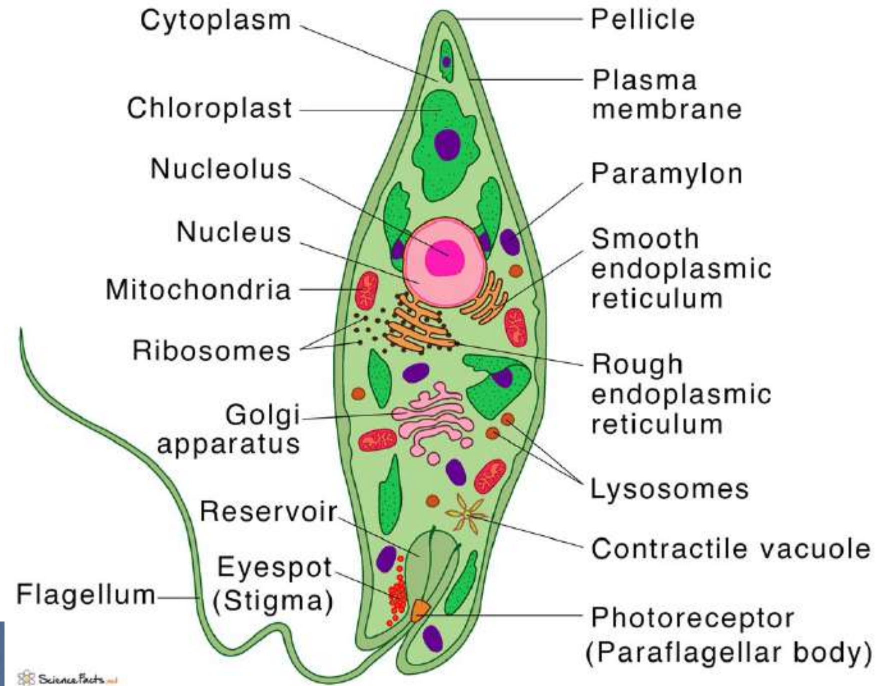
Glaucophyta
Glaucophytes

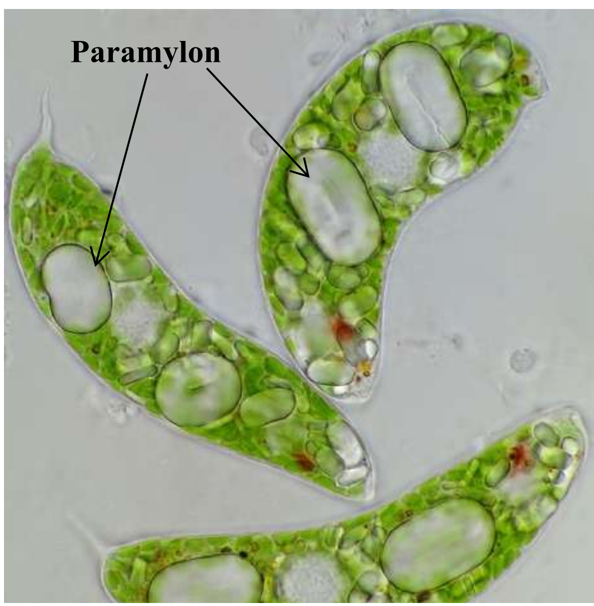
Rhodophyta
Rhodophytes or red algae

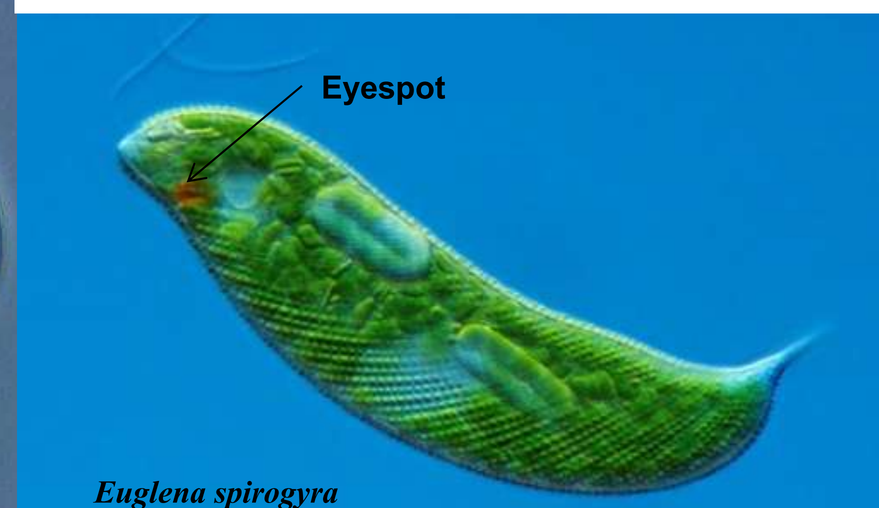
Chloroplastida **(green algae)**
Chlorophytes
Charophytes

Supergroup *Excavata, Discoba*, phylum *Euglenophyta* (euglenoids)

- **Unicellular:** with or without chloroplasts.
- **Photosynthetic apparatus**: chloroplasts with three membranes (secondary endosymbiosis).
- **Photosynthetic pigments**: chlorophylls *a* and *b*, and carotenoids.
- **Pyrenoids** are present.
- Storage material: cytoplasmic **paramylon**.
- Habitat: mostly freshwater.



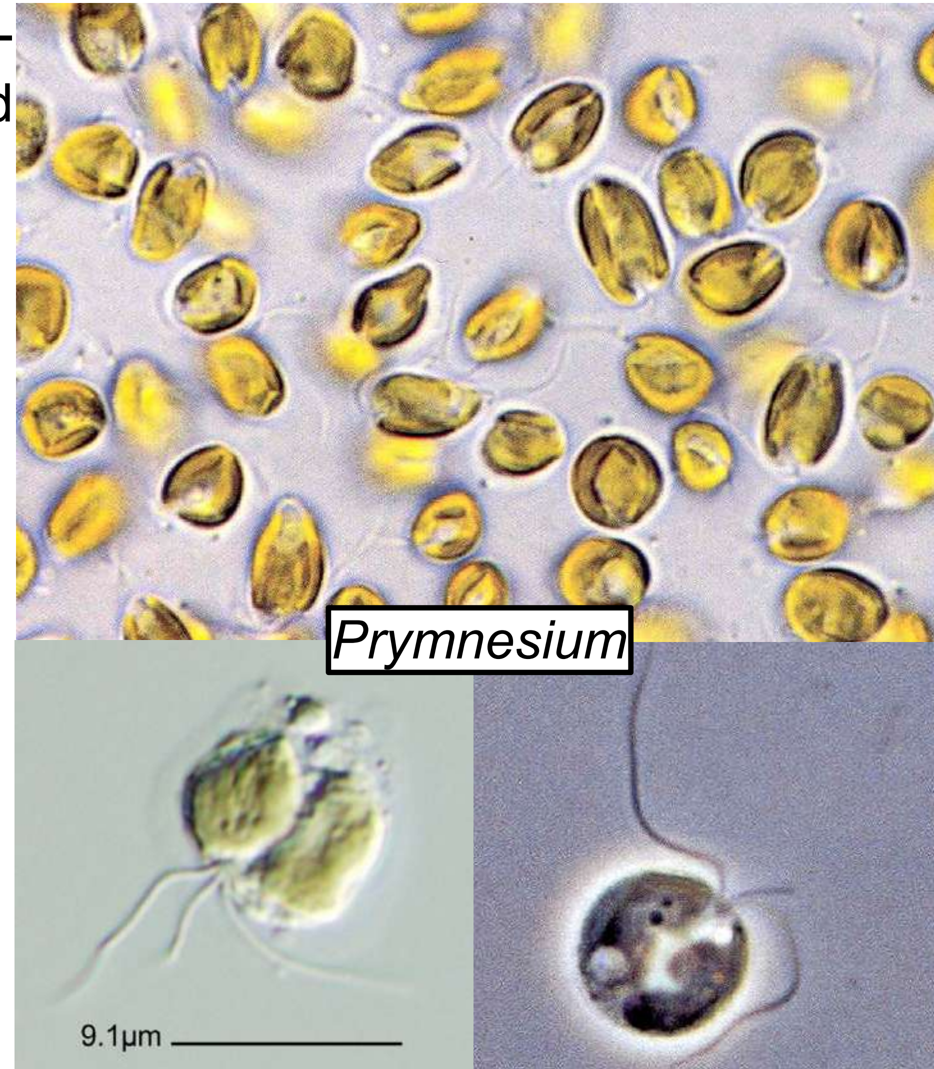




Group *Haptista* (or Hacrobia), phylum *Haptophyta* (haptophytes and coccolithophores)

- Unicellular, flagellate or non-flagellate. Found in tropical and subtropical oceans.
- Some species are involved in **toxic *blooms*** (*Chrysochromulina*,

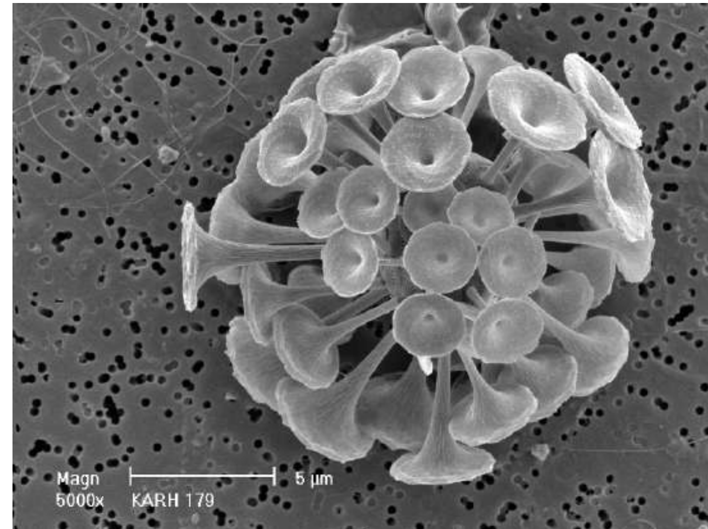
Emiliania huxleyi (coccolithophore)



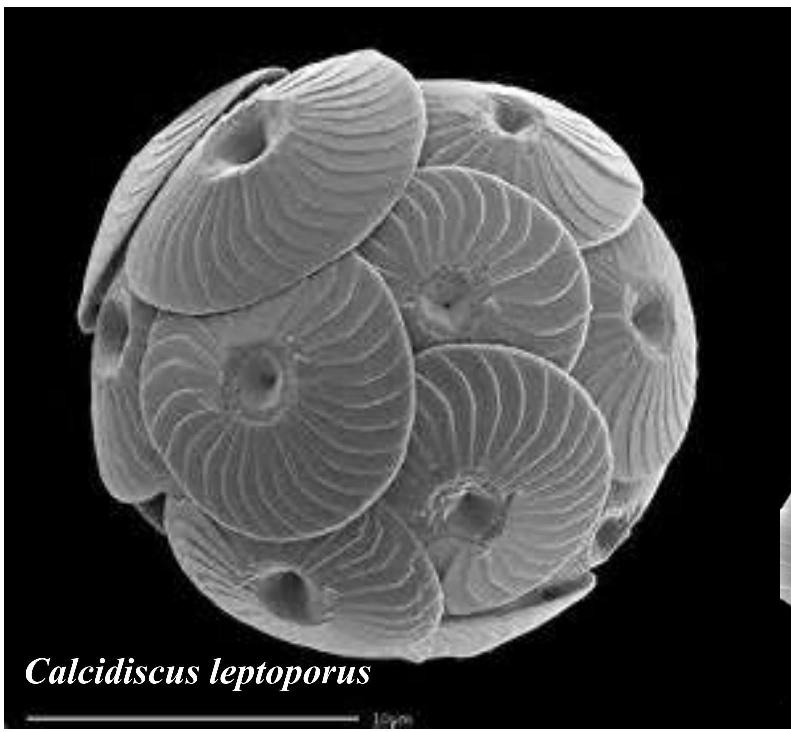
They have a cellular covering of cellulose scales.
In coccolithophorids, the scales are calcified and called coccoliths; the whole is called a coccosphere.

Group *Haptista* (or Hacrobia), phylum *Haptophyta* (haptophytes and coccolithophores)

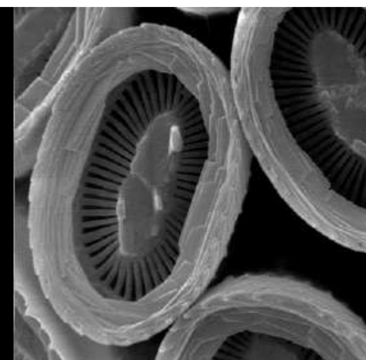
Coccoliths can be simple or complex. They form elaborate covers and are important for systematics (species identification).

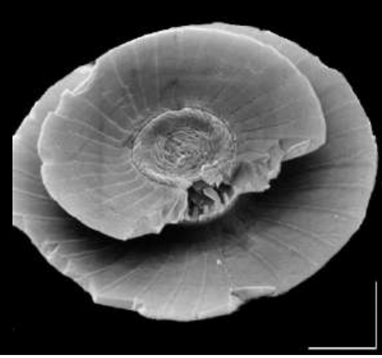


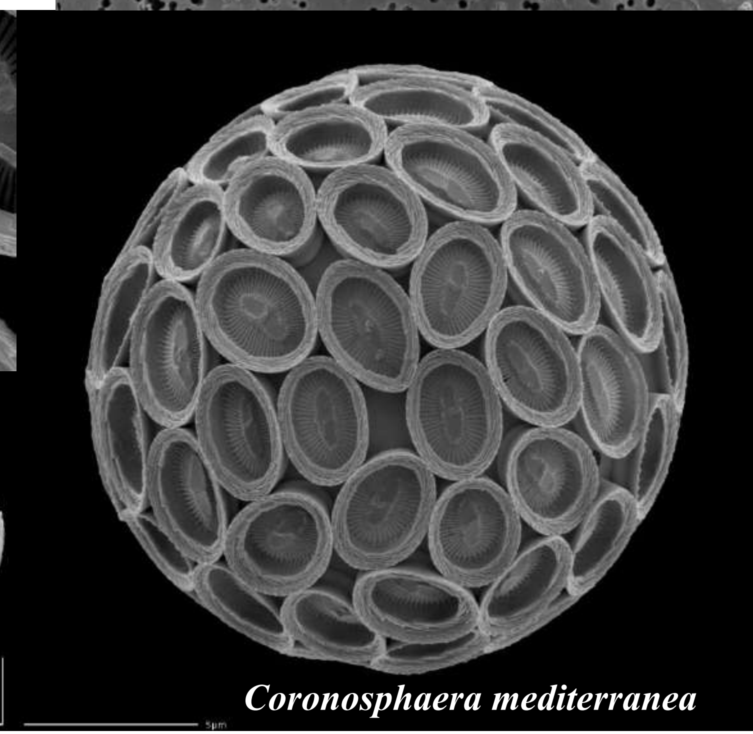
Stratigraphic value



Calcidiscus leptoporus

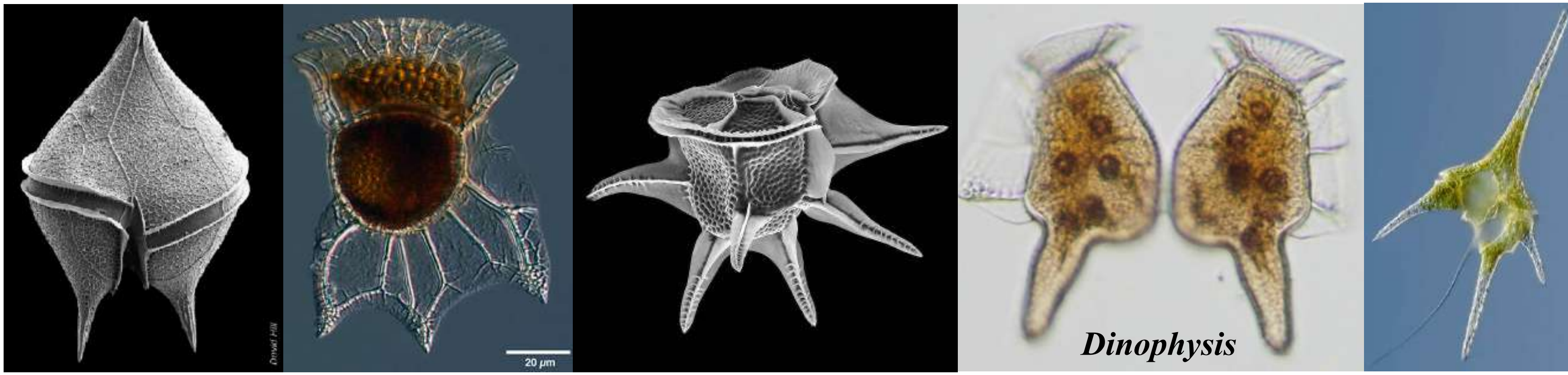






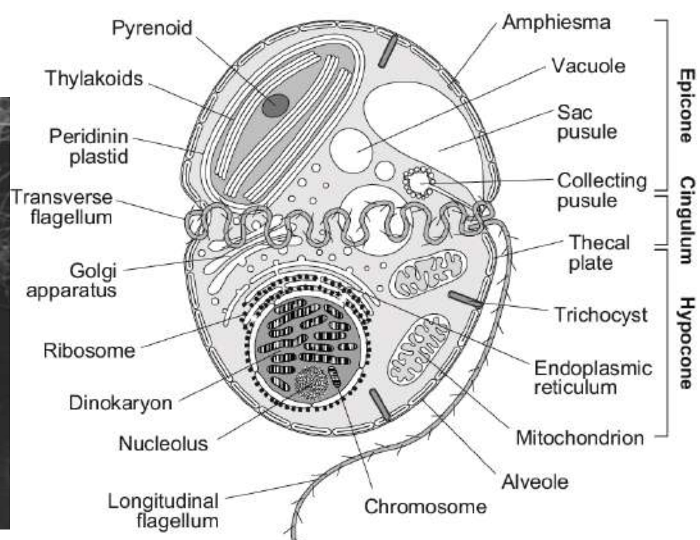
Coronosphaera mediterranea

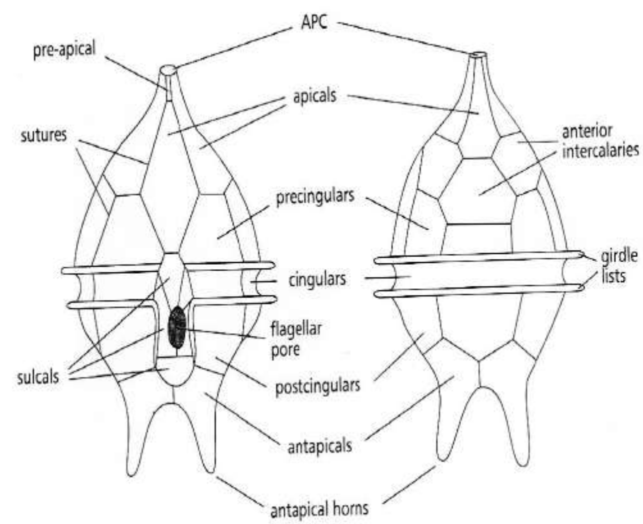
Group SAR, phylum *Dinophyta* (Dinoflagellates)



- **Unicellular** and flagellate.
- 50% of the species are obligate **heterotrophs**. Others are **photosynthetic**.
- Flagellar apparatus: **two flagella** (one longitudinal flagella projecting outside the cell and one transverse, wavy/helicoidally arranged). **Cingulum** and **sulcus**.
- Thecal plates made of **cellulose**.

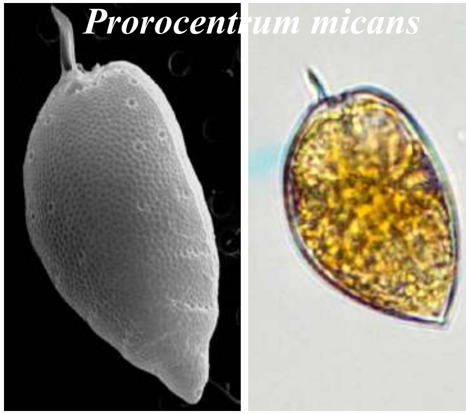
- Golden brown plastids with **three membranes** and thylakoids in groups of three.
- Photosynthetic pigments: **chlorophylls *a*** and ***c***, and xanthophylls (**peridinin**).
- Reserve substance: **cytoplasmic starch**.



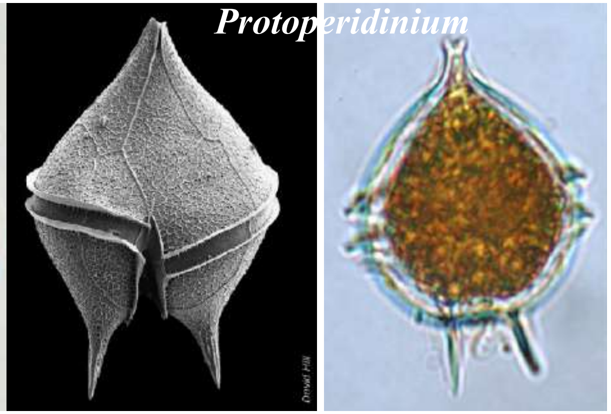


Group SAR, phylum *Dinophyta* (Dinoflagellates)

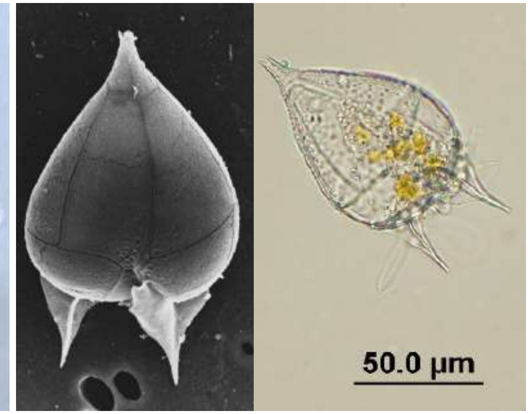
Prorocentrum micans



Protoperidinium

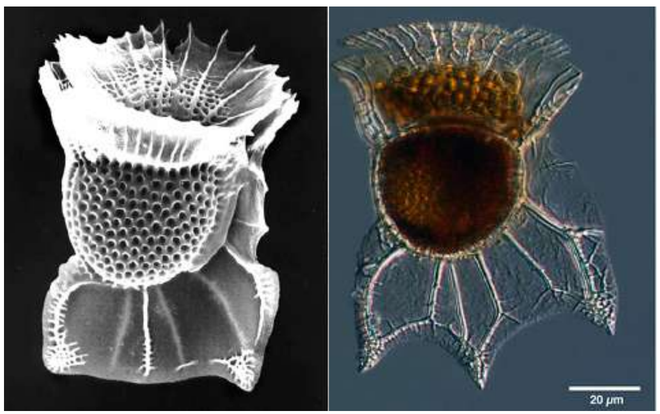


Podolampas

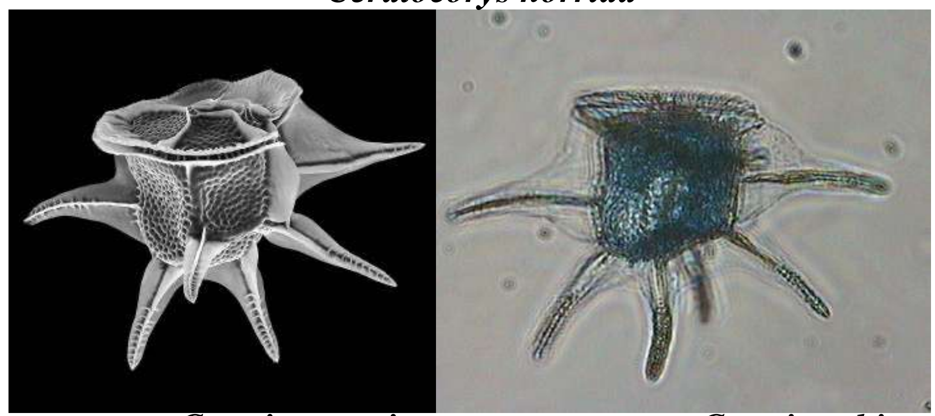


Ceratium fusus

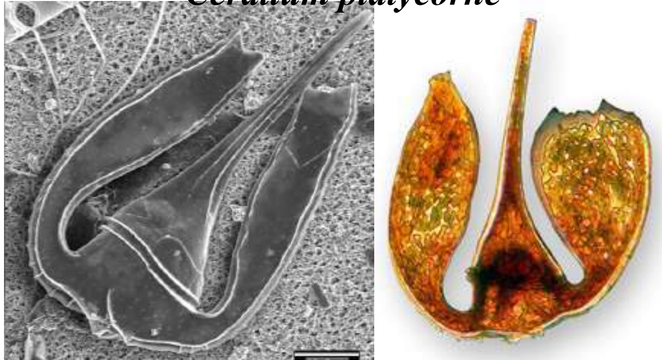
Ornithocercus



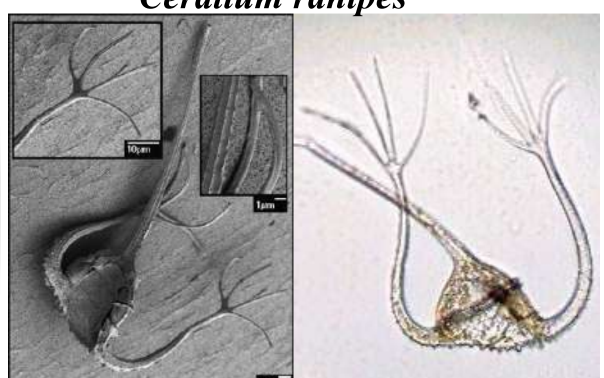
Ceratocorys horrida



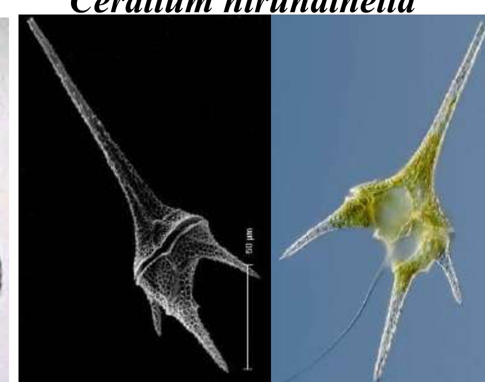
Ceratium platycorne



Ceratium ranipes

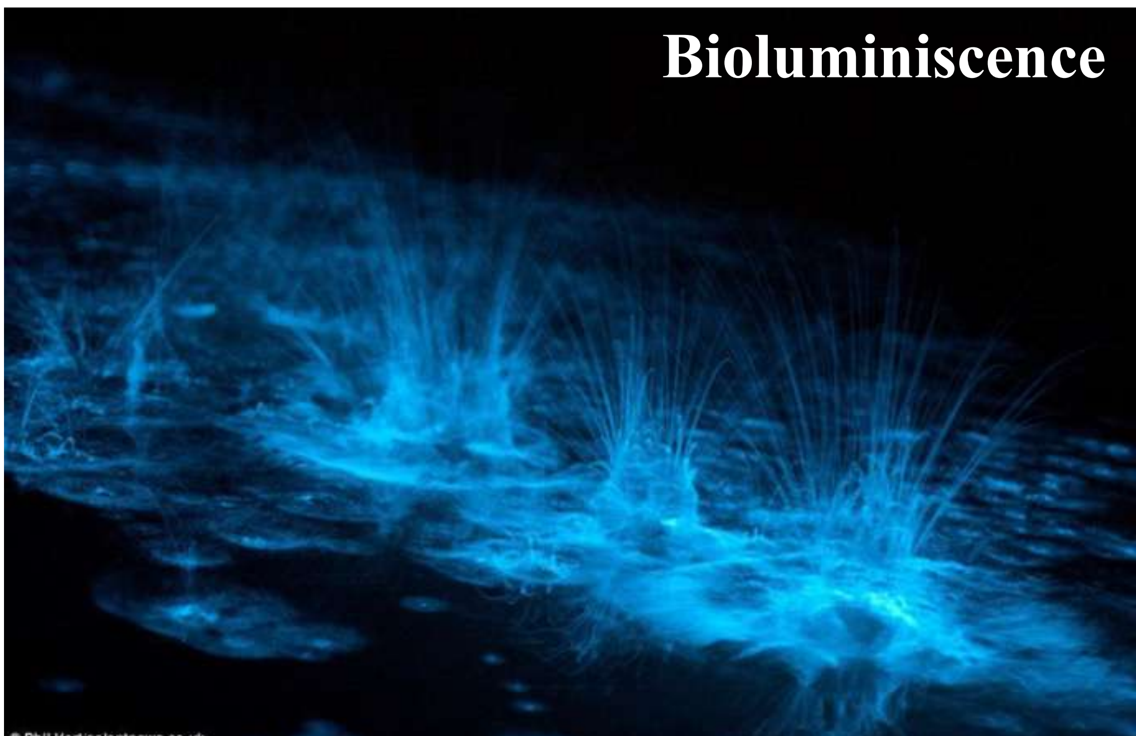


Ceratium hirundinella

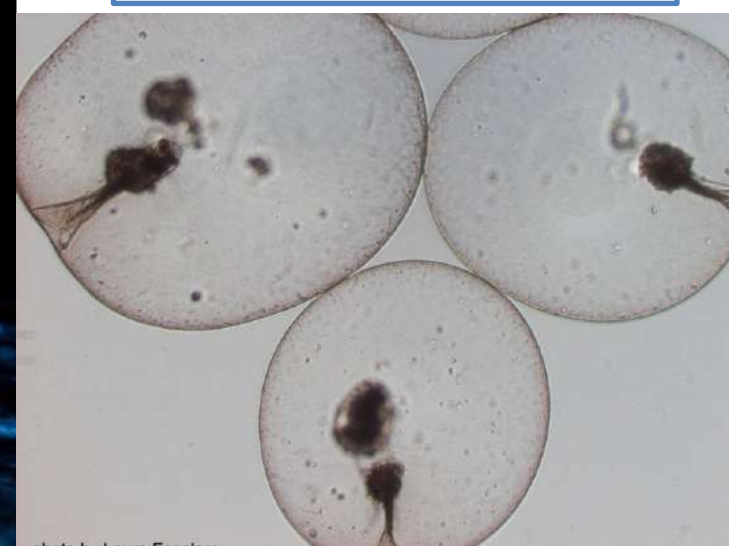


Group SAR, phylum *Dinophyta* (dinoflagellates)

- Ancient group with about 2,000 extant marine and freshwater species.
- Wide distribution; in oceans most species are planktonic, while some are benthic and others symbiotic.
- They are usual constituents of the deep chlorophyll maximum, which is located between 75-150 m.
- Bioluminiscence in some species (e.g. *Noctiluca scintillans*).

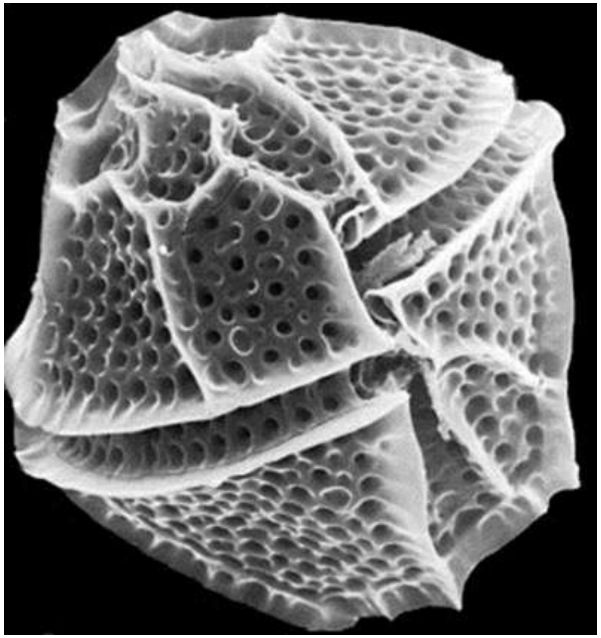


Noctiluca scintillans

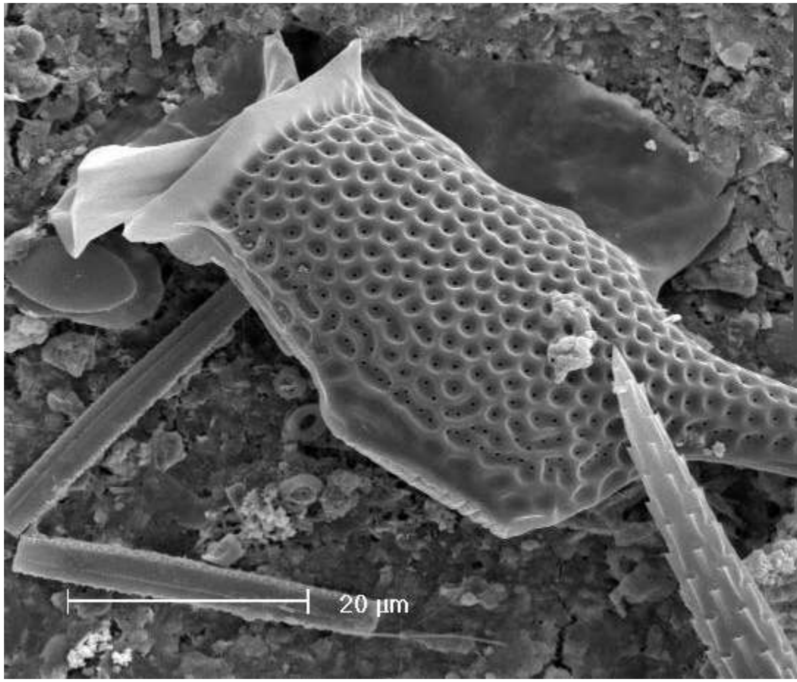


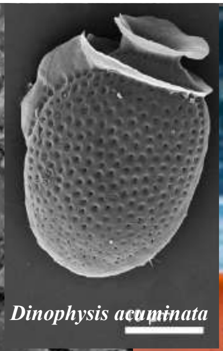
Group SAR, phylum *Dinophyta* (dinoflagellates)

- **Red tides** (roughly 60 spp. involved) under conditions of stability and nutrient abundance. These species produce **hepatotoxis** and **neurotoxic** substances.
- Toxic species (*Gymnodinium*, *Gonyaulax*, *Dinophysis*, *Prorocentrum*). **PSP**, **DSP** and **ciguatera**. Effects: neurotoxic, paralytic, diarrheic, amnesic.



Gonyaulax



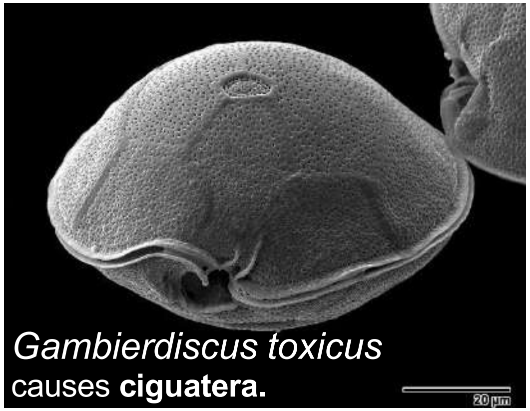


Group SAR, phylum *Dinophyta* (dinoflagellates)

Table 1. Seafood poisonings caused by neurotoxins identified from marine dinoflagellate species.

Type of poisoning	Toxins	Sources of toxins	Primary vector	Action target	Ref.
PSP	Saxitoxins and gonyautoxins	*Alexandrium* spp., *Gymnodinium* spp., *Pyrodinium* spp.	Shellfish	Voltage-gated sodium channel 1	23, 27-29
NSP	Brevetoxins	*Kerenia brevis, Chatonella marina, C. antiqua, Fibrocapsa japonica, Heterosigma akashiwo*	Shellfish	Voltage-gated sodium channel 5	33, 39-41, 46, 52
	Yessotoxins	*Protoceratium reticulatum, Lingulodinium polyedrum Gonyaulax spinifera*	Shellfish	Voltage-gated calcium/sodium channel?	94-95
CFP	Ciguatoxins	*Gambierdiscus toxicus*	Coral reef fish	Voltage-gated sodium channel 5	55, 62, 63
CFP	Maitotoxins	*Gambierdiscus toxicus*	Coral reef fish	Voltage-gated calcium channel	69, 70
AZP	Azaspiracids	*Protoperidinium crassipes*	Shellfish	Voltage-gated calcium channel	72, 76
Palytoxin poisoning	Palytoxins	*Ostrepsis siamensis*	Shellfish	Na^+-K^+ ATPase	97, 109-111

Notes: PSP, paralytic shellfish poisoning; NSP, neurotoxic shellfish poisoning; CFP, ciguatera fish poisoning, AZP, azaspiracid poisoning. Wang (2008)

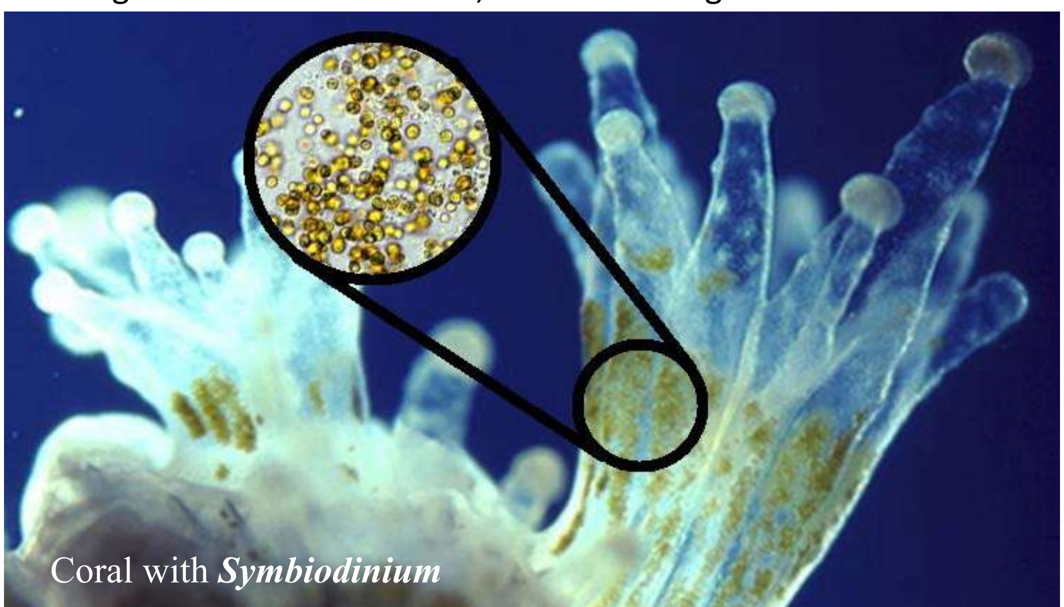


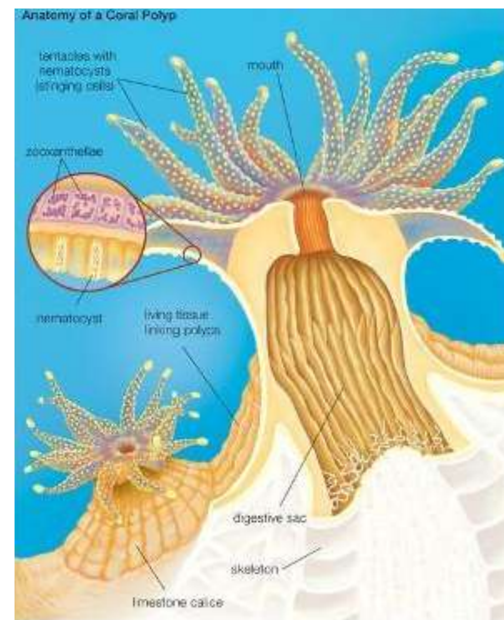
Gambierdiscus toxicus causes **ciguatera.**

Group SAR, phylum *Dinophyta* (dinoflagellates)

Most reef-building corals contain photosynthetic dinoflagellates called **zooxanthellae** (e.g. *Symbiodinium microadriaticum*) that live in their tissues. Corals and algae have a **symbiotic mutualistic relationship**. Corals provide algae with a protected environment and the compounds they need for photosynthesis. In return, algae produce oxygen and help corals to remove wastes. Most importantly, zooxanthellae supply corals with glucose, glycerol and amino acids, which are the products of photosynthesis. Corals use these products to make proteins, fats and carbohydrates and to produce calcium carbonate. The relationship between the algae and coral polyp facilitates a tight recycling of nutrients in nutrient-poor tropical waters. Indeed, as much as 90 percent of the organic material photosynthetically produced by the zooxanthellae is transferred to the host coral tissue. <u>This is the driving force behind the growth and productivity of coral reefs</u>.

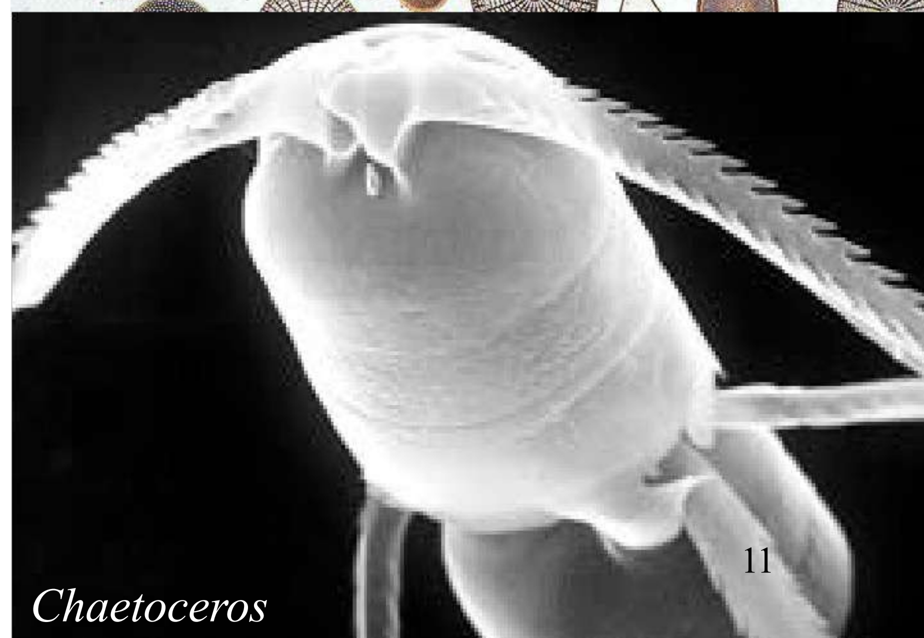
As well as providing corals with essential nutrients, **zooxanthellae are responsible for the unique and beautiful colours of many stony corals.** Sometimes when corals become **physically stressed**, the polyps expel their algal cells and the colony takes on a stark white appearance. This is commonly described as “**coral bleaching**”. If the polyps go too long without zooxanthellae, coral bleaching can result in the coral's death.


Coral with ***Symbiodinium***



Group SAR, Stramenopila, phylum *Ochrophyta*, class *Bacillariophyceae* (diatoms)

- This widely diversified group (250 genera, 100,000 spp.) has enjoyed great evolutionary success.
- They are present in oceans, freshwater, soils, wet rocks, etc.
- In freshwaters they are an essential component of the aquatic microflora. In oceans, they are a key component of the phytoplankton of cold and nutrient-rich waters.
- Marine diatoms account for 20-25% of the total production of the biosphere (1.4×10^{14} kg dry-weight/year).

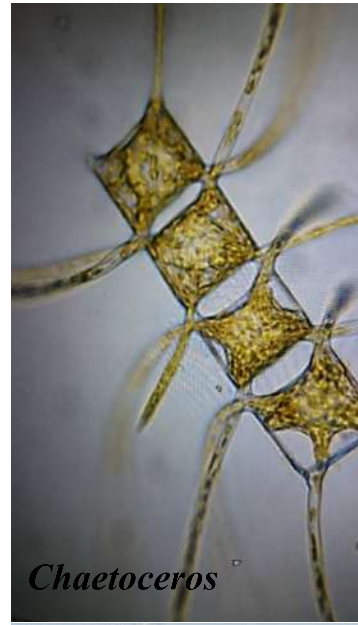


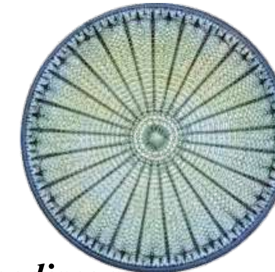
Chaetoceros

Group SAR, Stramenopila, phylum *Ochrophyta*, class *Bacillariophyceae* (diatoms)

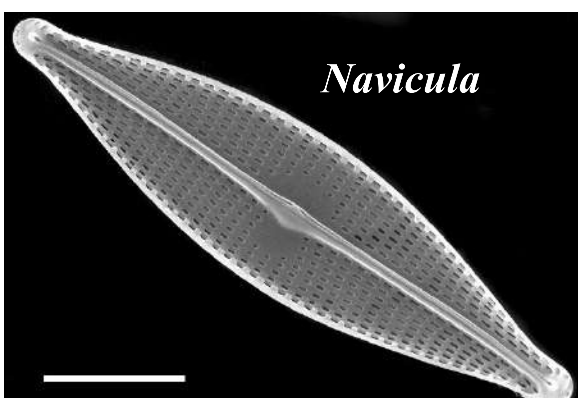
Morphological types:

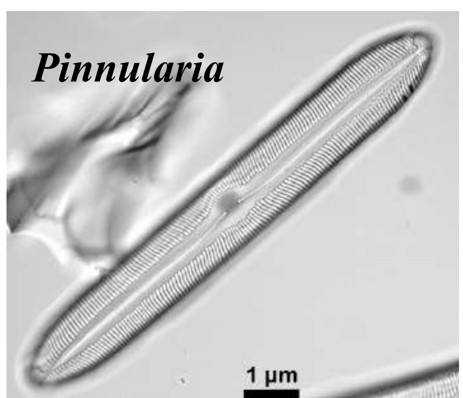
- **Centric**: often circular. Radial symmetry.
- **Pennate**: lanceolate or elliptical. Bilateral symmetry. With or without raphe.



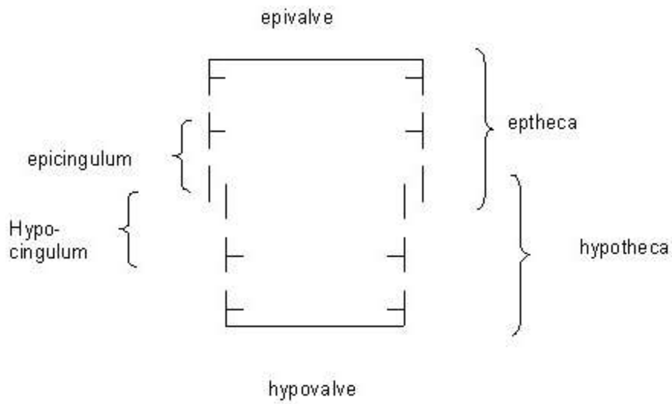


Stephanodiscus

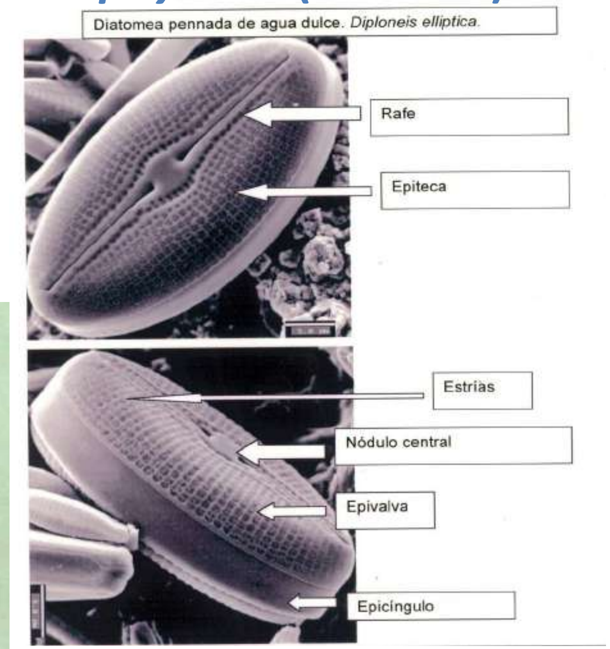


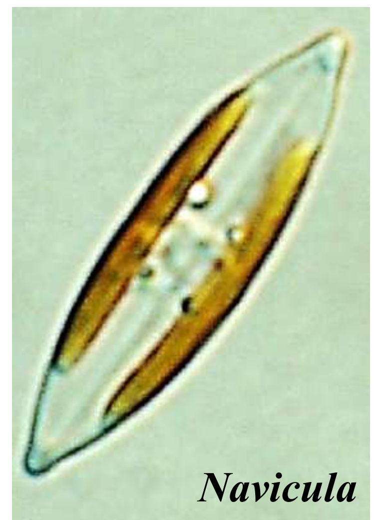


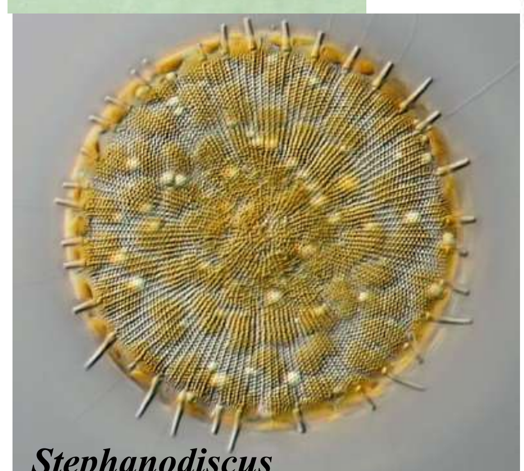
Group SAR, Stramenopila, phylum *Ochrophyta*, class *Bacillariophyceae* (diatoms)

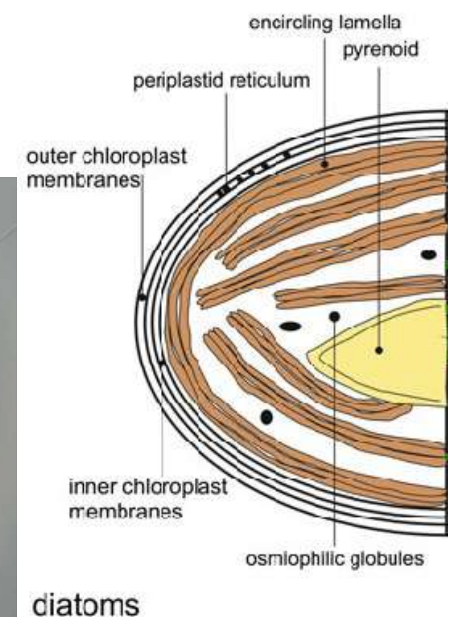


- The two-part **cell** of a diatom, called **frustule**, is made up of polymerised, opaline **silica** ($SiO_2 \bullet nH2O$) and consists of overlapping halves.
- **Chloroplasts**: there are two parietal chloroplasts in pennate diatoms and more than two in centric diatoms.
- Photosynthetic pigments: **chlorophylls *a*** and ***c***, and **fucoxanthin**.
- Storage material: **chrysolaminarin** and lipids.



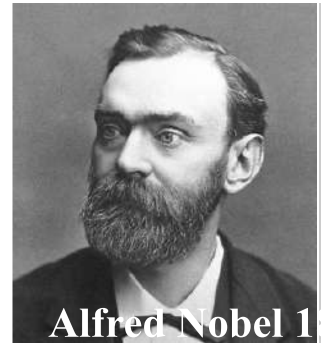

Navicula


Stephanodiscus



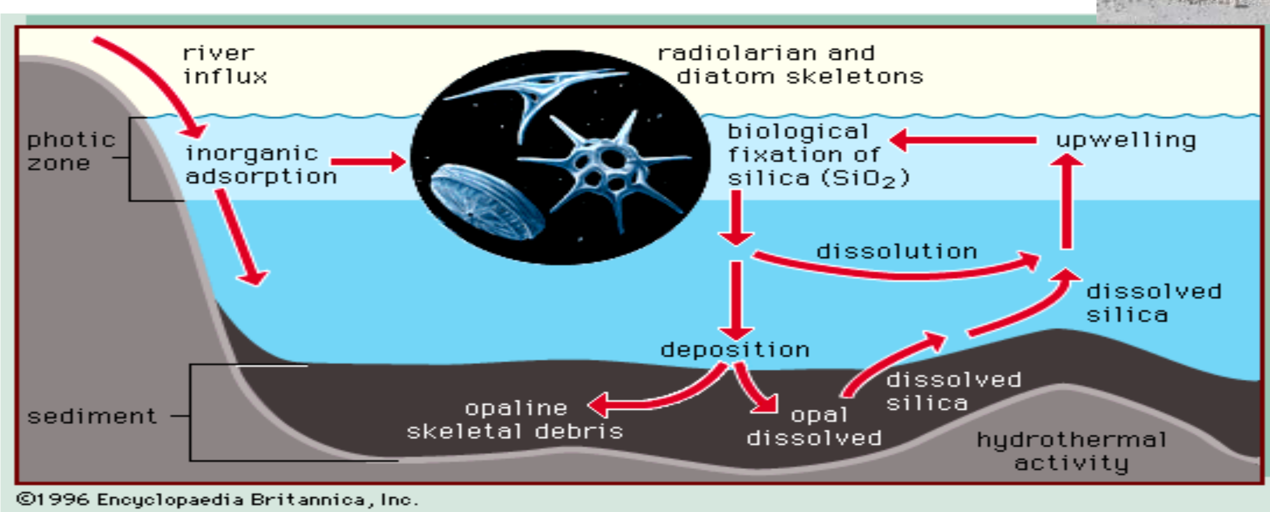
Group SAR, Stramenopila, phylum *Ochrophyta*, class *Bacillariophyceae* (diatoms)

- These are abundant in oceanic areas characterised by *upwellings*.

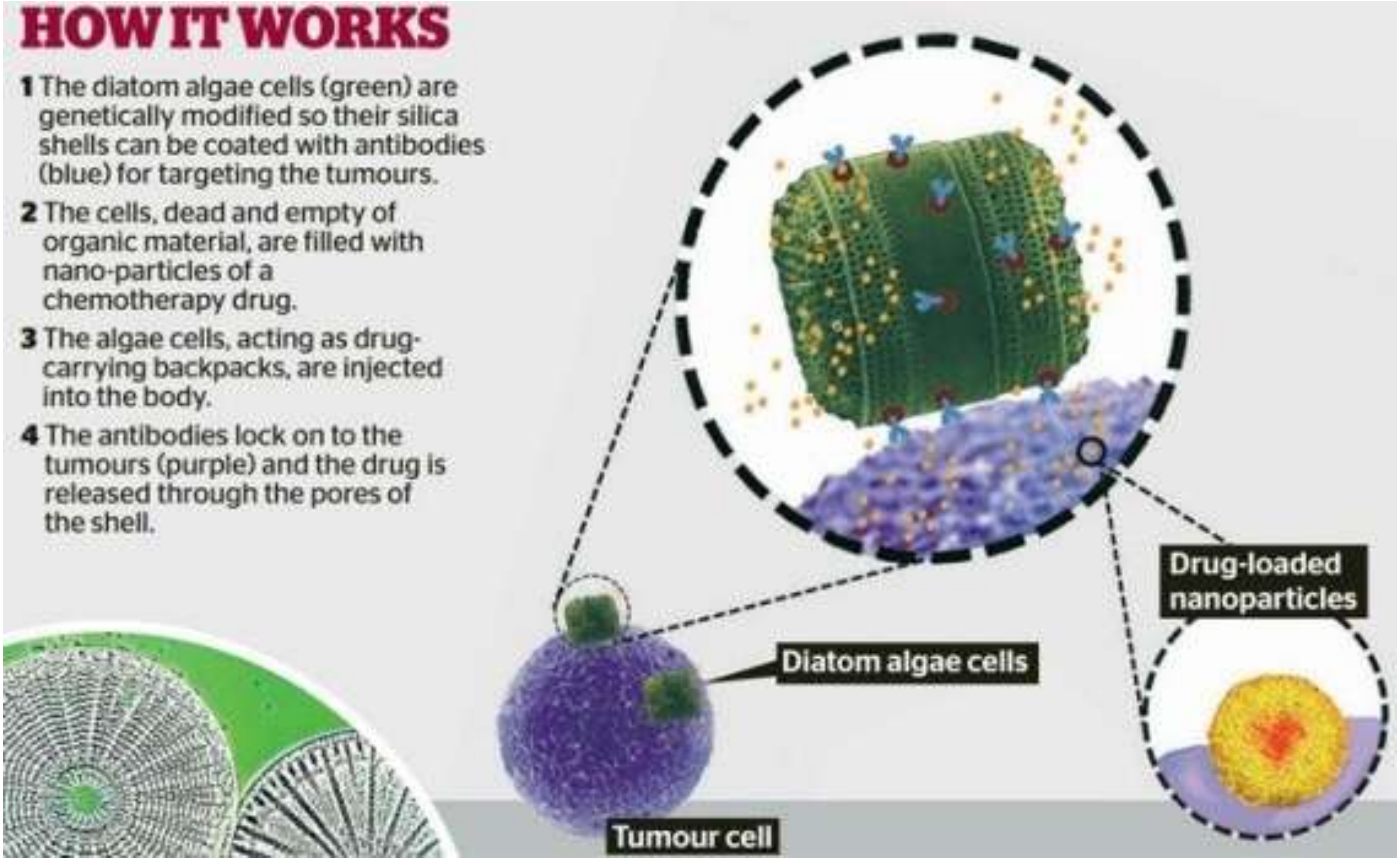


Applications:

- Diatomaceous earth.
- Bioindicator of freshwater quality: development of biological indexes.
- Cosmetics, pharmaceuticals, medicines, etc.



Group SAR, Stramenopila, phylum *Ochrophyta*, class *Bacillariophyceae* (diatoms)



https://i0.wp.com/news.algaeworld.org/wp-content/uploads/2016/07/diatom-kill-cancer-1.jpg

Lecture 07part 1
The colonisation of land by plants
(Bonus lecture)

Main topics

Adaptation of plant to land	Bryophytes and cormophytes	Reproductive structures and the embryo
Isospory and heterospory	Groups and diversity of embryophytes	

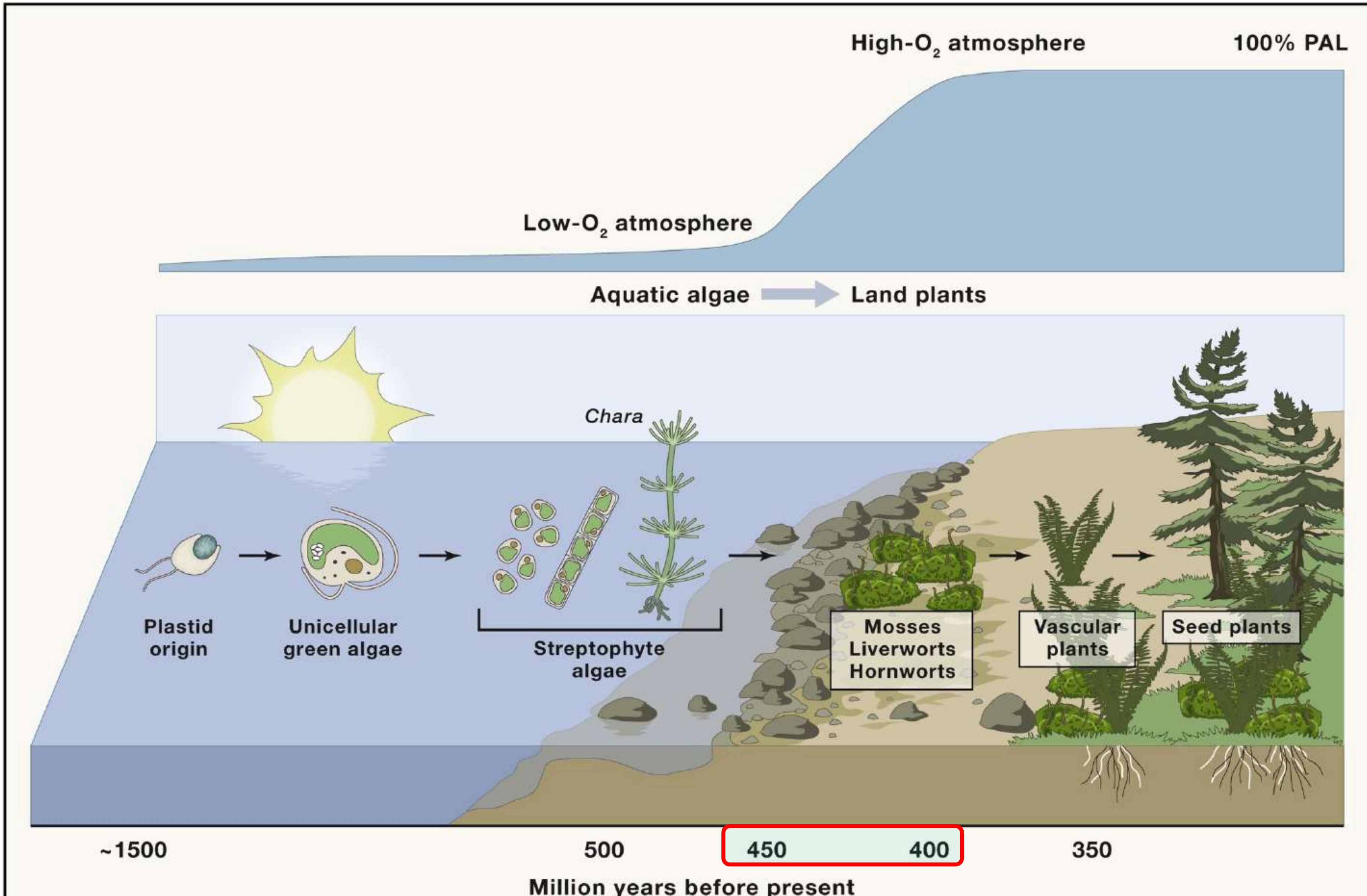
Land colonisation and adaptation

- Just over 400 million years ago, the formation of the **ozonosphere**, a protective layer against high-energy rays from the sun, was completed.

- **UV radiation is highly mutagenic: it can cause severe damage to DNA, leading to DNA strand deformations that prevent normal DNA function and render organisms unviable.**

- Once plants were protected from UV radiation and supported by a greater amount of light energy, they were able to begin the process of colonising the terrestrial environment.

Land plants contributed to atmospheric oxygenation



Adapted from Martin & Allen (2018)

The abiotic features of the aquatic and terrestrial environments are different

Over 400 million years ago, plants colonised the terrestrial environment. This development was enabled by the emergence of a wide range of structural and physiological characteristics that allowed them to live in the new conditions.

Aquatic environment

- Stable – constant humidity and slow variation in temperature.
- Dense.
- Low light.
- Nutrients.

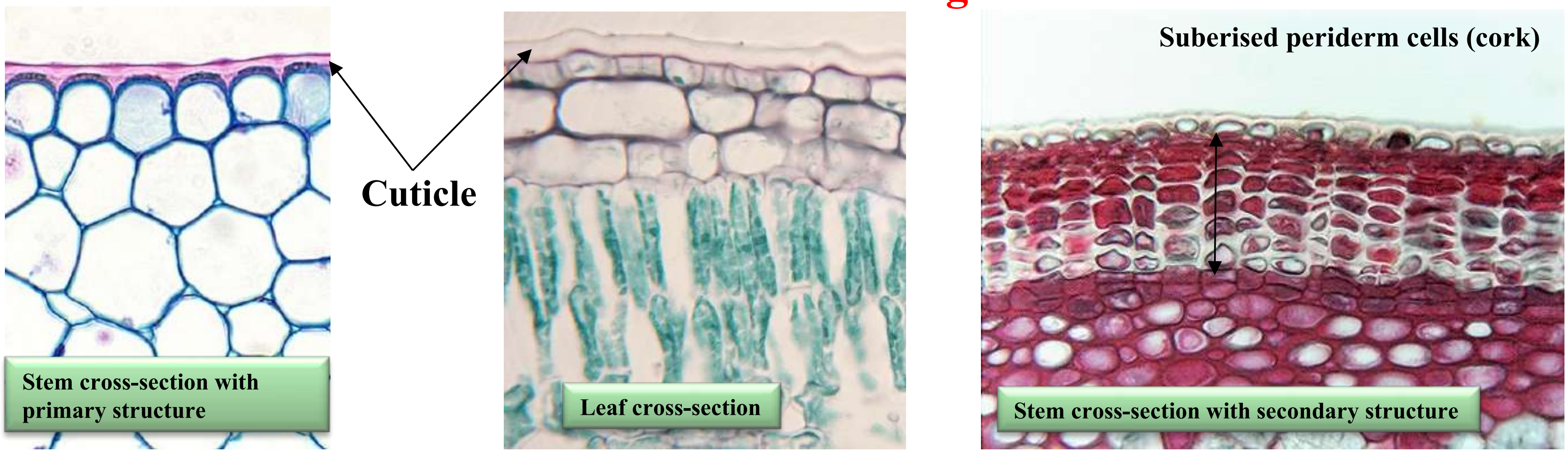
Terrestrial environment

- Sudden and prolonged variations in humidity; sudden variations in temperature.
- Not very dense.
- More light.
- Nutrients in soil.

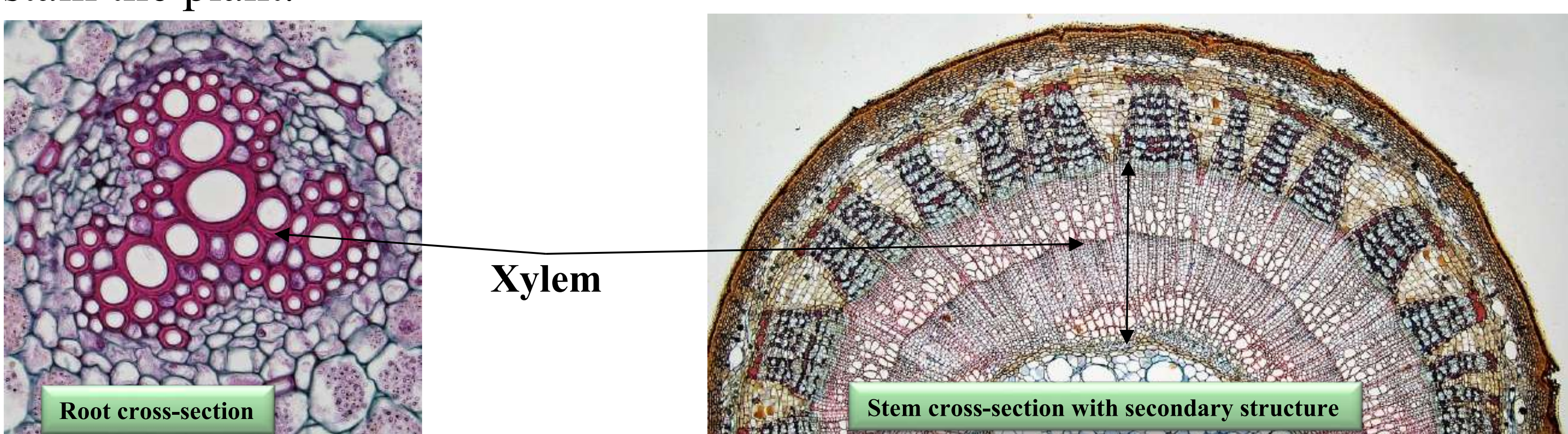
Synthesis of new compounds and development of specialised tissues

The terrestrial environment is more demanding and extreme than the aquatic environment. The response of some organisms involved the synthesis of new compounds in their cell walls and greater specialisation of their cells to form **TISSUES**.

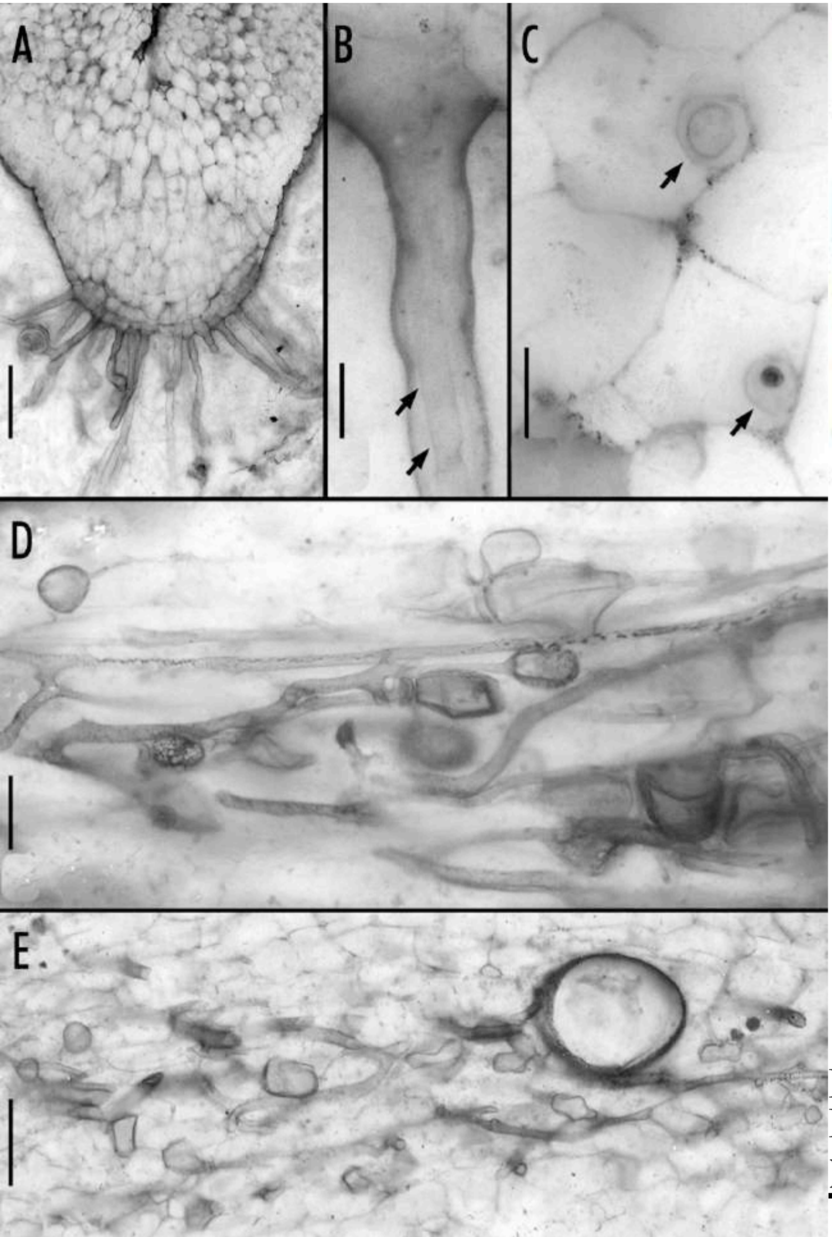
- **Cutin** and **suberin** reduce water loss: **insulating tissues.**

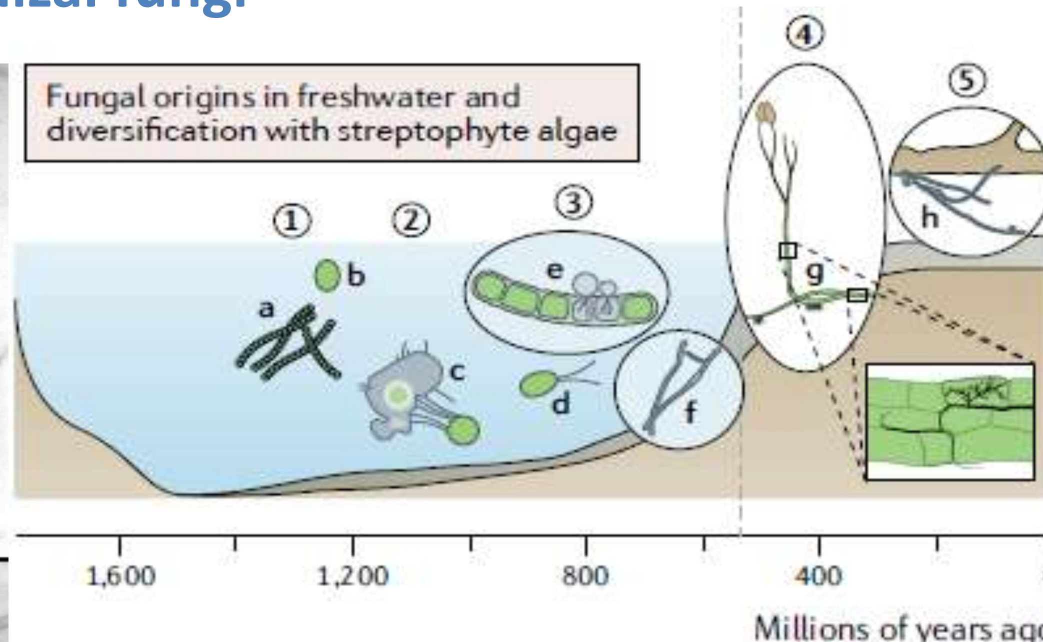


- **Lignin**, which hardens the cell wall of conductive vessels (**xylem**), helps to sustain the plant.



The role of symbiosis: mycorrhizal fungi





The colonisation of plants into the terrestrial environment probably involved symbiotic fungi, which contributed to the uptake of nutrients (especially phosphorus) in the primitive roots or rhizoids.

Fossils of *Nothia aphylla* from the Lower Devonian Rhynie chert (ca. 400 Mya) showing **fungal hyphae** (Krings et al. 2007).

Main topics

Adaptation of plant to land	Bryophytes and cormophytes	Reproductive structures and the embryo
Isospory and heterospory	Groups and diversity of embryophytes	

Bryophytes and cormophytes

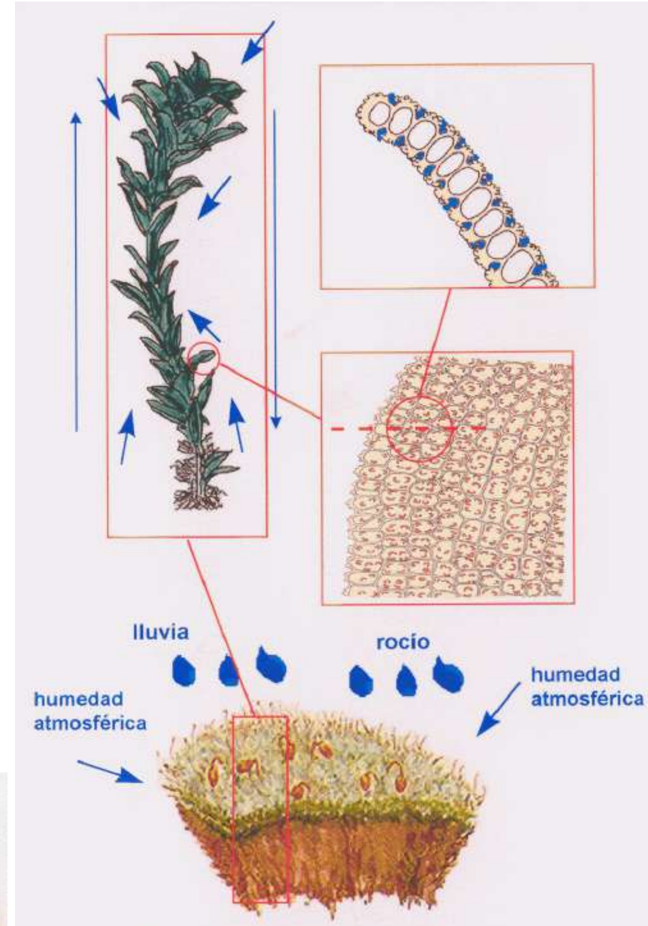
Many attempts to colonise the terrestrial environment were probably made. Plant organisms living on land today, however, have **two adaptive strategies**:

Bryophytes

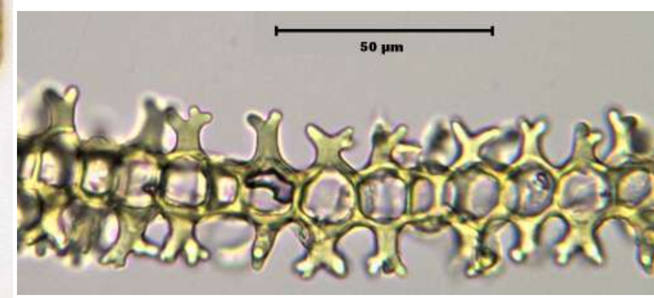
Cormophytes

Bryophytes

- Bryophytes are structurally simple organisms.
- They are poikilohydrous.
- Most lack water transport systems (they have no xylem or phloem).
- Some live in constantly moist environments.
- Others have developed tolerance to desiccation.



Pseudocrossidium revolutum



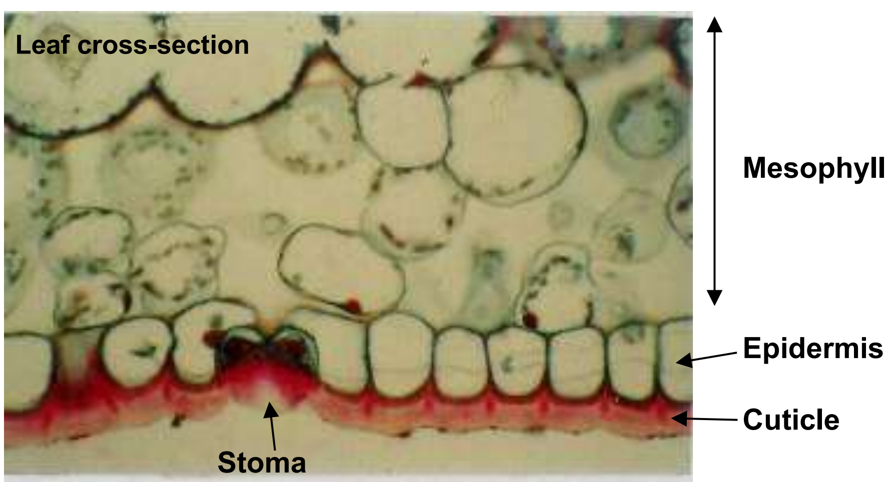
Cross-section of the lamina of ***Syntrichia papillosissima*** showing the prominent **papillae**.

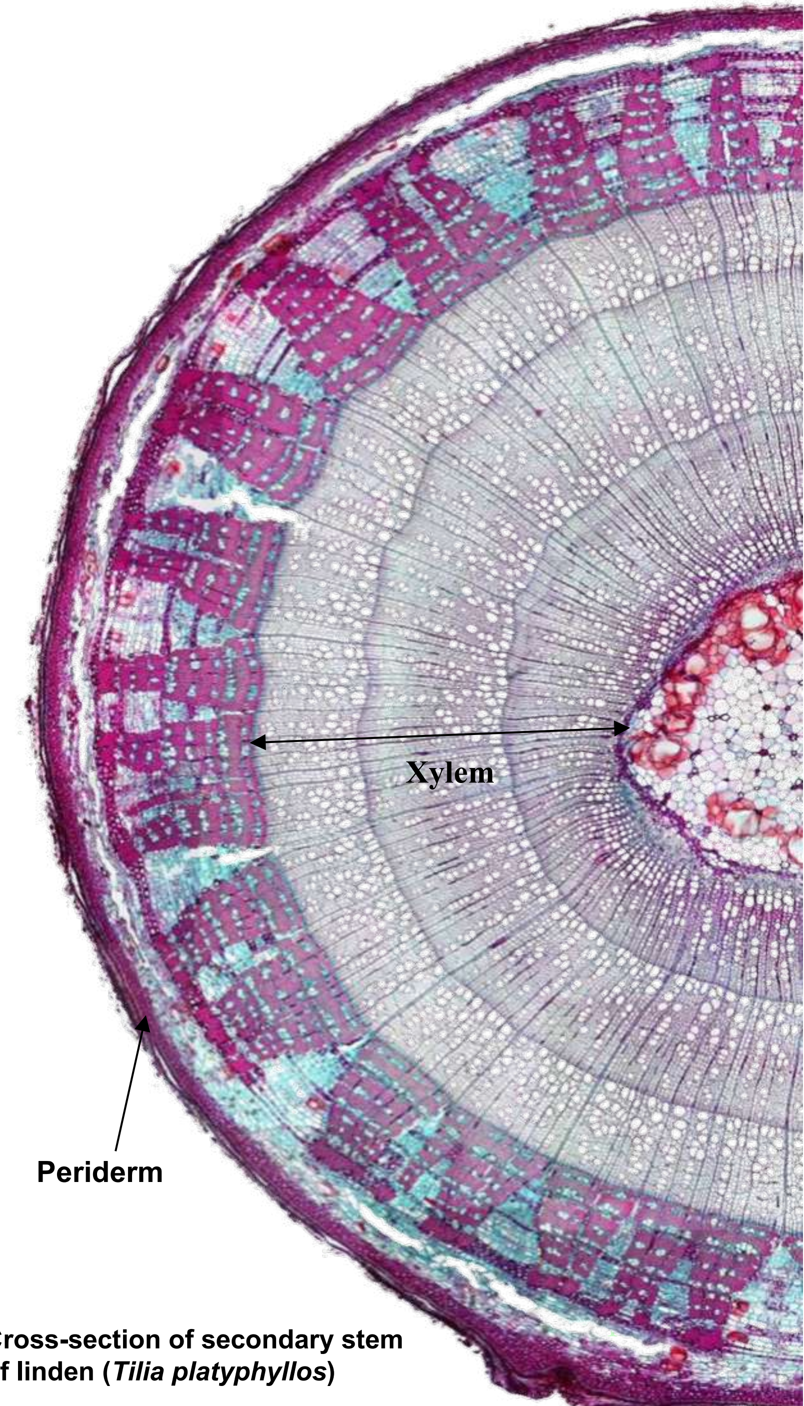
The cormophytes

Cormophytes are complex organisms with tissues specialised in:

- water uptake and transport (**lignified cells** forming the **xylem**).
- plant protection to avoid desiccation (**cutinised epidermis** and **suberised cells** forming tissues such as **periderm**).

They are **homeohydrous** organisms not resistant to desiccation (with some exceptions).





Cross-section of secondary stem of linden (*Tilia platyphyllos*)

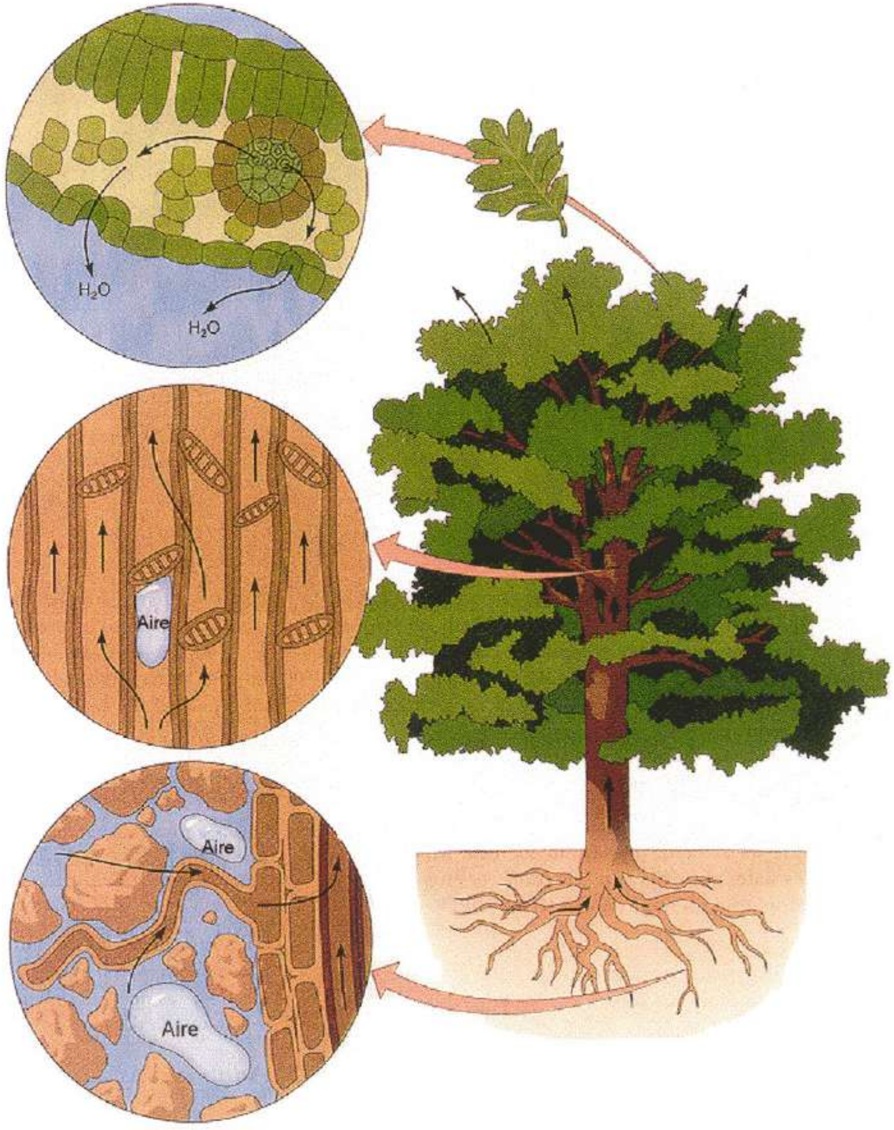
Cormophytes

The vegetative structure of cormophytes is divided into:

•**The root**, whose function is to absorb water and mineral nutrients and fix the plant to the soil.

•**The stem**, whose main function is to support the leaves and conduct the sap.

•**The leaves**, which specialise in photosynthesis.

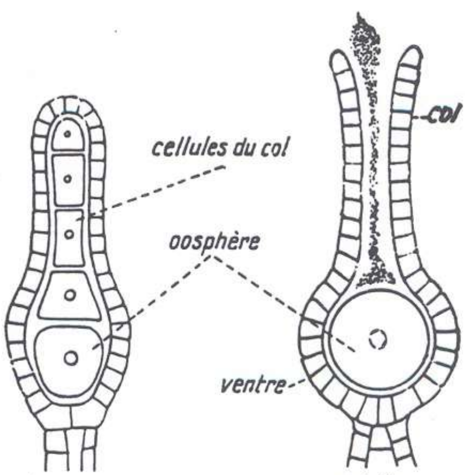


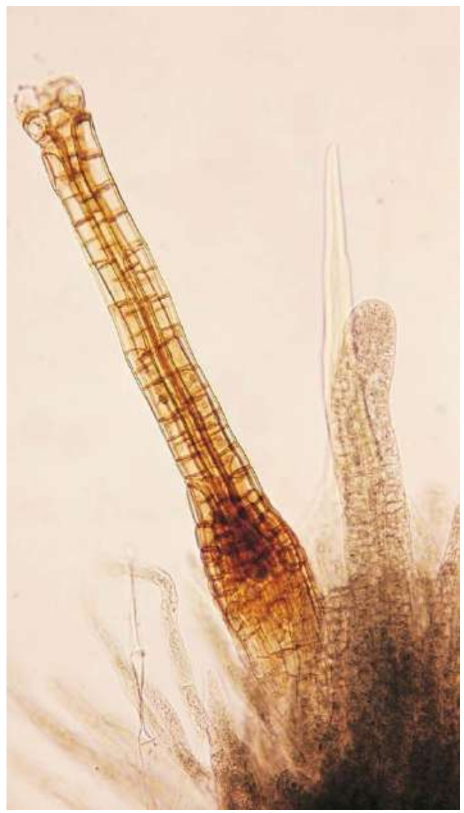
Main topics

Adaptation of plant to land	Bryophytes and cormophytes	Reproductive structures and the embryo
Isospory and heterospory	Groups and diversity of embryophytes	

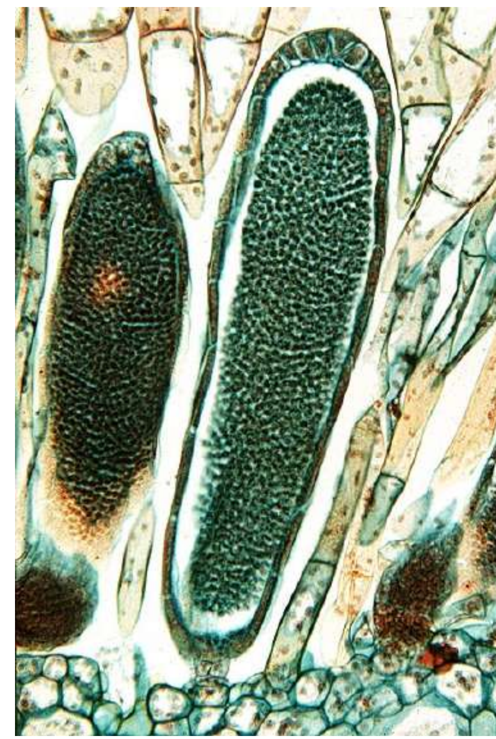
Modifications in reproductive structures: the gametangia

- Transition to terrestrial life involved a series of **modifications to both vegetative and reproductive structures**.
- There is a tendency for **gametes and spores to be protected**.
- Gametes are formed inside gametangia, which have a **sterile cell wall**.





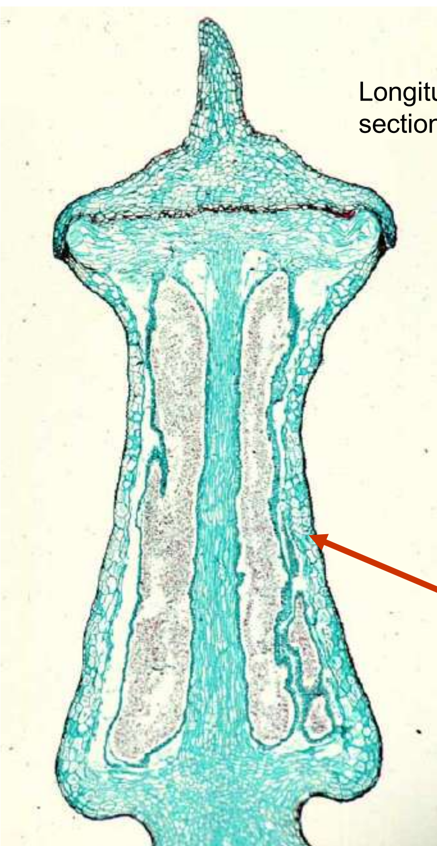
Archegonium of a moss



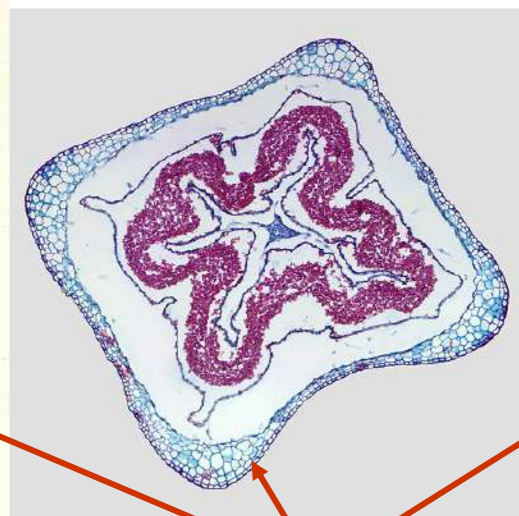
Anteridia of a moss

Sporangia

The spore-producing structures (**sporangia**) are more complex than those of green algae. Their cell wall consists of one or more layers of sterile cells that serve to protect the spores.



Longitudinal and transverse section of a moss capsule



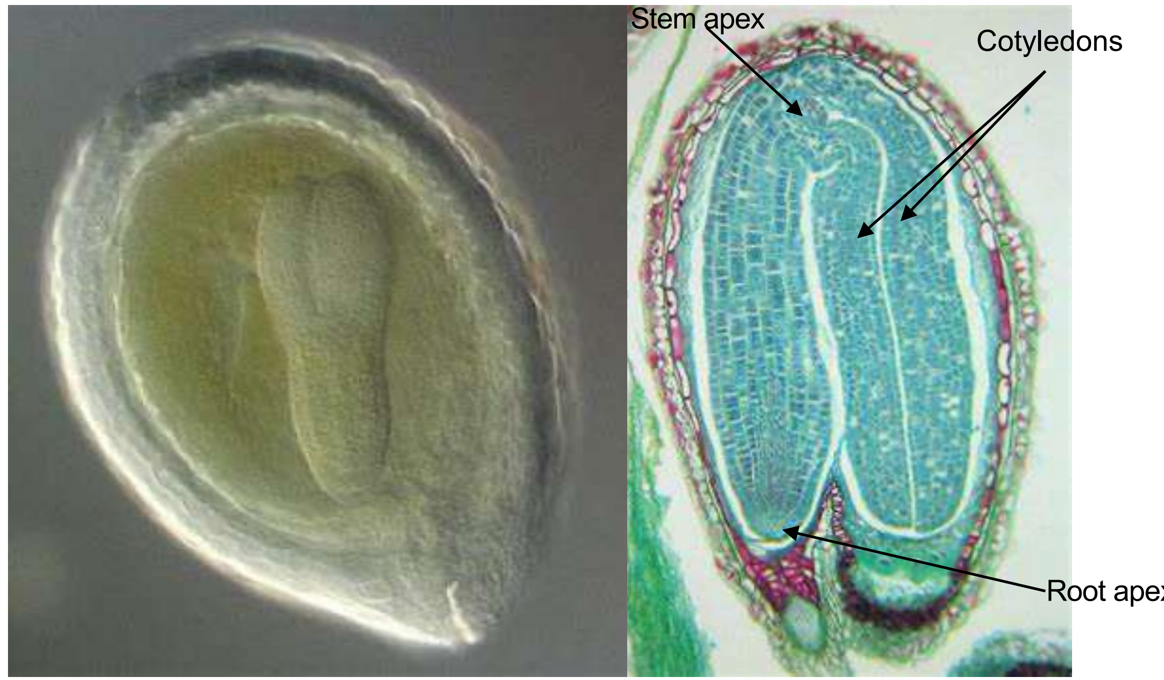
Sterile cells protecting the sporogenous tissue

Sporangium of *Selaginella*

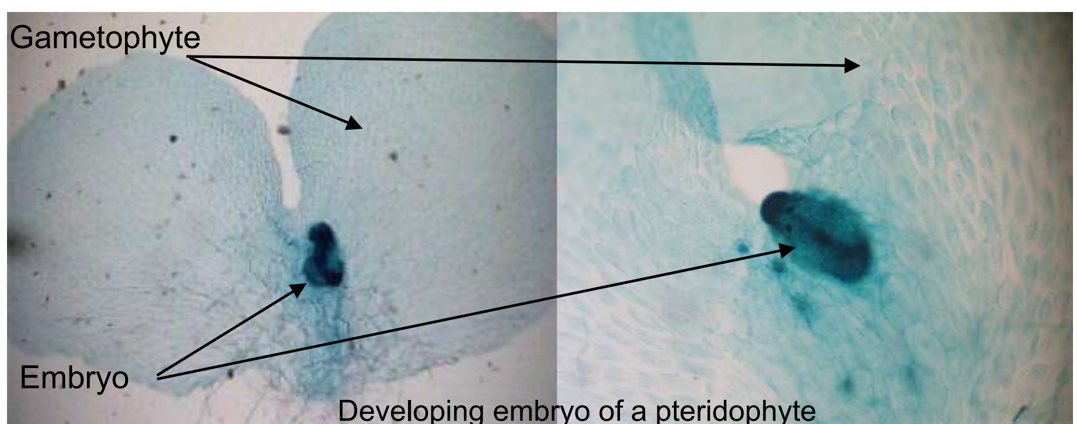
The embryo

The emergence of the **embryo** from the zygote is interpreted as an adaptation to terrestrial life.

Developing embryo in the belly of the archegonium: *Riccia* sp. (*Marchantiophyta*)



Spermatophyte embryos inside the seed.

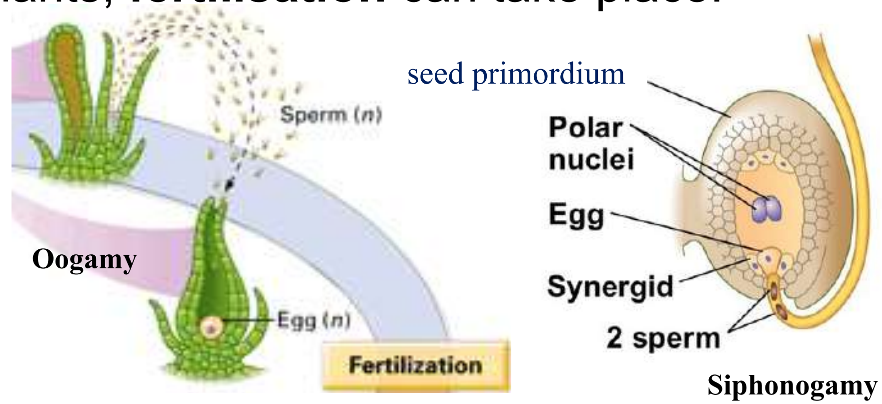


Developing embryo of a pteridophyte

Sexual reproduction and life cycles

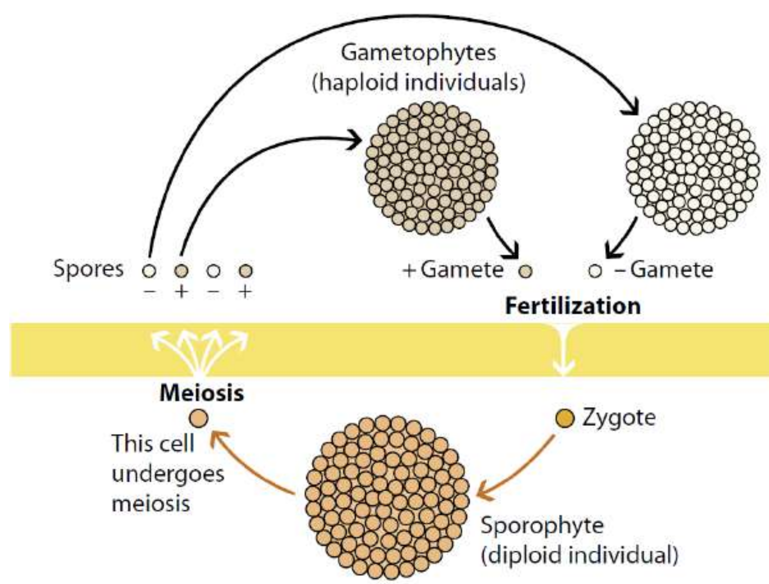
In the **sexual reproduction** of terrestrial plants, **fertilisation** can take place:

- **Oogamy**: in bryophytes, pteridophytes and some gymnosperms;
- **Siphonogamy**: in some gymnosperms and angiosperms.



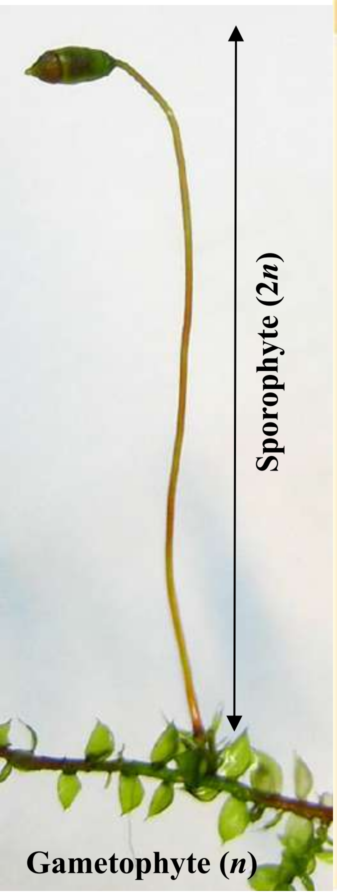
The life cycle of land plants is always **digenetic haplo-diploid and heteromorphic** with sporic meiosis.

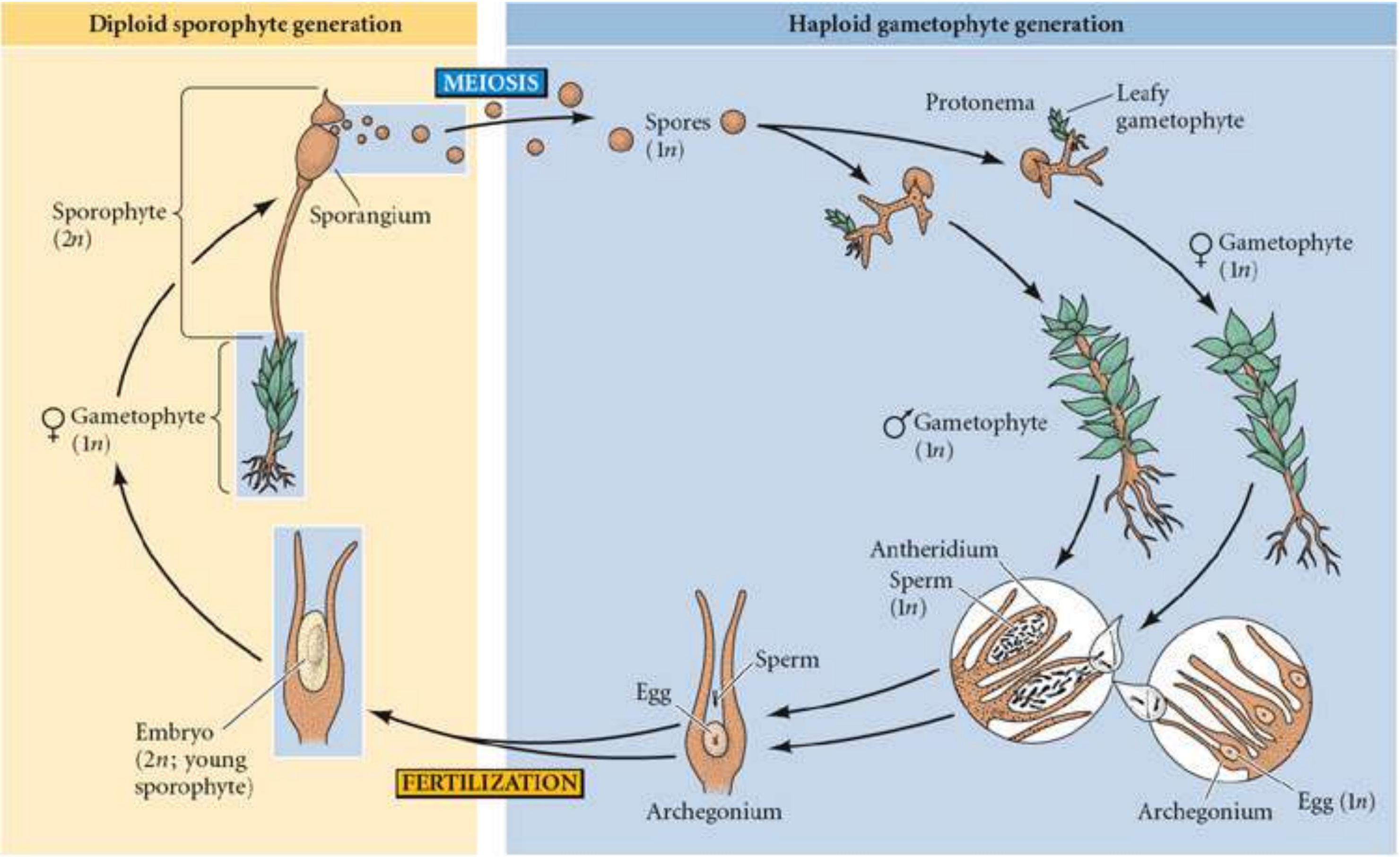
Land plants alternate between two generations: a haploid **gametophyte** and a diploid **sporophyte**. These two generations are morphologically different (at least in all land plants living today).



Sexual reproduction and life cycles in bryophytes

In **bryophytes**, the generation that lives the longest, and is therefore the **dominant** one in their life cycle, is the **gametophyte**.

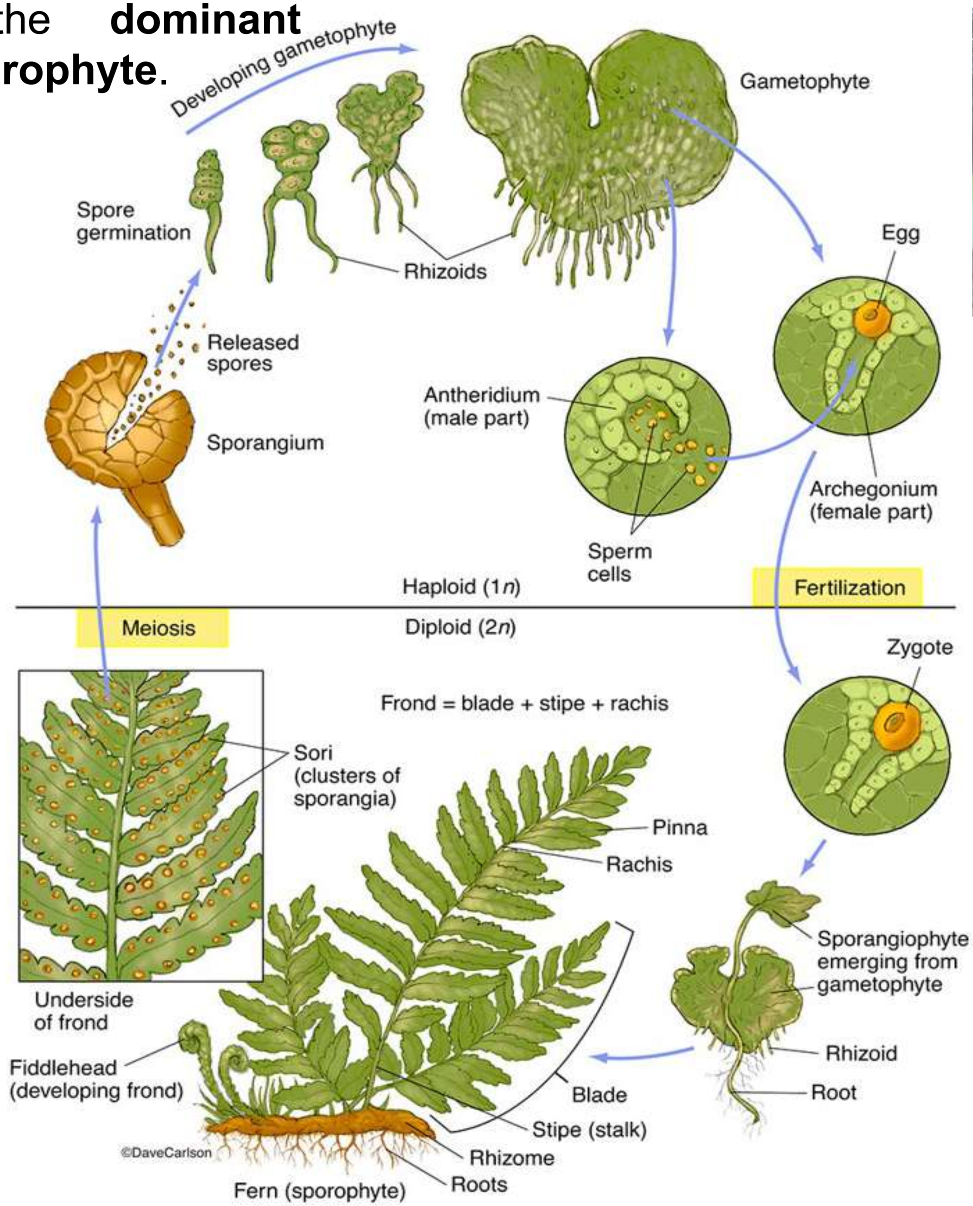




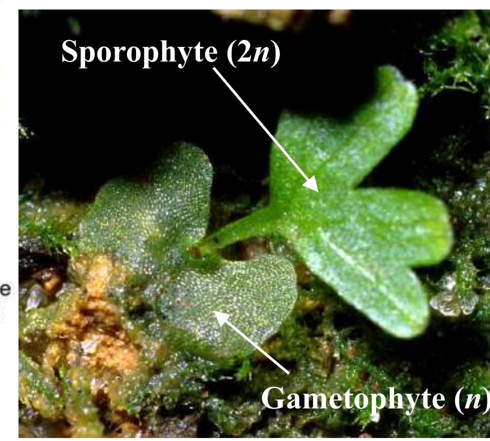
Sexual reproduction and life cycles in pteridophytes (cormophytes)

In **cormophytes** the **dominant generation is the sporophyte**.

Sporophyte (2n)



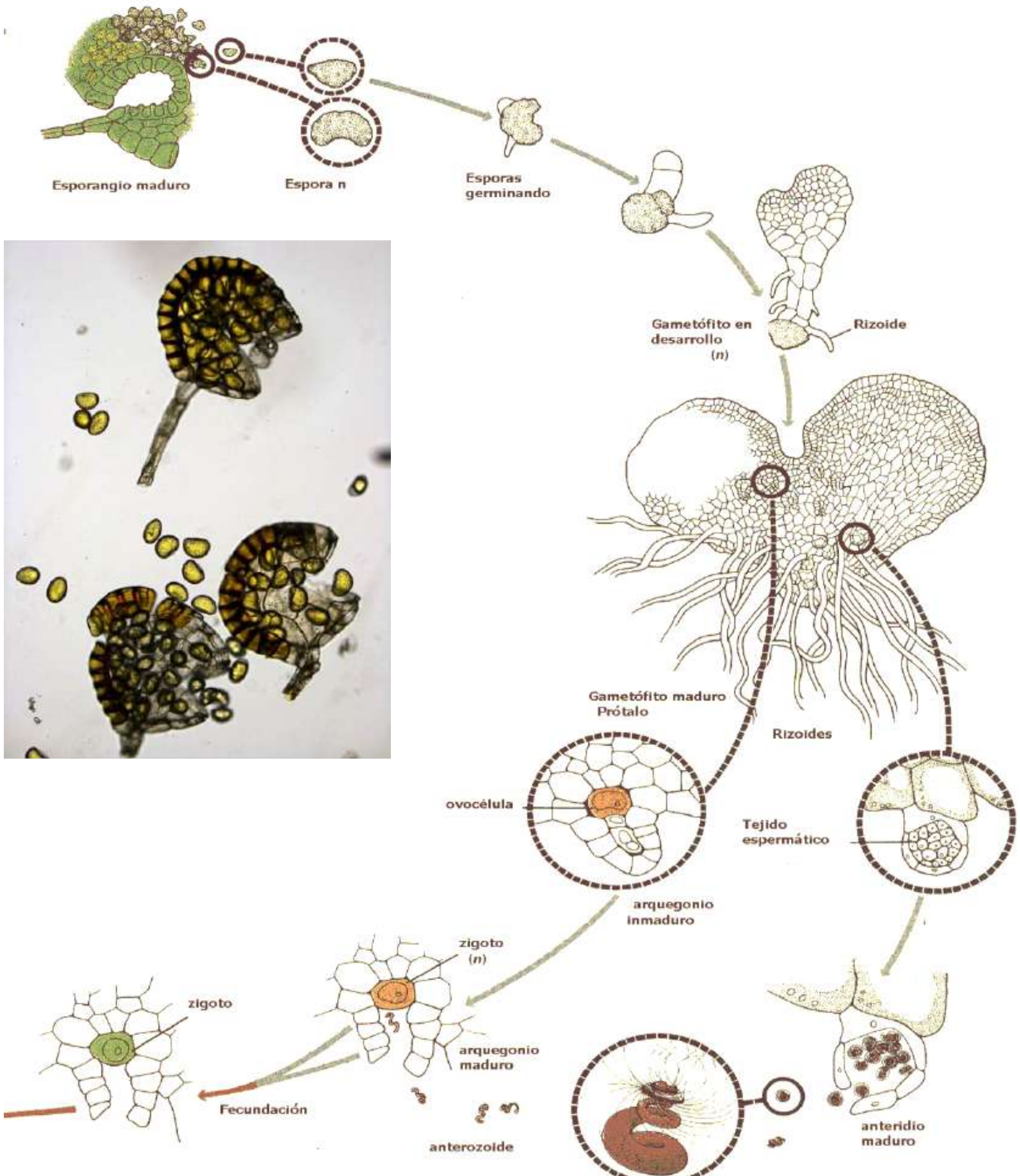
Gametophyte (n)



Main topics

Adaptation of plant to land	Bryophytes and cormophytes	Reproductive structures and the embryo
Isospory and heterospory	Groups and diversity of embryophytes	

Isospory



Plants whose sporophytes produce only one type of spore are **isosporic.** These include:

-**bryophytes**.

-some **lycopodiophytes** and some **monilophytes** (pteridophytes).

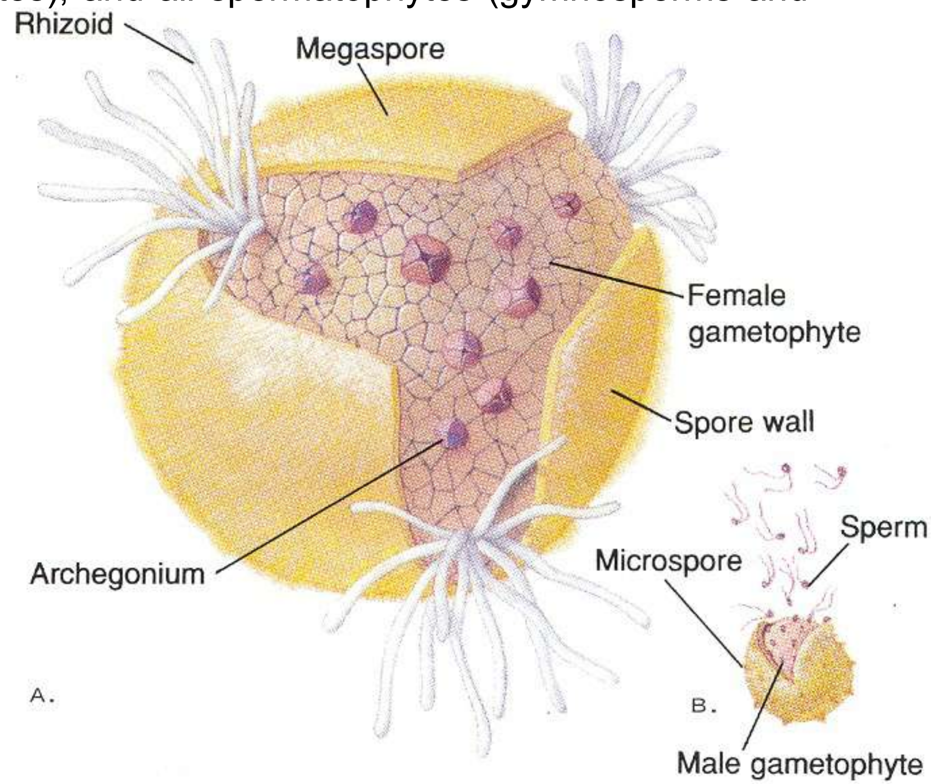
Heterospory

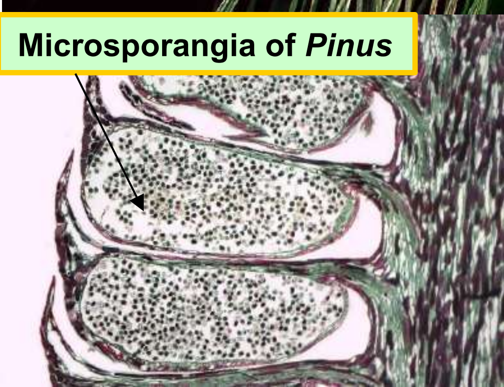
Heterosporic plants are those whose sporophytes produce two types of meiospores:

some lycopodiophytes, some monilophytes (pteridophytes), and all spermatophytes (gymnosperms and angiosperms).

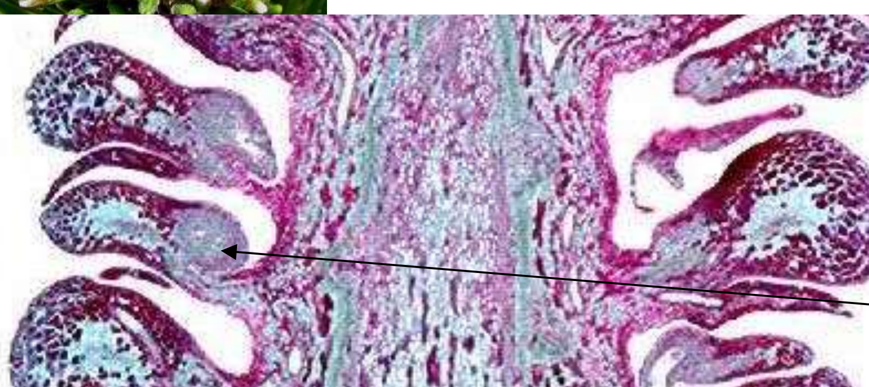
Microspores (which are small and produced in large numbers) give rise to the **male gametophyte**.

Megaspores (which are large and few) give rise to the **female gametophyte**.



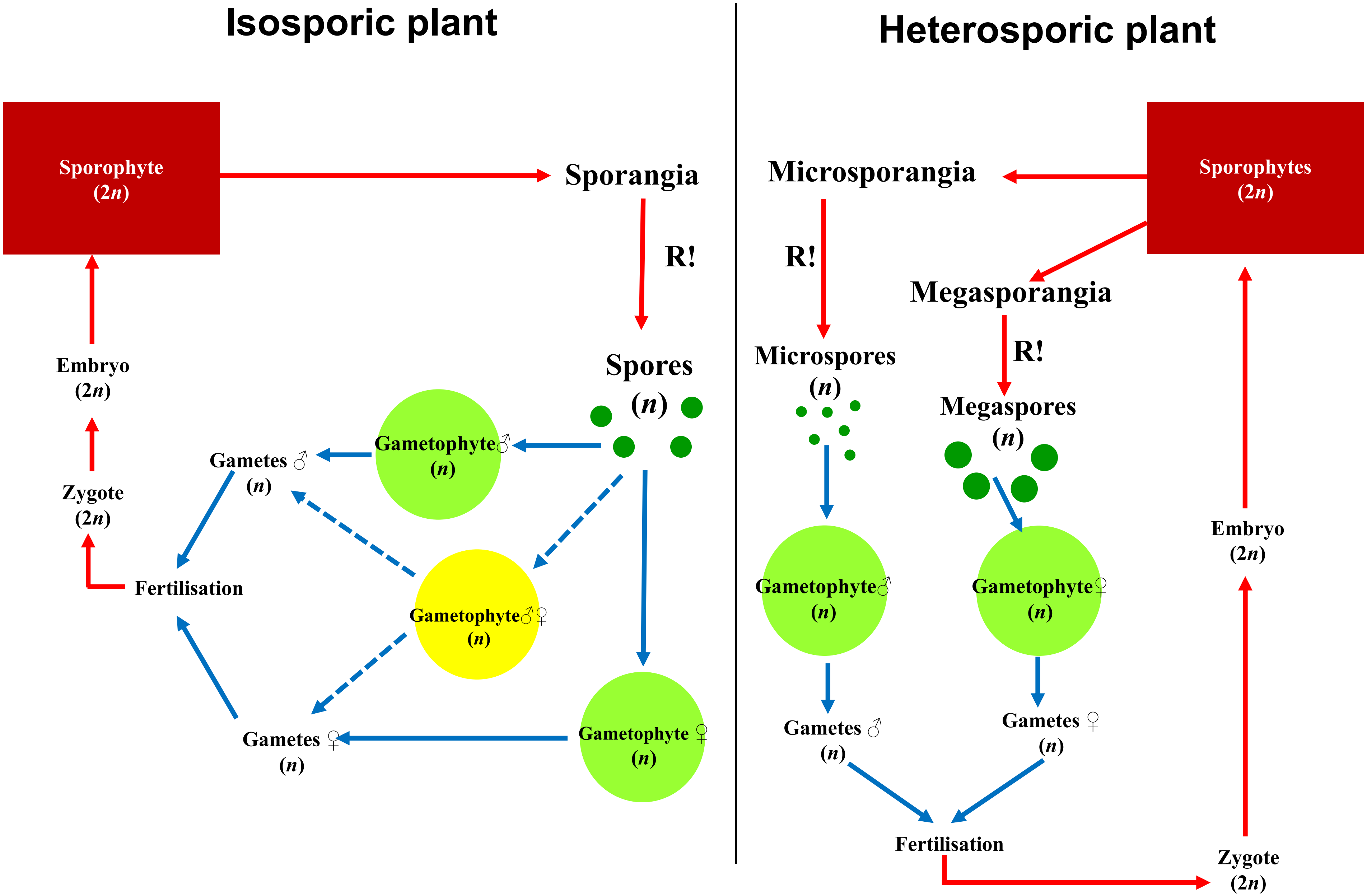


Microsporangia of *Pinus*

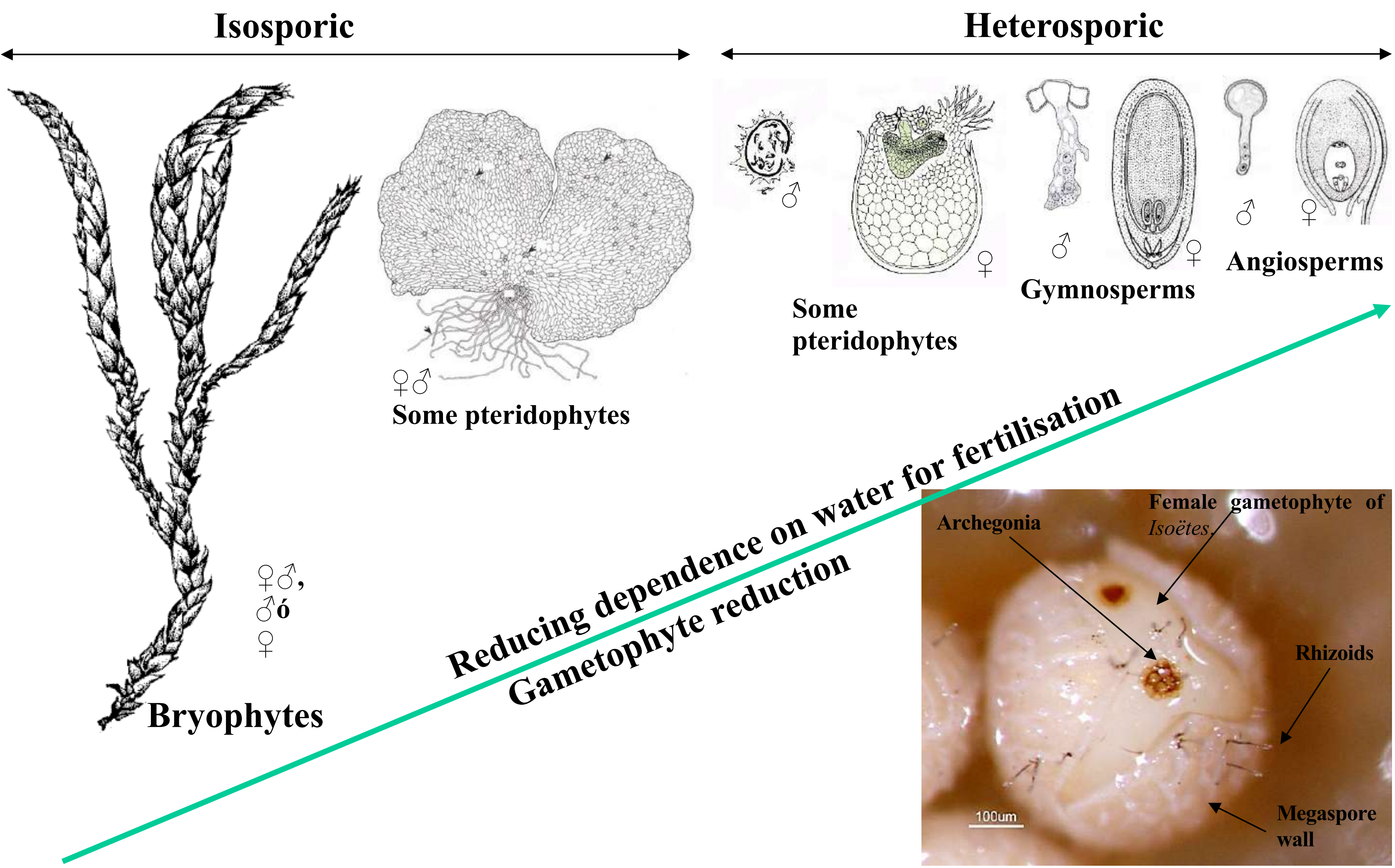


Megasporangia of *Pinus*

Variants of the life cycle of embryophytes or terrestrial plants



Isosporic and heterosporic plants



Main topics

- Adaptation of plant to land
- Bryophytes and cormophytes
- Reproductive structures and the embryo
- Isospory and heterospory
- Groups and diversity of embryophytes

Embryophyte groups

- **Bryophytes**: simple, non-lignified conductive systems, gametophyte dominant.

- **Cormophytes**: lignified conductive vessels (xylem), sporophyte dominant:
  - <u>spores</u> as dispersal units: **Pteridophytes**
  - <u>seeds</u> as dispersal units: **Spermatophytes**
    - naked seeds: **Gymnosperms**
    - seeds within fruits (derived from ovaria): **Angiosperms**

Diversity of embryophytes

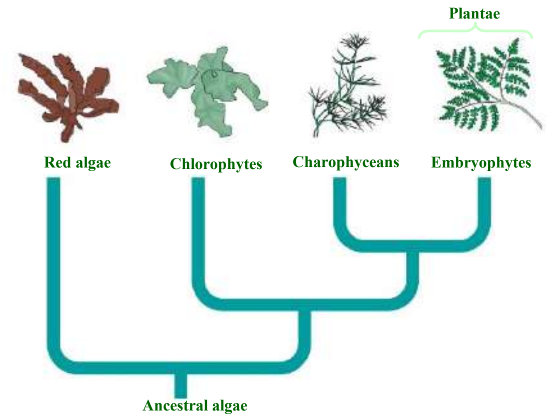
There are approximately 328,600 species.

Their habitat is mainly terrestrial.

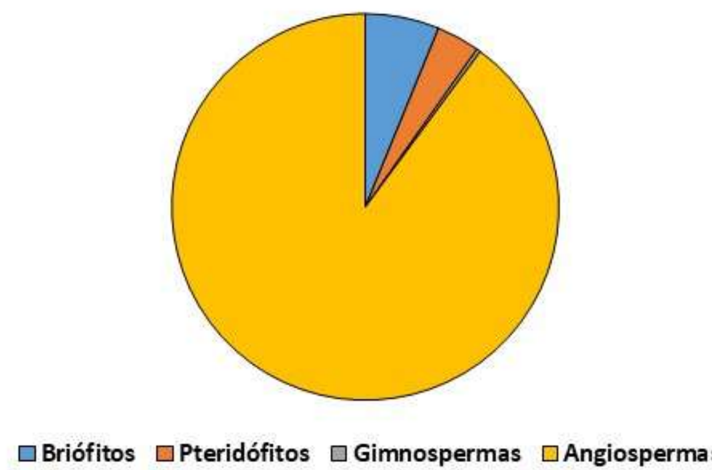
Some have colonised secondarily to the aquatic environment.

Terrestrial plants have a common origin from green algae (charophytes).

They comprise different groups:

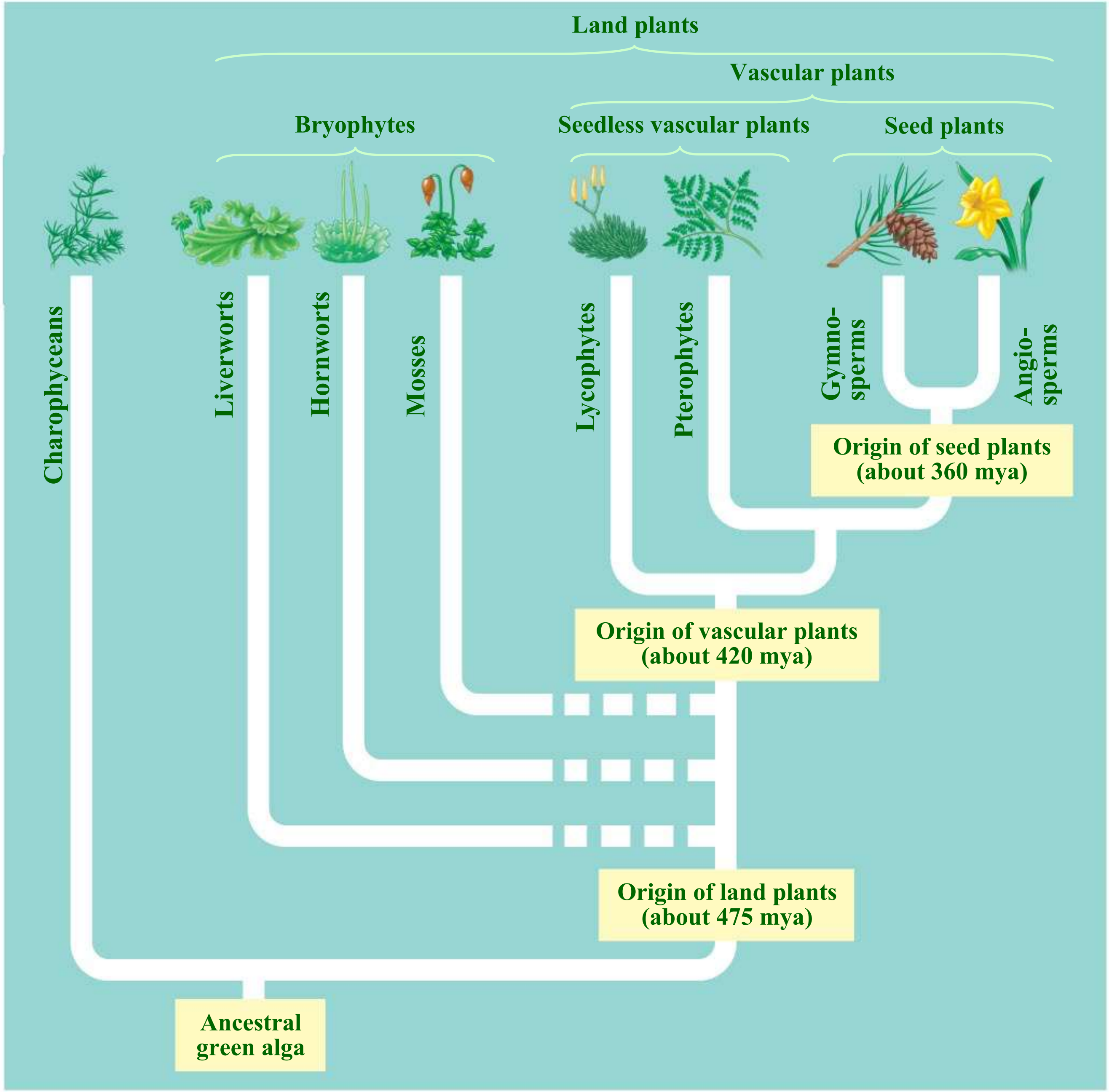


- **Bryophytes**: 20,300 species
- **Pteridophytes**: 11,850 species
- **Gymnosperms**: 1,079 species
- **Angiosperms**: 295,400 species



The oldest fossil remains date back to the Ordovician period roughly 450 million years ago.

Christenhusz, M. J.M. & Byng J.W. 2015. *Phytotaxa* 261: 201-217.
Söderstrom, L. et al. 2016. *Phytotaxa* 59: 1-828.

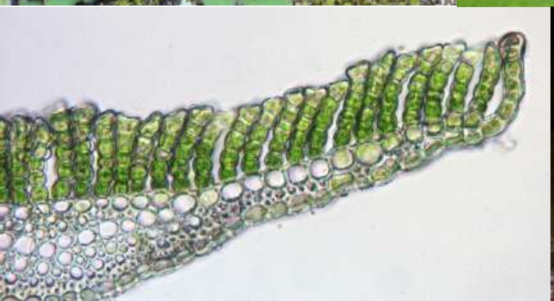

Land plants
Vascular plants
Bryophytes
Seedless vascular plants
Seed plants
Charophyceans
Liverworts
Hornworts
Mosses
Lycophytes
Pterophytes
Gymno-
sperms
Angio-
sperms
Origin of seed plants
(about 360 mya)
Origin of vascular plants
(about 420 mya)
Origin of land plants
(about 475 mya)
Ancestral
green alga




Lecture 07part 2
Bryophytes











Main topics

Bryophytes (main traits)	Liverworts	Hornworts	Mosses

Main traits of bryophytes

- Bryophytes are structurally simple plants, mainly of **terrestrial** habitat.
- Their organisation is **non-cormophytic**, with **simple conducting vessels** and non-lignified cells.
- They are small in size, ranging from a few millimetres to a few centimetres. Most do not exceed 10 cm.
- They are **poikilohydrous** and in many cases resistant to desiccation.
- Sexual reproduction is by **oogamy**, with a mobile (flagellate) male gamete.

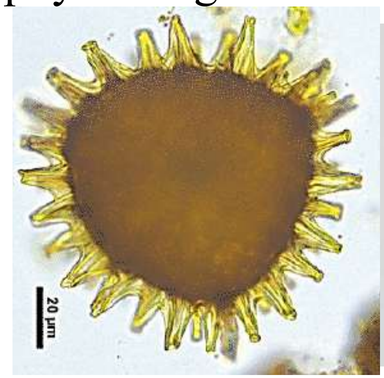
They have **digenetic haplo-diploid and heteromorphic life cycles**, with **sporic meiosis** and a **dominance of the gametophyte over the sporophyte. The latter does not have an independent life, i.e. it lives at the expense of the gametophyte and is ephemeral.**

Main characteristics of bryophytes

Gametophyte: haploid gamete-producing generation, ephemeral, annual or perennial. **IMPORTANT:** The gametophyte (or gametophytic stage of the life cycle) includes the spore, protonema and gametophore.

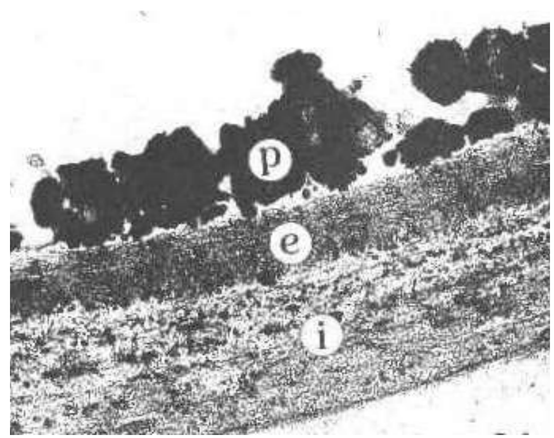
Bryophyte spores:

- are often unicellular
- are haploid
- are produced by meiosis **(sporic meiosis)**
- have a well-structured wall that can be divided into three layers:
    - **intine**: callose and pectins
    - **exine**: sporopollenin
    - **perine**: sporopollenin (only in mosses)



Riella heliospora spore

Pellia epiphylla multicellular spore



TEM image of the spore wall of the moss *Pterygoneurum lamellatum* showing the three layers (Carrión et al. 1995).

***Bryum* sp.** spores

The gametophore

The gametophore corresponds to the mature stage of the gametophytic phase. A **foliose** or **thalloid** plant produces **female gametangia** (the archegonia) and/or **male gametangia** (the antheridia).

FOLIOSE

THALLOID

The gametophore

The gametophore corresponds to the mature stage of the gametophytic phase. A **foliose** or **thalloid** plant produces **female gametangia** (the archegonia) and/or male gametangia (the antheridia).

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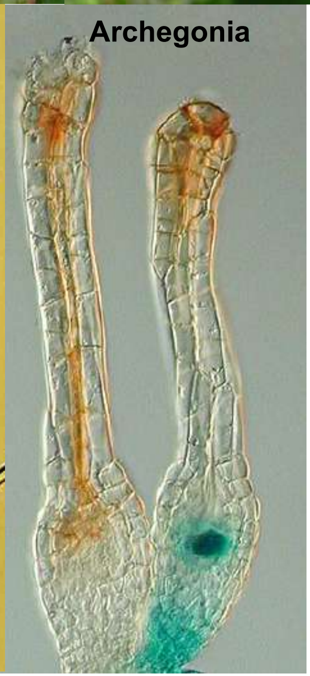
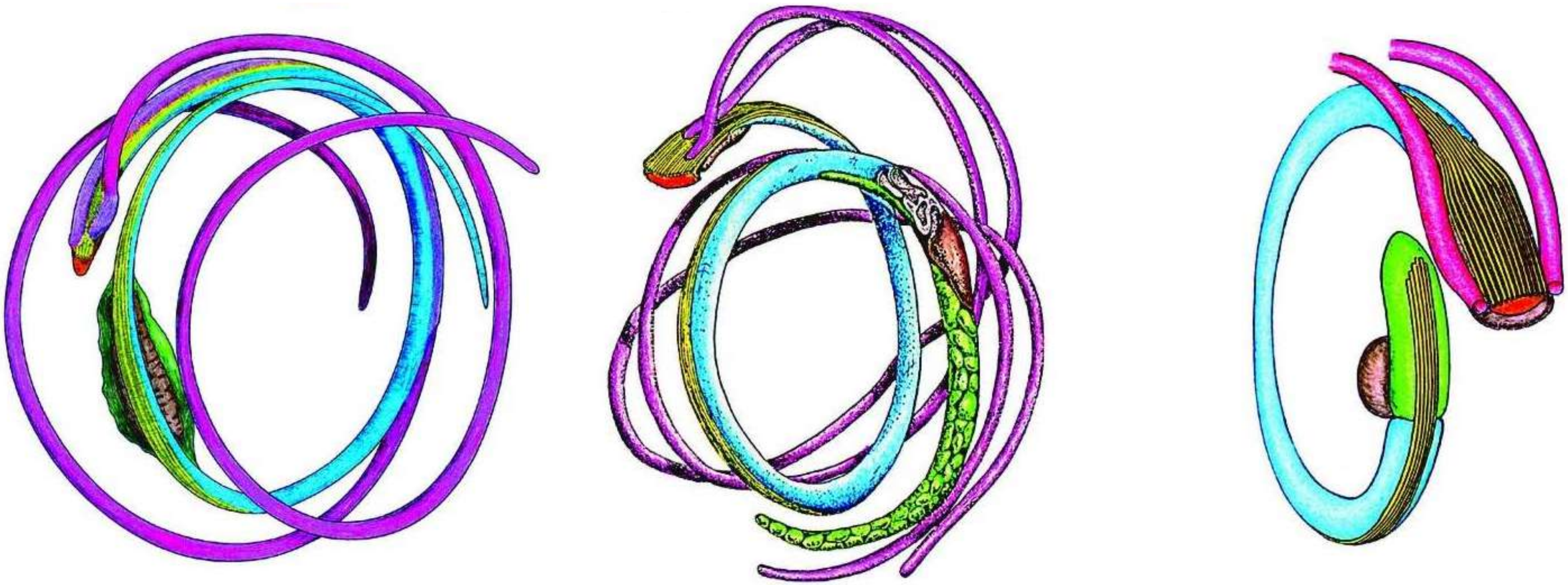


Male gametes are biflagellate with the flagella arranged in spirals

Mosses | **Liverworts** | **Hornworts**



Aulacomnium palustre | *Blasia pusilla* | *Phaeoceros laevis*

- nucleus
- flagella
- mitochondria
- microtubule bundle and lamellar band

Renzaglia *et al*. 2000

The sporophyte

The sporophyte corresponds to the **diploid stage of the life cycle**.

The zygote remains inside the belly of the archegonium, where it is nourished by sugars, amino acids and other substances supplied by the gametophyte (**matrotrophy**).

- It lives always attached to the gametophore via the placenta.
- Early in its development it is photosynthetic.
- It is an unbranched structure.
- It produces a single sporangium.
- It produces spores by meiosis.

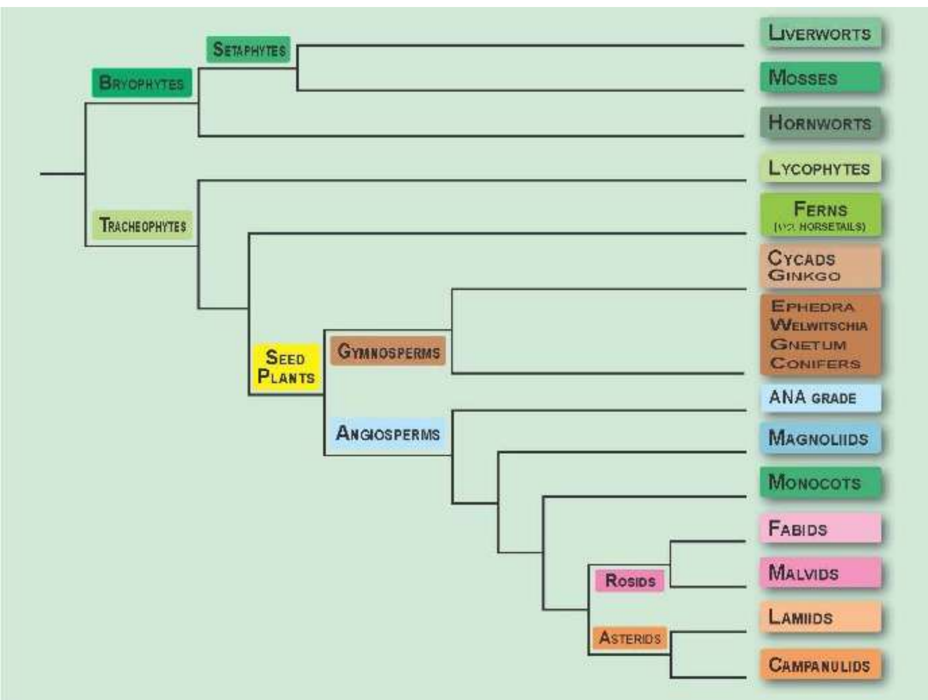


Bryophytes comprise three phyla

Based on the most recent phylogenies (e.g., Cole et al. 2019), which include representatives of all current bryophyte orders and families, it appears that bryophytes constitute a **monophyletic group**. Hornworts apparently diverged initially and are sisters to the group that includes mosses and liverworts.

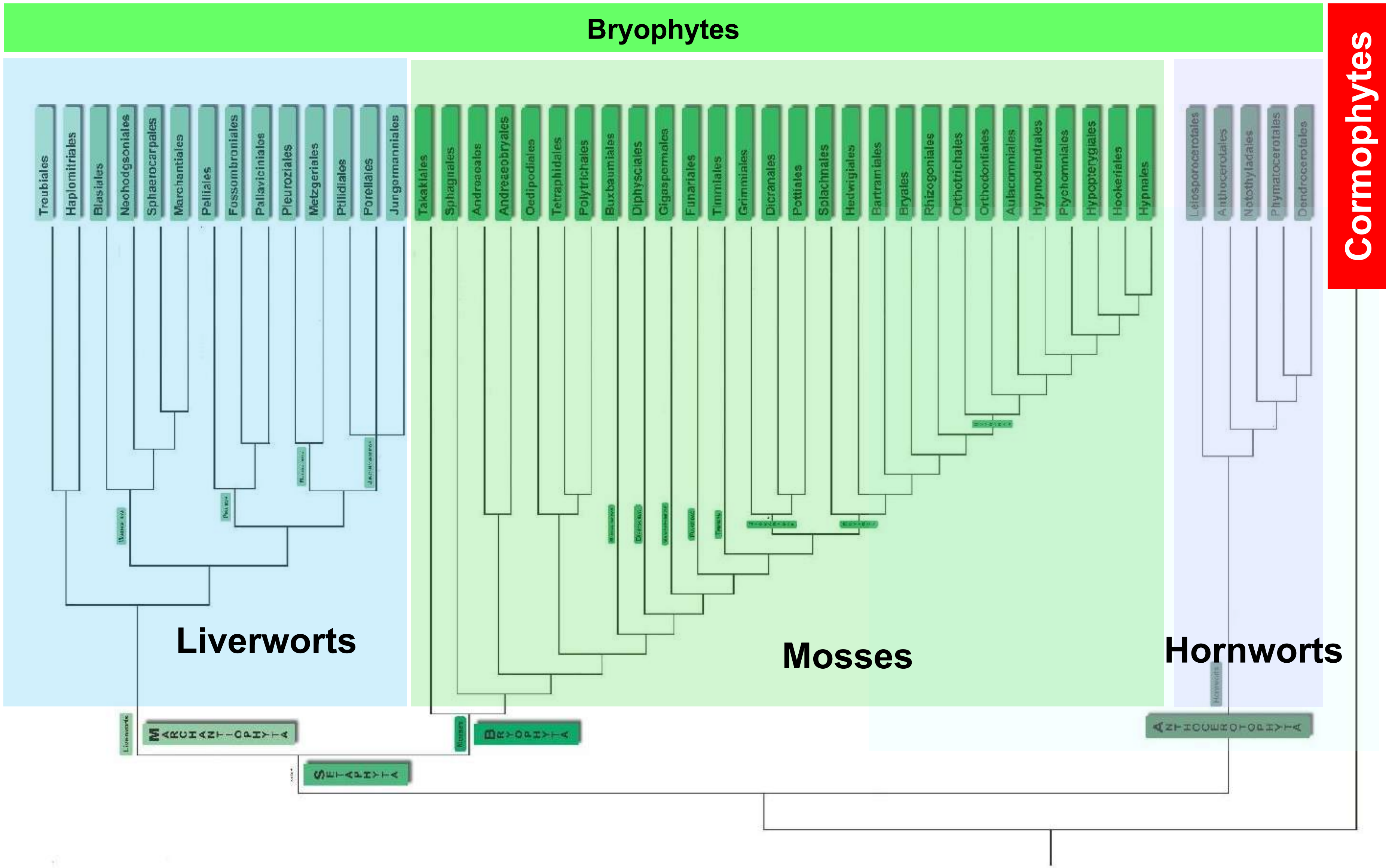
Phylum ***Marchantiophyta*** (liverworts)

Phylum ***Bryophyta*** (mosses)



Phylum ***Anthocerotophyta*** (hornworts)

Evolutionary relationships among the bryophyte groups



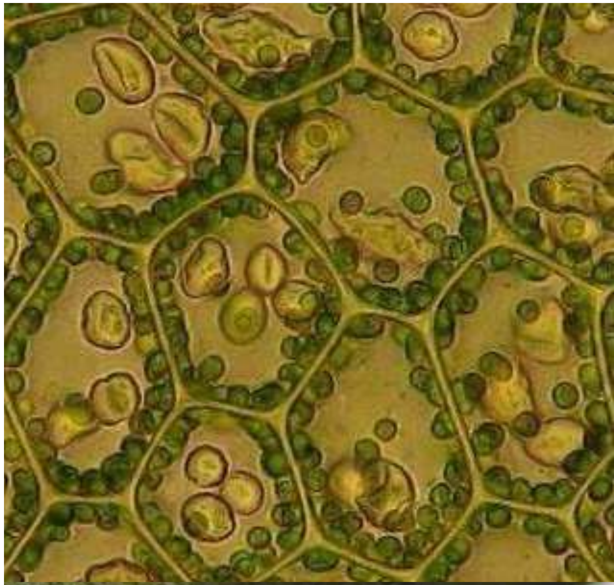
Cole, T., Hilger, H. & Goffinet, B. (2019). Bryophyte Phylogeny Poster (BPP), 2019. 10.7287/peerj.preprints.27571.

Main topics

Bryophytes (main traits)	Liverworts	Hornworts	Mosses

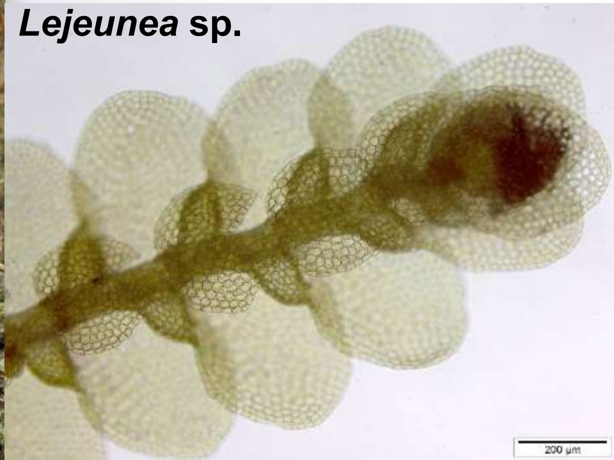
Ph. *Marchantiophyta* (liverworts): main traits

- Numerous plastids per cell, without pyrenoid.
- Water-conducting cells (without lignin) are present only in the gametophore of some species.
- Rhizoids are unicellular and hyaline, not branched.
- Stomata are absent in both generations (gametophyte & sporophyte).



Young sporophyte of ***Pellia* sp.**

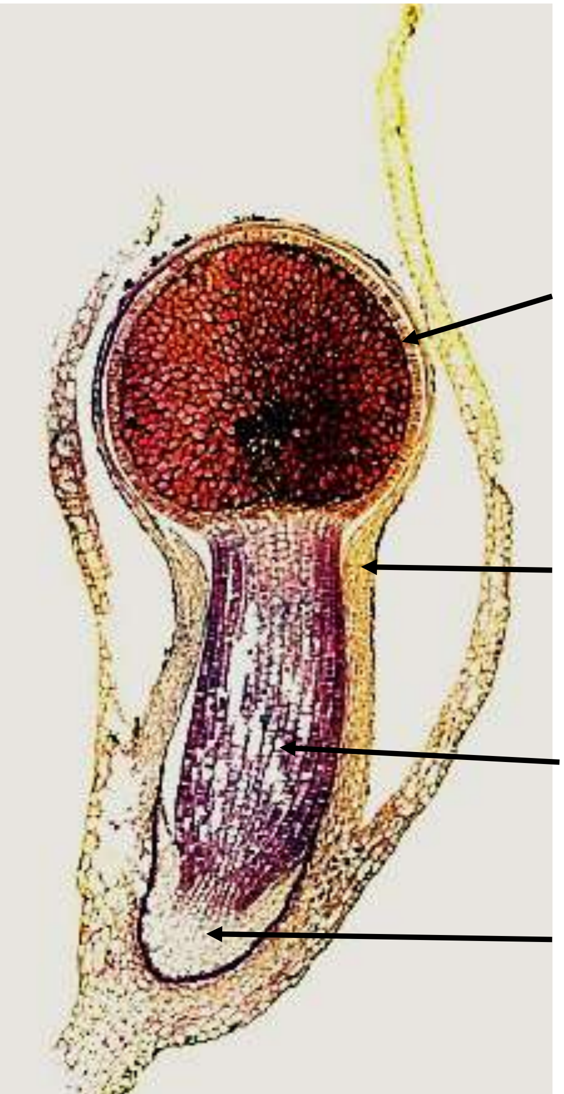
***Fossombronia* sp.**



***Lejeunea* sp.**

Ph. *Marchantiophyta* (liverworts): main traits

- Sporophyte grows via the activity of an apical cell.
- Simultaneous spore maturation.
- Capsule with a hyaline seta elongates just before spore release.
- Undifferentiated, spherical or elongated capsule of distinct size and growth.
- Spores (n) and elaters (2n).
- Over 5,000 species.



Capsule, sphaerical or elongated, containing spores (*n*) and elaters (2*n*)

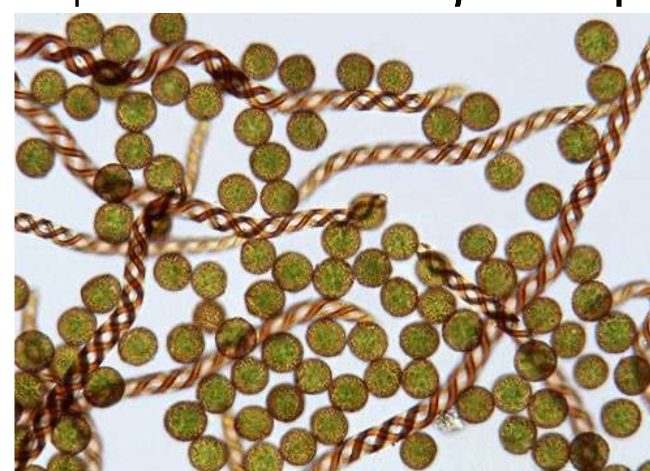
Calyptra, derived from the archegonium (*n*)

Seta (2*n*)

Stalk (2*n*)

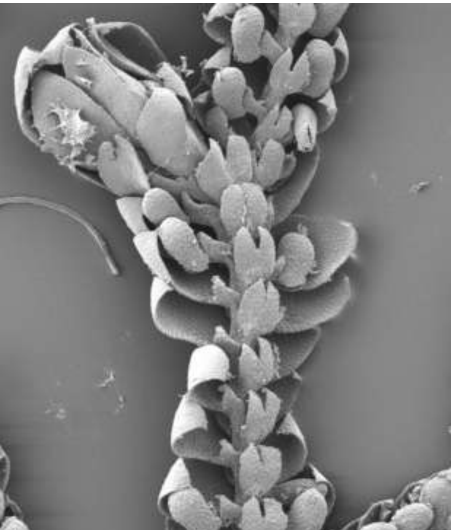
Capsules

Spores and elaters of ***Lepidozia* sp.**



Gametophores of liverworts may be foliose or thalloid

Foliose gametophores may have two or three rows of phyllidia ("leaves"). **Thalloid gametophores** are anatomically structured in different layers (epidermis, photosynthetic tissue, storage tissue, etc.).

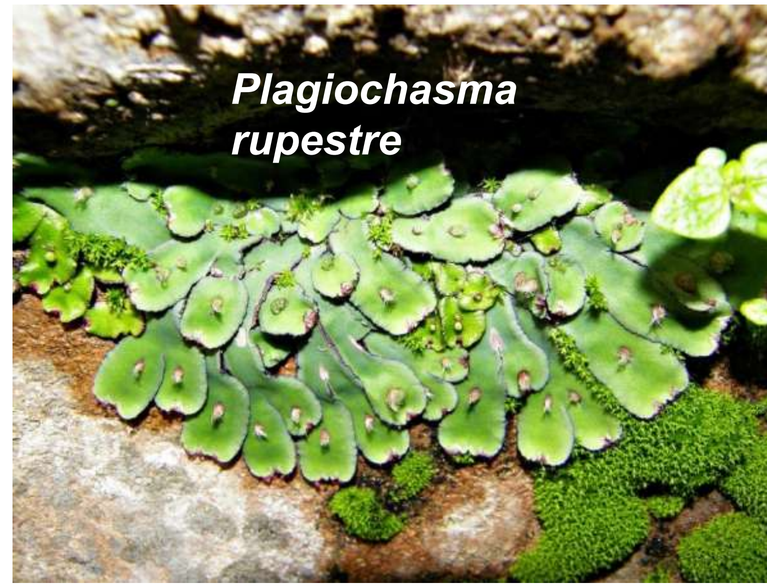


Ventral view of ***Frullania tamariscii***

Ventral view of ***Lejeunea japonica***

Thalloid

Foliose

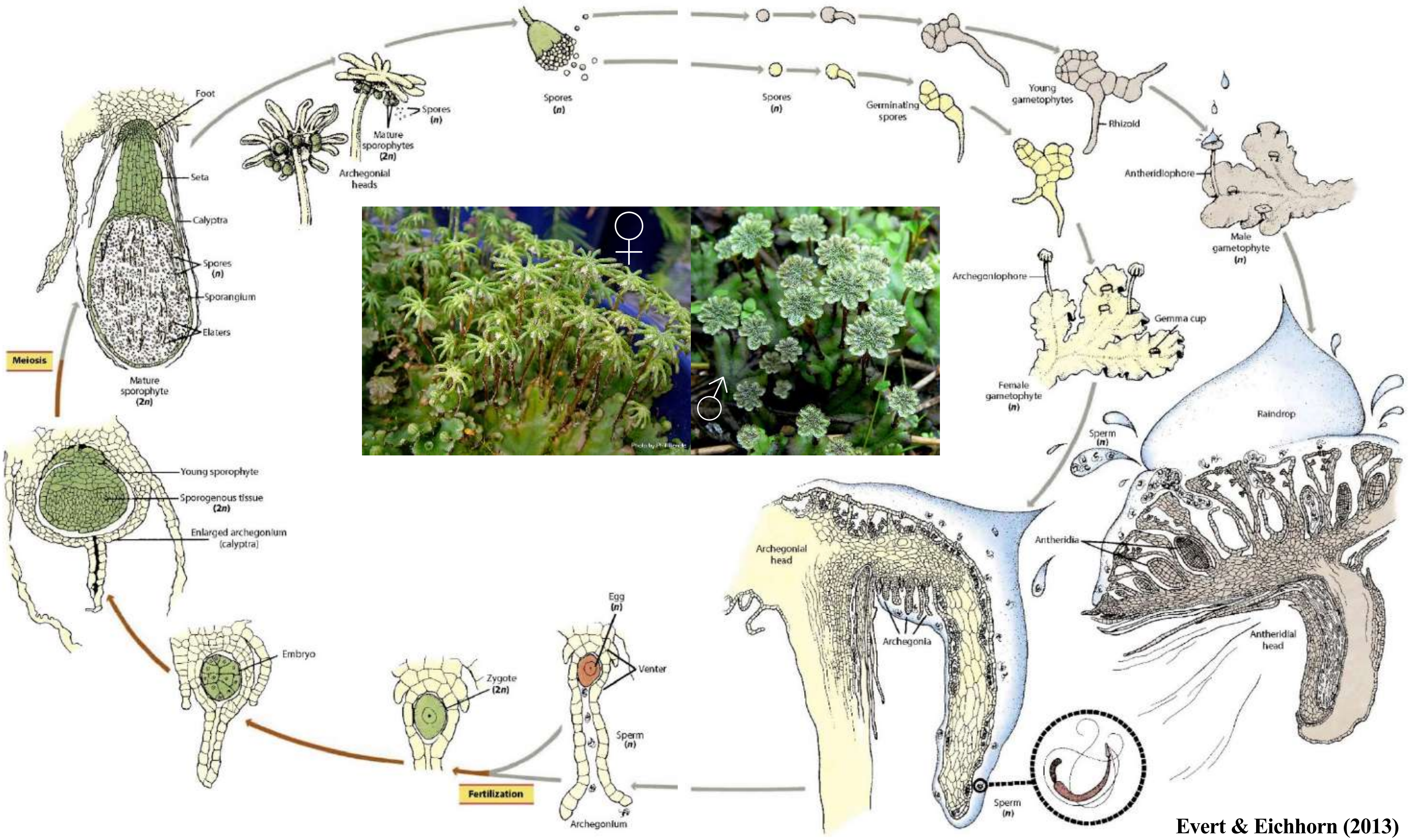


Plagiochasma rupestre

Targionia hypophylla

Life cycle of *Marchantia polymorpha*

Digenetic haplo-diploid and heteromorphic



Evert & Eichhorn (2013)

Some species are adapted to live in wet environments or near water-splash zones; others live in dry environments.

Main topics

Bryophytes (main traits)	Liverworts	Hornworts	Mosses

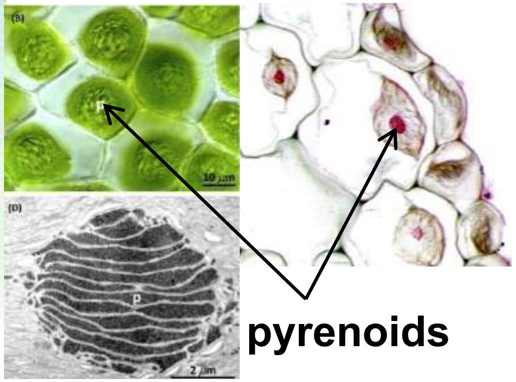
Ph. *Anthocerotophyta* (hornworts): main traits

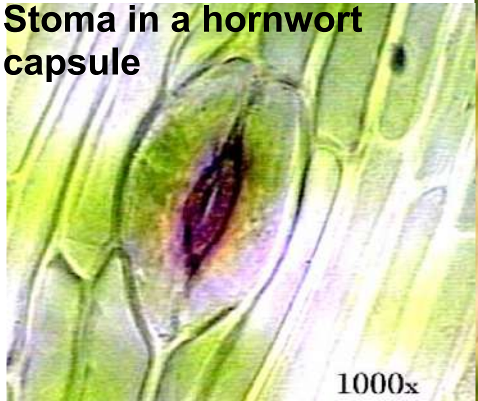
- These have one or a few plastids per cell (archaeplasts), with a **pyrenoid**.
- **Stomata** are present in the gametophore and sporophyte.
- The gametophore is **thalloid** and forms small, dark green rosettes that are always multi-stratified and have irregular or dichotomous branching and a fleshy consistency.
- Inside the thallus are cavities that are filled with mucilage and colonised by **symbiotic cyanobacteria** of the genus *Nostoc*.
- The sporophyte grows by means of a **basal meristem**.
- The rhizoids are unicellular and hyaline.


Thalloid gametophore of *Notothylas orbicularis*


Anthoceros punctatus

Dendroceros crispatus





Stoma in a hornwort capsule


Gametophore cells with a unique chloroplast

Ph. *Anthocerotophyta* (hornworts): main traits

- The **sporophyte** comprises a **stalk** and a **capsule**.

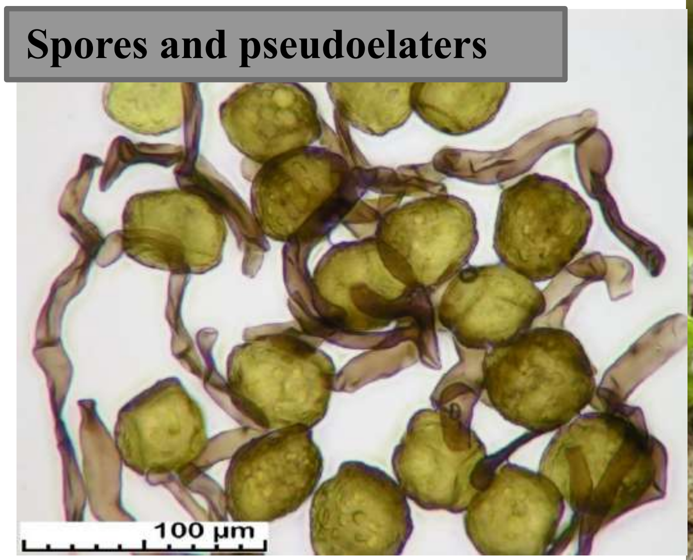
- It has the appearance of a sharp, horn-shaped cylinder with a swollen foot that sinks into the dorsal part of the gametophore. It can grow to 10-12 cm.
- The **capsule** contains:

- the **columella**
- the sporogenous tissue in which the **spores** (n) and **pseudoelaters** (n) are found.

- The capsule wall shows typical stomata.

Roughly 300 species exist.

Anthoceros, *Dendroceros*, *Notothylas*, *Phaeoceros*, *Phymatoceros*, etc.



Main topics

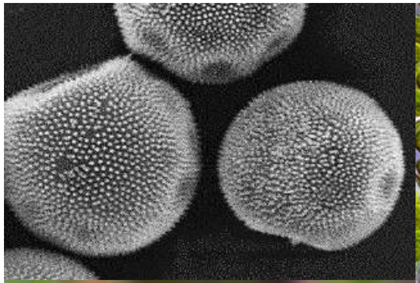
Bryophytes (main traits)	Liverworts	Hornworts	Mosses

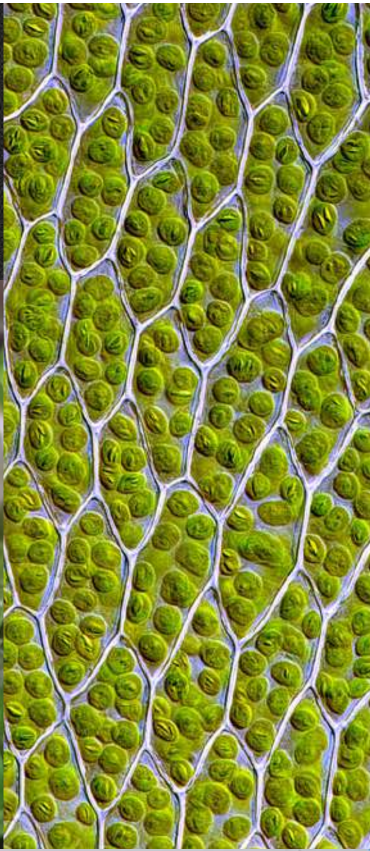
Ph. *Bryophyta* (mosses): main traits

- With almost 13,000 species, this is the largest group of bryophytes.

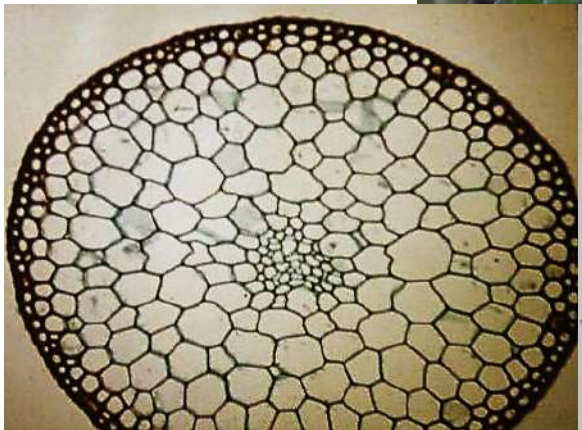
- Gametophore foliaceous, with phyllidia ("leaves"), usually arranged in several (occasionally two) rows around the caulidium.

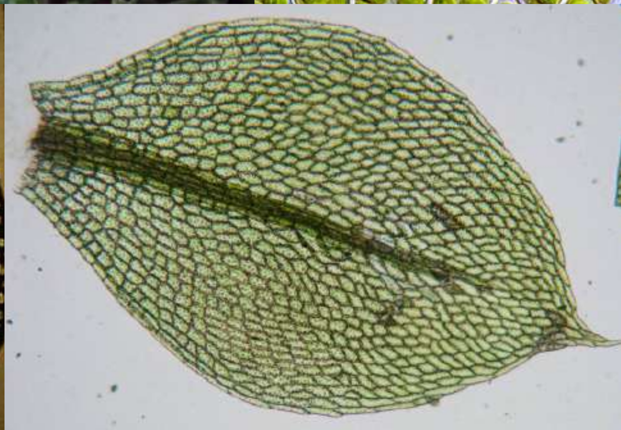
- Numerous plastids per cell; no pyrenoid.
- Multicellular rhizoids.
- Caulidium sometimes has a central cordon of conductive cells (non-lignified hydroids and leptoids).





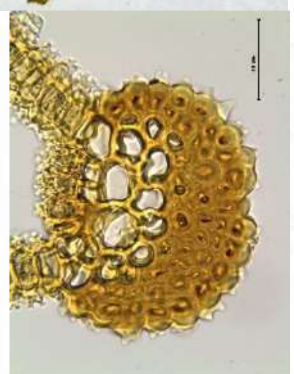
Cross-section of the caulidium of ***Polytrichum* sp.**

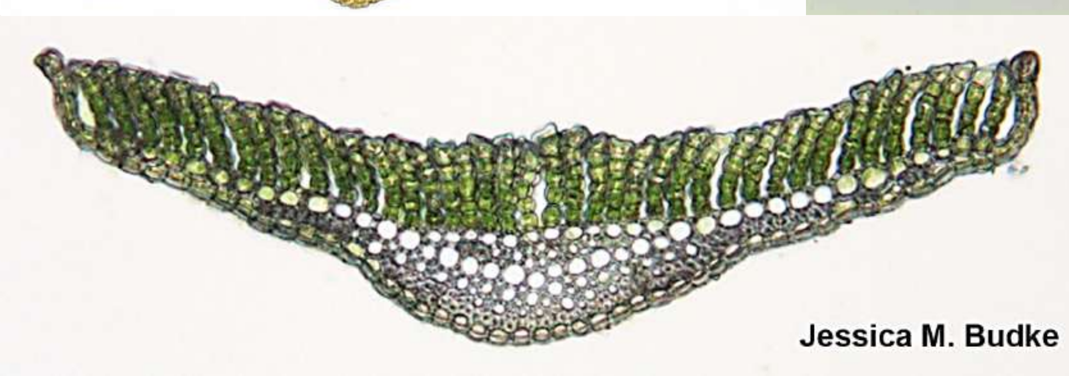




Phyllidia

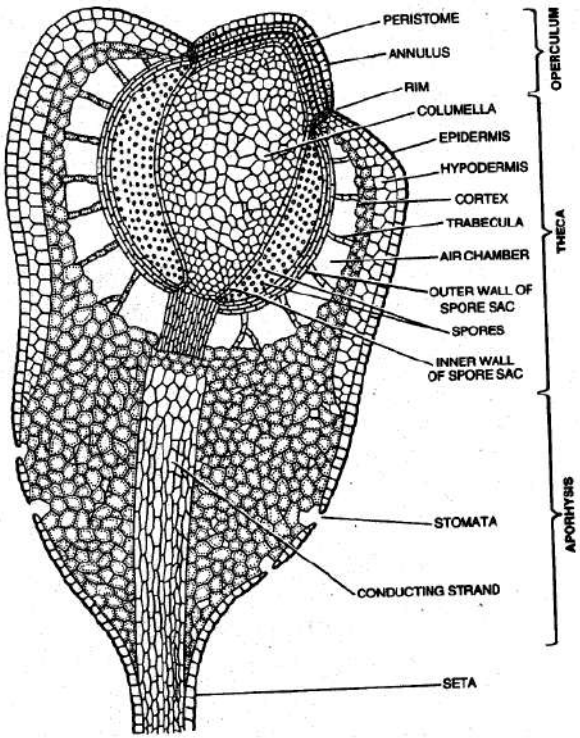
- Phyllidia are organs responsible for photosynthesis.
- They have a wide variety of shapes.
- They usually have one layer of cells, though sometimes they have more than one.
- They may or may not have a midrib.
- They are usually arranged in several rows (but sometimes in two).

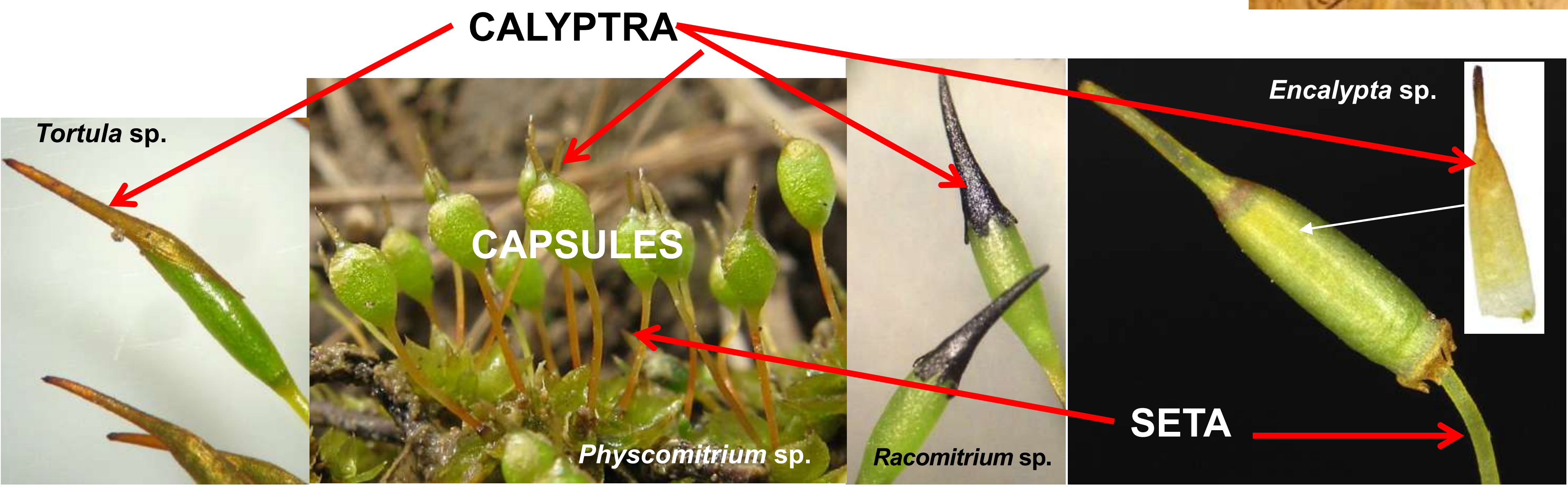




The sporophyte of mosses

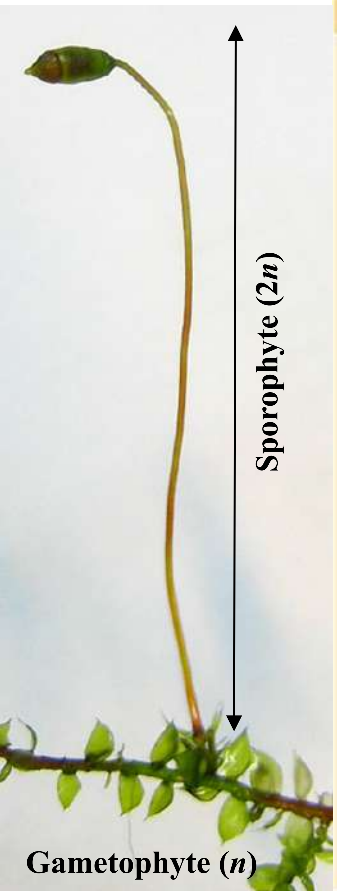
- The **sporophyte** of mosses consists of a **stalk**, a **seta** and a **capsule**.
- The capsule wall is multi-layered and has **stomata**.
- The capsule has a mass of sterile central tissue: the columella.
- It has a **calyptra**, which is generated from the neck of the archegonium and is preserved until the end of the sporophyte's development.

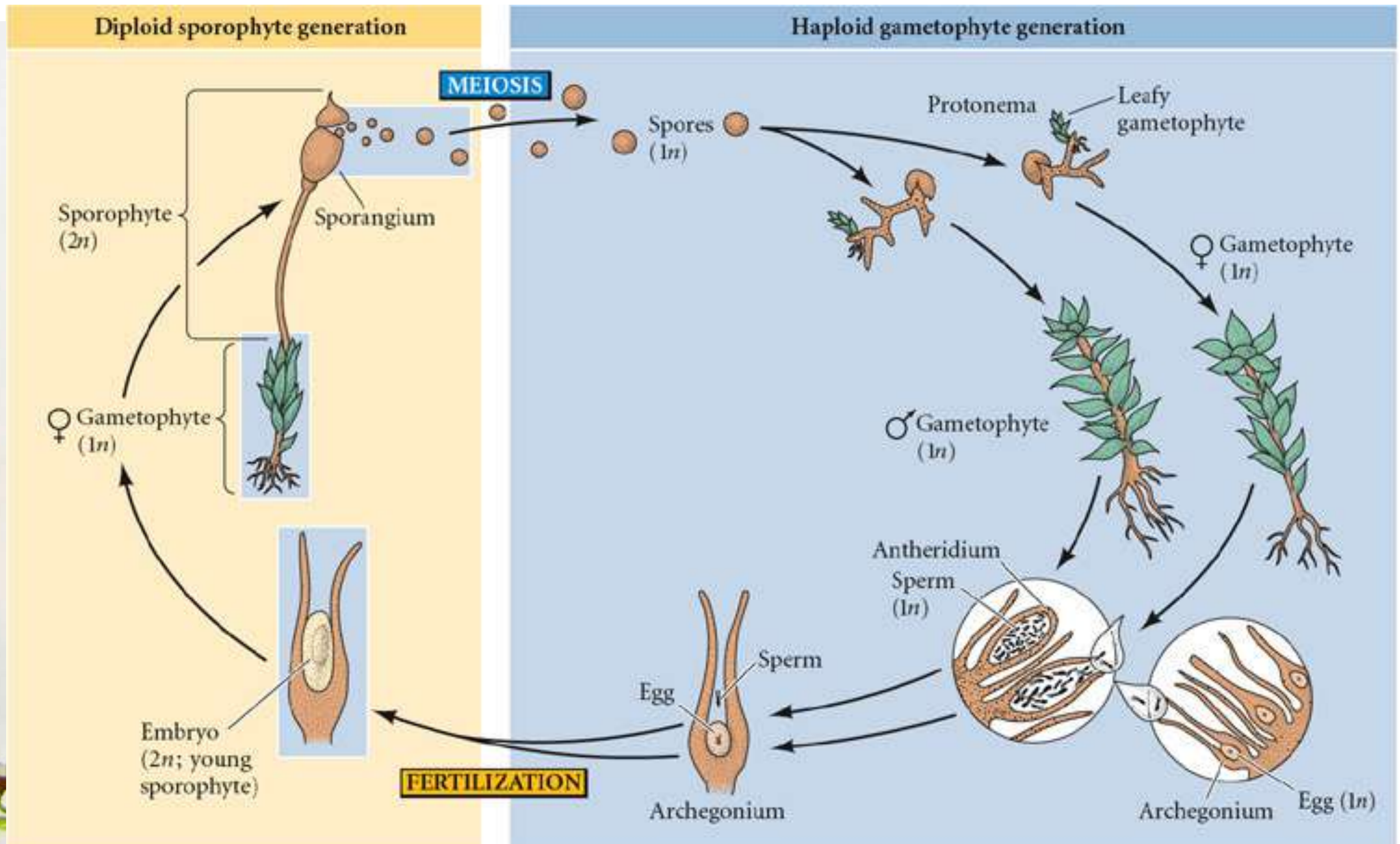




The life cycle of a moss

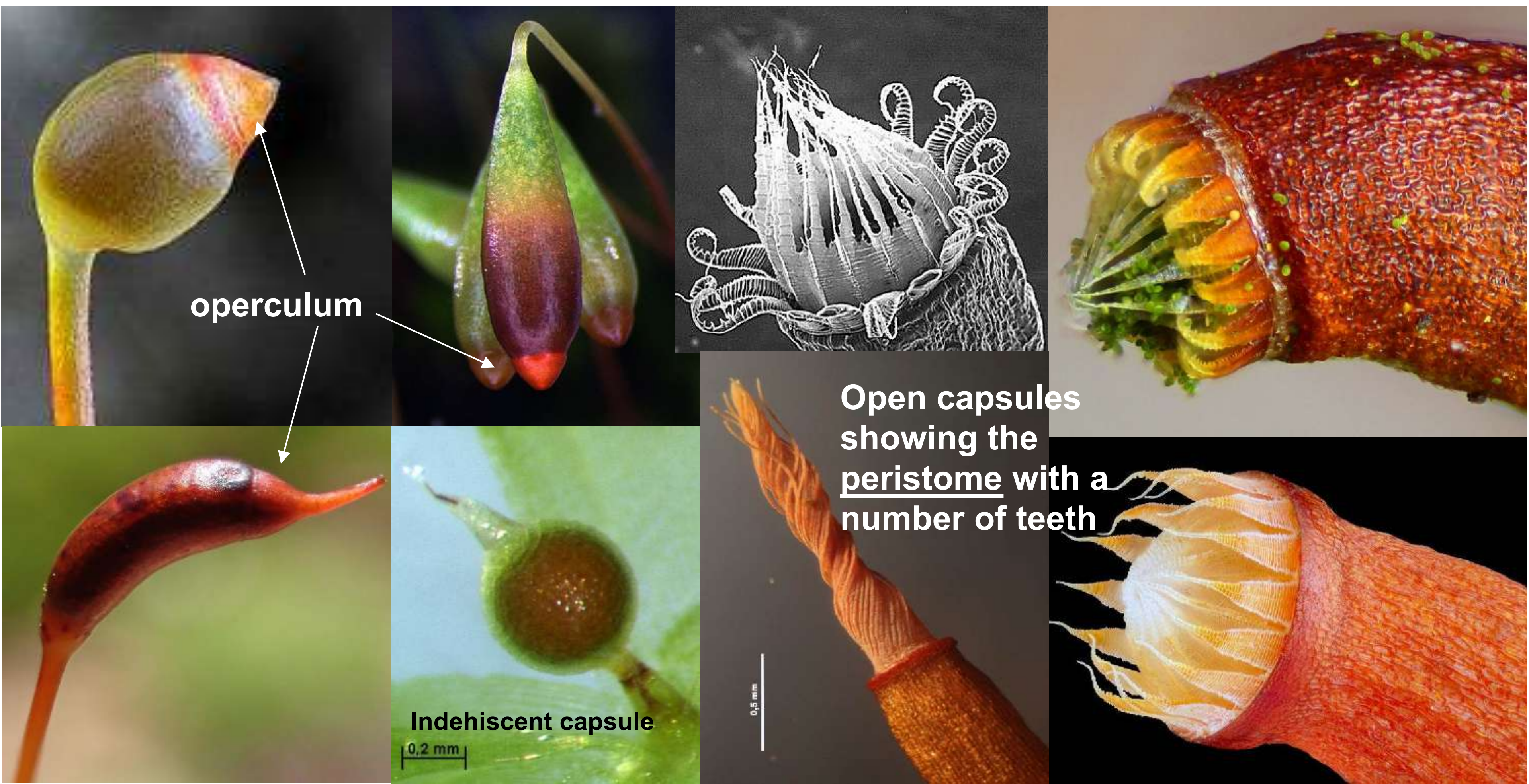
In **bryophytes**, the generation that lives the longest – and is therefore the **dominant** one in their life cycle – is the **gametophyte**.





Capsular dehiscence in the sporophyte

The capsule of many mosses opens via an **operculum** that is detached when the spores are mature. Other species have indehiscent capsules or other types of dehiscence.

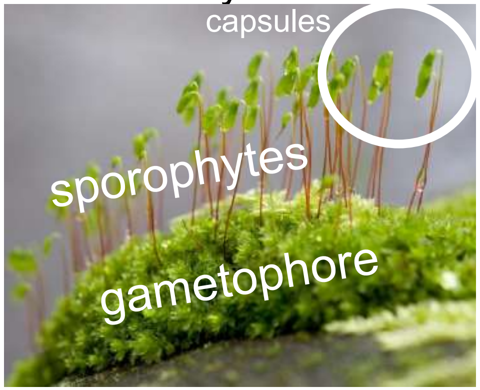


Detailed explanation of a moss life cycle

A moss begins its life cycle when haploid spores, which are produced in the **sporophyte capsule**, land on a moist substrate and begin to germinate. From the one-celled spore, a highly branched system of filaments, called the **protonema,** develops.

Cell specialisation occurs within the protonema to form a horizontal system of reddish-brown, anchoring filaments, called **caulonemal** filaments, and upright, green filaments, called **chloronemal** filaments. Each protonema, which superficially resembles a filamentous alga, can spread over several centimetres to form a fuzzy green film over its substrate. As the protonema grows, some cells of the caulonemal filaments specialise to form leafy buds that will ultimately form the adult gametophyte shoots (**gametophores**). Numerous shoots typically develop from each protonema such that, in fact, a single spore can give rise to a whole clump of moss plants. Each leafy shoot continues to grow apically, producing leaves in spiral arrangement on an elongating stem. In many mosses the stem is differentiated into a central strand of thin-walled water-conducting cells, called **hydroids**, surrounded by a parenchymatous cortex and a thick-walled epidermis. The leaves taper from a broad base to a pointed apex and have laminas that are only one-cell layer thick. A hydroid-containing midvein often extends from the stem into the leaf.

Near the base of the shoot, reddish-brown, multicellular **rhizoids** emerge from the stem to anchor the moss to its substrate. Water and mineral nutrients required for the moss to grow are absorbed not by the rhizoids but by the thin leaves of the plant as rainwater washes through the moss cushion.

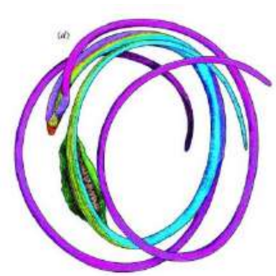


Detailed explanation of a moss life cycle

As **is typical of bryophytes, mosses produce large, multicellular sex organs for reproduction. Many bryophytes are unisexual, or sexually dioicous**. In mosses male sex organs, called **antheridia**, are produced in clusters at the tips of shoots or branches on the male plants, while the female sex organs, the **archegonia**, are produced in similar fashion on female plants. Numerous <u>motile sperm</u> are produced by mitosis inside the brightly coloured, club-shaped antheridia while a single egg develops in the base of each vase-shaped archegonium. As the sperm mature, the antheridium swells and bursts open. Drops of rainwater falling into the cluster of open antheridia splash the sperm to nearby females. Beating their two whiplash flagellae, the sperm are able to move short distances in the water film that covers the plants to the open necks of the archegonia. Slimy mucilage secretions in the archegonial neck help pull the sperm downwards to the egg. The closely packed arrangement of the individual moss plants greatly facilitates fertilisation. Rain forest bryophytes that hang in long festoons from the trees rely on torrential winds with the rain to transport their sperm from tree to tree, while the small pygmy mosses of exposed, ephemeral habitats depend on the drops of morning dew to move their sperm. Regardless of where they grow, **all bryophytes require water for sperm dispersal and subsequent fertilisation.**

Archegonia

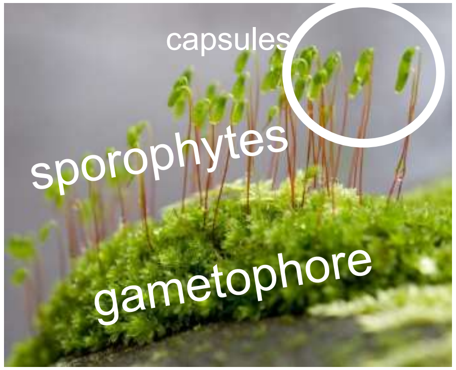
Anteridia

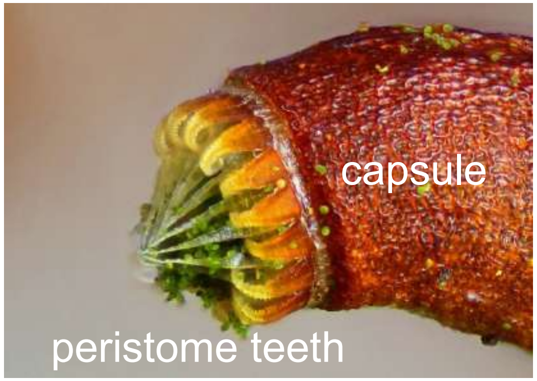


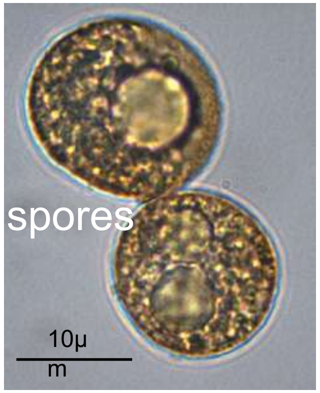
Sperm

Detailed explanation of a moss life cycle

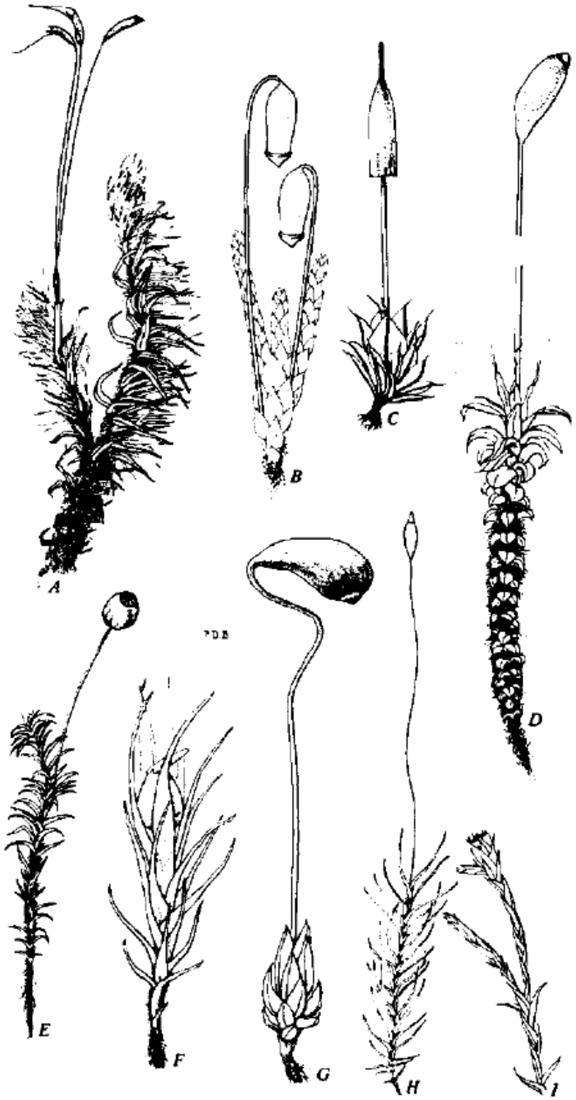
Embryonic growth of the sporophyte begins within the archegonium soon after fertilisation. At its base, or foot, the growing embryo forms a nutrient-transfer zone, or placenta, with the gametophyte. Both organic nutrients and water move from the gametophyte into the sporophyte (matrotrophy) as it continues to grow. In mosses the sporophyte stalk, or **seta**, tears the archegonial enclosure early in development, leaving only the foot and the very base of the seta embedded in the gametophyte. The upper part of the archegonium remains over the tip of the sporophyte as a cap-like **calyptra**. Sporophyte growth ends with the formation of a sporangium or **capsule** at the tip of the seta. **Within the capsule, water-resistant spores are formed by meiosis.** As the mature capsule swells, the calyptra falls away. This allows the capsule to dry and break open at its tip. Special membranous structures, called **peristome teeth**, which are folded down into the spore mass, now bend outward, flinging the spores into the drying winds. Moss spores can travel great distances on the winds, even moving between continents on the jet streams. Their walls are highly protective, allowing some spores to remain viable for up to 40 years. Of course, if the spore lands in a suitable, moist habitat, germination will begin the cycle all over again.



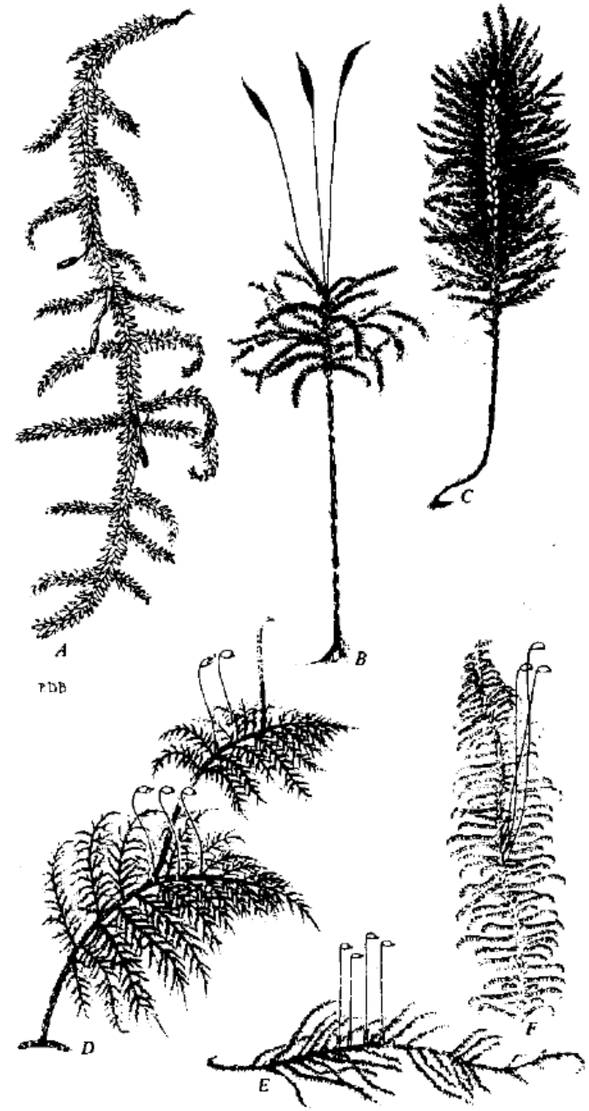




Growth forms



Acrocarpous mosses



Pleurocarpous mosses

Mosses live mostly in terrestrial habitats

Mosses live on the **forest floor**, in thickets, and even in open and exposed environments such as **biological crusts**.


Dicranum scoparium


Hylocomium splendens


Brachythecium rutabulum


Syntrichia ruralis

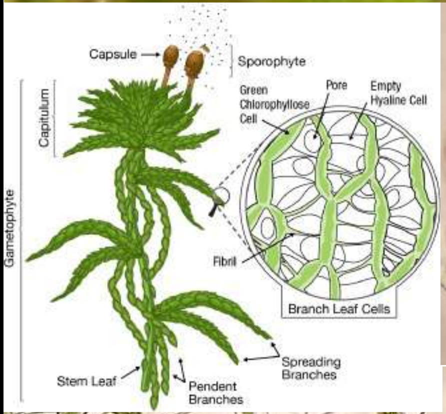
Mosses also grow on rocks

Epiphytes grow on twigs, branches or the bark of trees

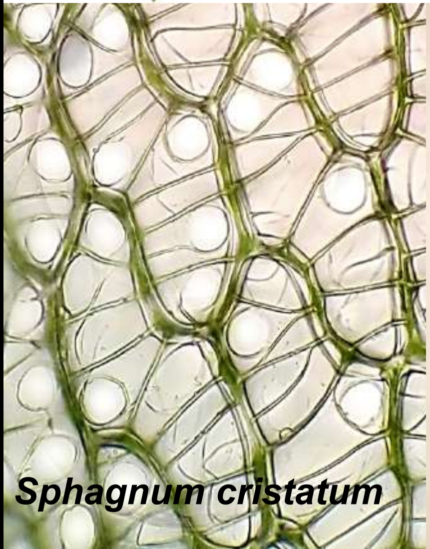
Wet meadows and peat bogs
Sphagnum spp. (peat moss)

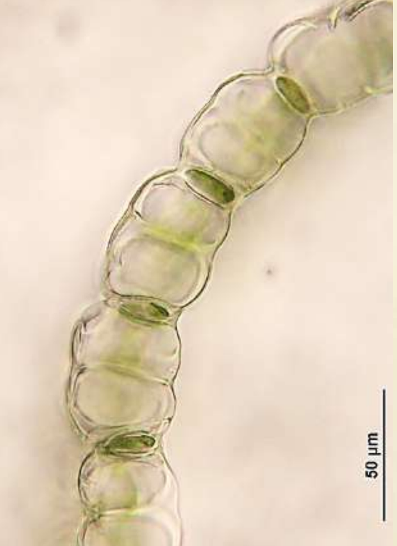
Tollund Man
(375-210 BC)

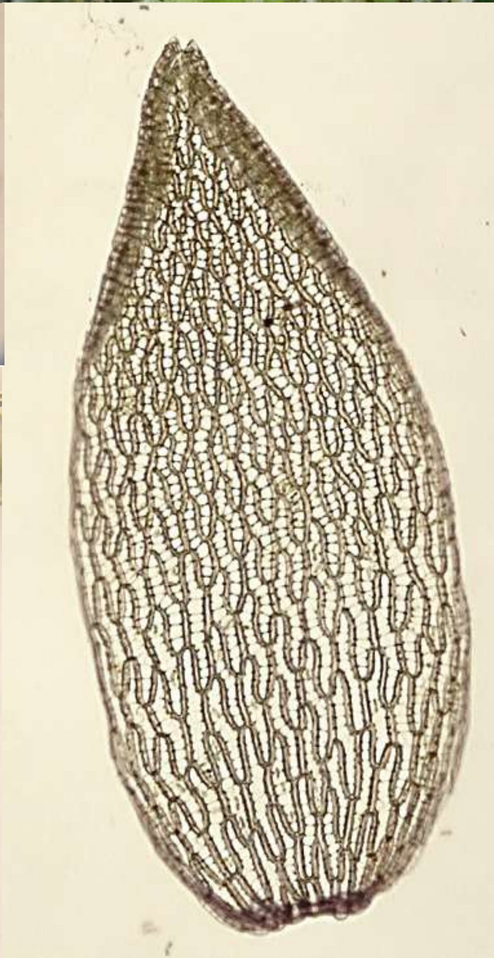
Sphagnum spp. (peat moss)



Sphagnum palustre







Uses of bryophytes

“**Bryophytes** are used to cure hepatic disorders, skin and cardiovascular **diseases**, used as antipyretic, **antimicrobial** (antifungal & antibacterial), wound healing and as **food** by different tribal communities. Apart from ethno-medicinal uses some bryophytes possess **antitumor activities** against different cancer cell lines and this property of bryophytes needs to be more focused in the future” (Chandra et al. 2017). Some types of moss can be used as a **natural sponges**, since they absorb water quite well. **Peat moss** can be cut from the ground and burned as **fuel** or used for **gardening** and increasing the soil’s acidity. They also have a **decorative use**.

Comparative summary of several characteristics of bryophyte phyla

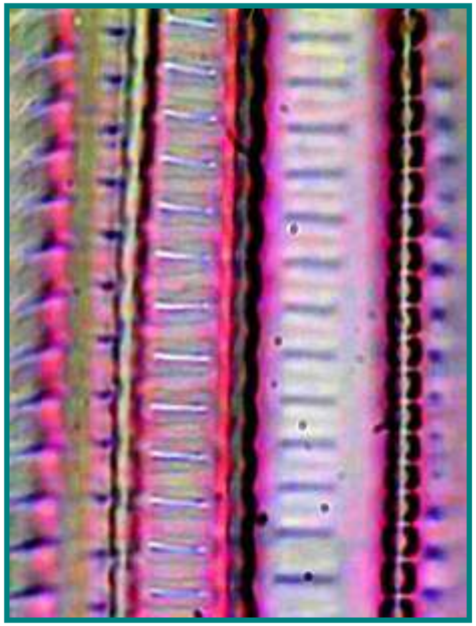
Phylum	General characteristics of the gametophyte	General characteristics of the sporophyte
Marchantiophyta (liverworts)	Both thalloid and foliose species; unicellular rhizoids; most cells have numerous chloroplasts.	Small and nutritionally dependent on gametophyte; unbranched; consist of a little more than a capsule in some genera, and a stalk, short seta and a capsule in others; lack stomata.
Bryophyta (mosses)	Foliose; multicellular rhizoids; most cells have numerous chloroplasts; some species have leptoids and non-lignified hydroids.	Small and nutritionally dependent on gametophyte; unbranched; consists of a stalk, long seta and a capsule; stomata present; some species have leptoids and non-lignified hydroids in the seta.
Anthocerotophyta (hornworts)	Thalloid; unicellular rhizoids; most have a single chloroplast per cell and a pyrenoid; some species associate symbiotically with cyanobacteria.	Small and nutritionally dependent on gametophyte; unbranched; consist of a stalk and a long, horn-shaped capsule; stomata present; no specialised conducting tissues.

Lecture 08
Pteridophytes: seedless vascular plants

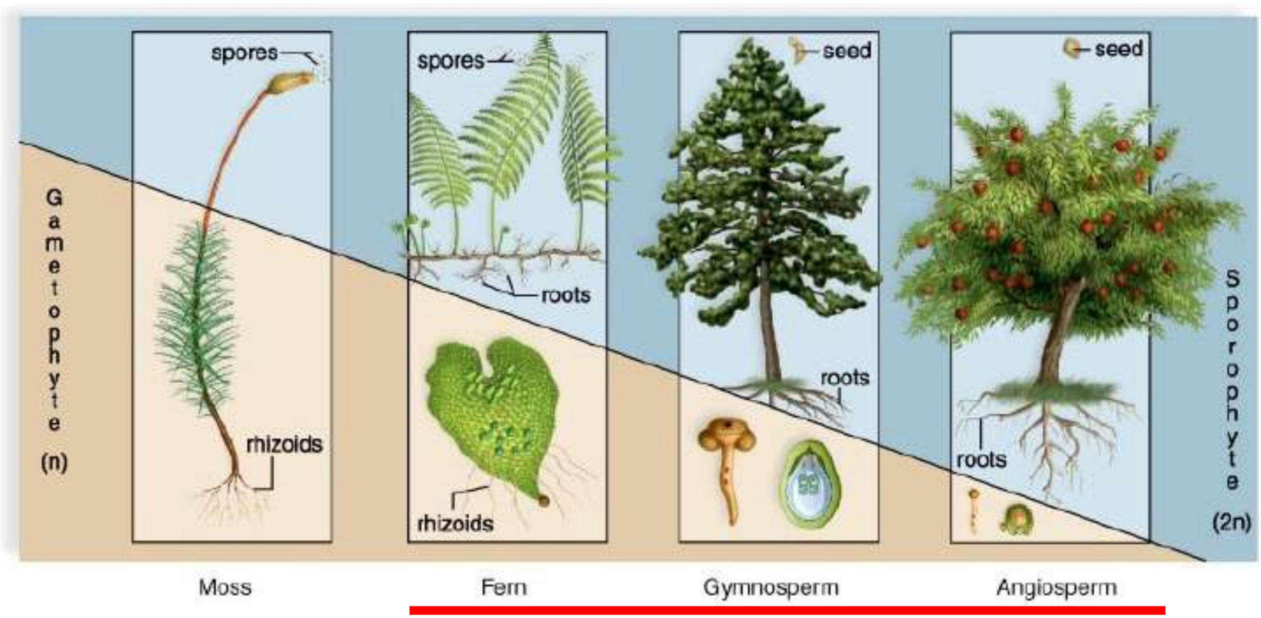
Main topics

The origin of cormophytes	Pteridophytes, or ferns
Phylum *Lycopodiophyta*	Phylum *Monilophyta*

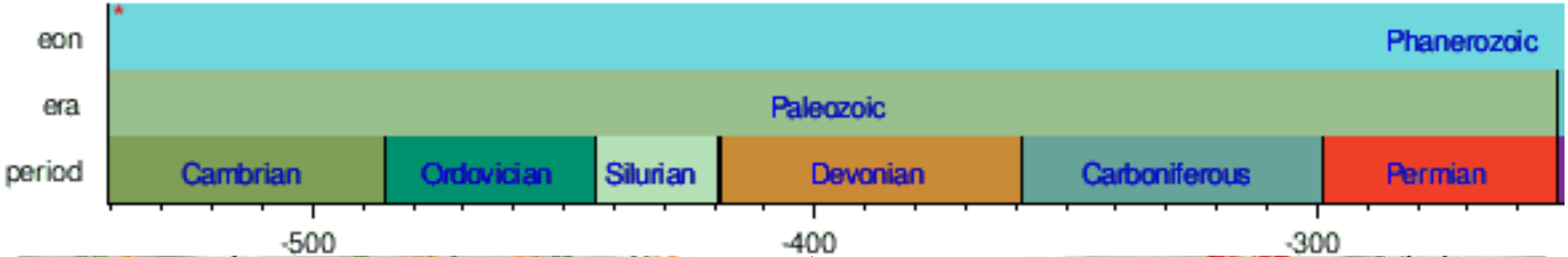
The origin of cormophytes (also called tracheophytes)

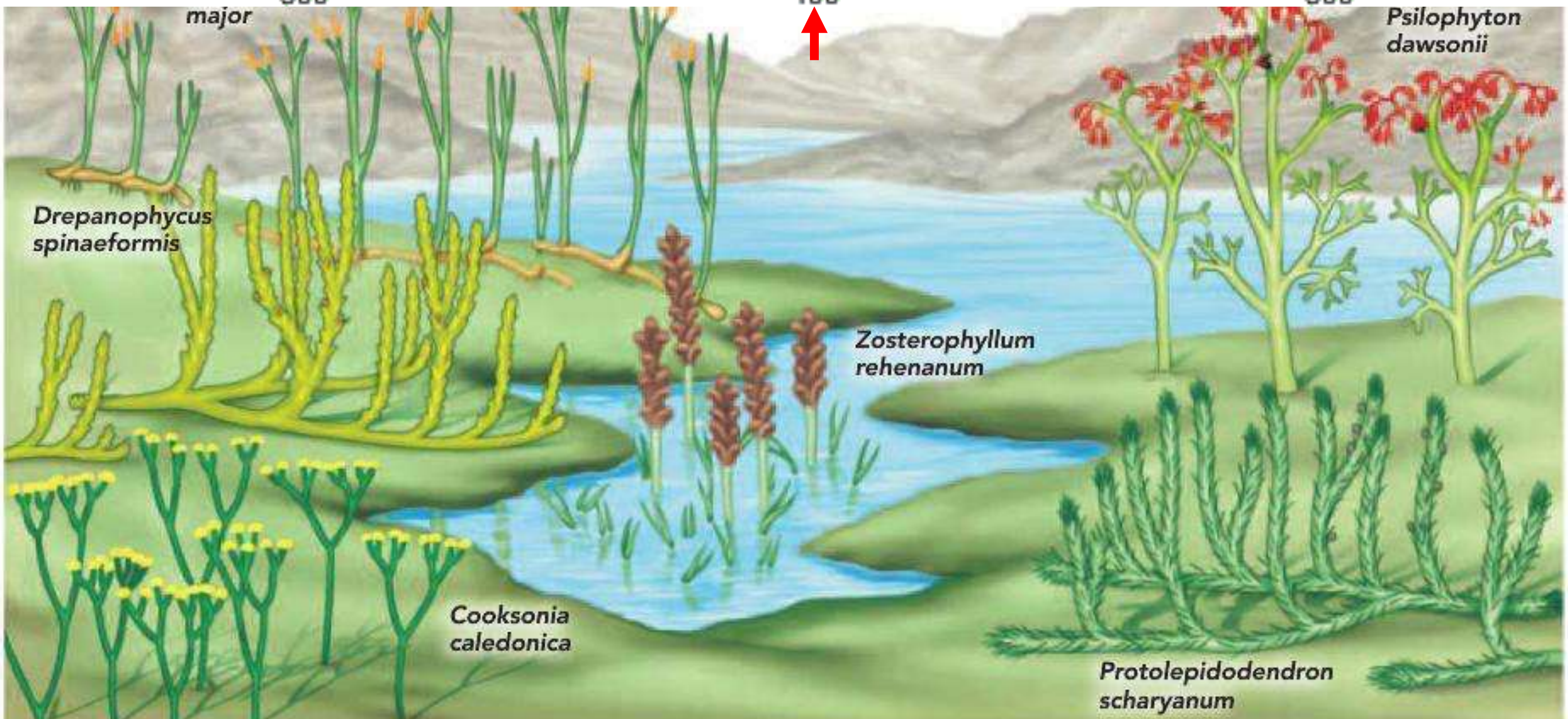


- Vascular plants (cormophytes, or tracheophytes) are the result of a process of **adaptation to the terrestrial environment**.
- The appearance of **lignin** was decisive, as this substance, incorporated into the cell wall, increases its **rigidity**.
- In primitive vascular plants, the underground areas of the plant were similar to the aerial ones. From these primitive vascular plants, others evolved with a much more complex vegetative structure consisting of a **root**, a **stem** and **leaves**.
- The complexity and persistence of the **gametophyte is progressively reduced**.



Extant tracheophytes





Devonian landscape. During the Devonian period (409-363 Mya), a series of plants of three different phyla (*Rhynophyta*, *Zosterophyllophyta* and *Trimerophyta*) had colonised swampy environments. Drier environments, far from water, were not colonised by these plants. By the end of the Devonian period, most of the species of these marsh plants had become extinct. It is not known whether the transition from green algae to land plants occurred on a single occasion or on several occasions.

Vascular plants are well adapted to the terrestrial environment and are dominant in these ecosystems.

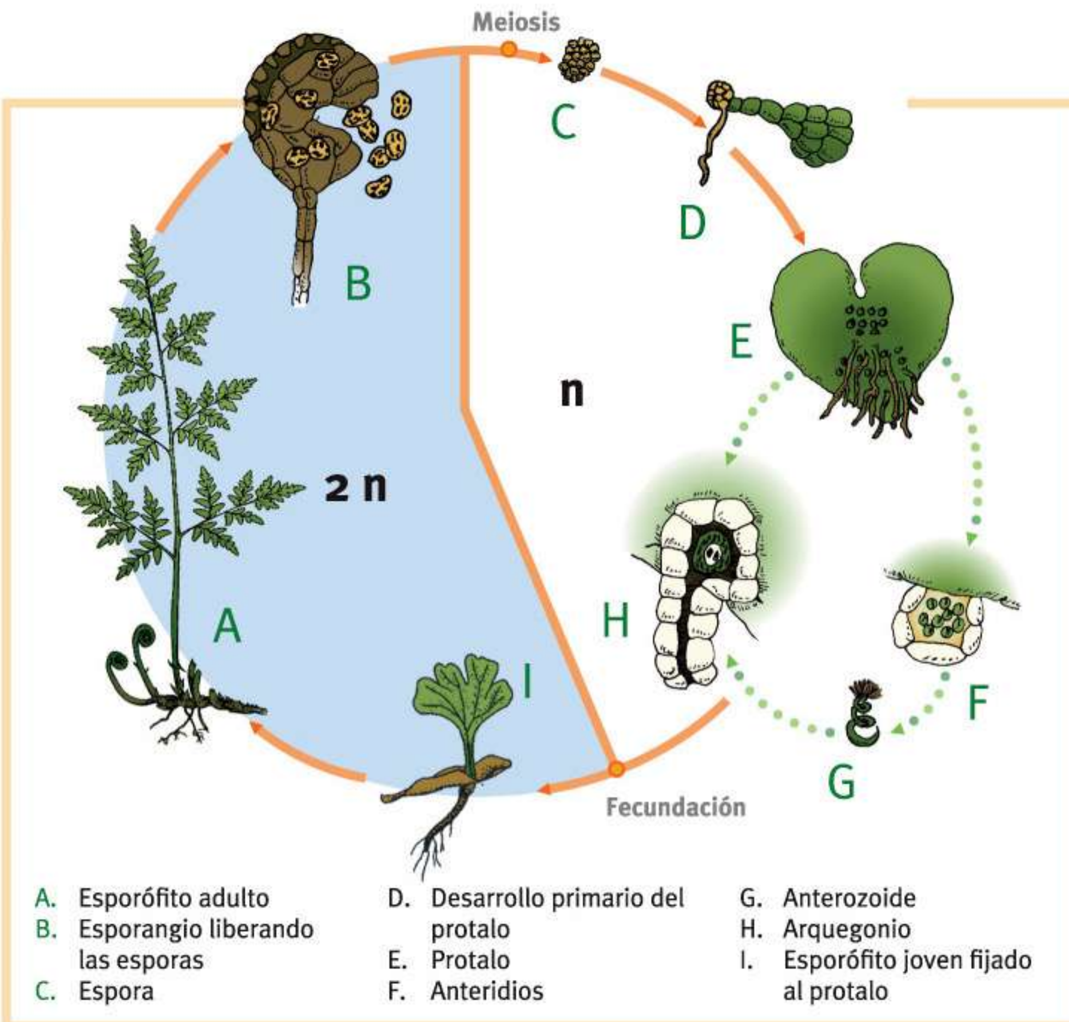
Vascular plants were diverse during the Devonian (408-362 million years ago).

Main topics

The origin of cormophytes	Pteridophytes, or ferns
Phylum *Lycopodiophyta*	Phylum *Monilophyta*

Vegetative and reproductive traits of pteridophytes: the life cycle

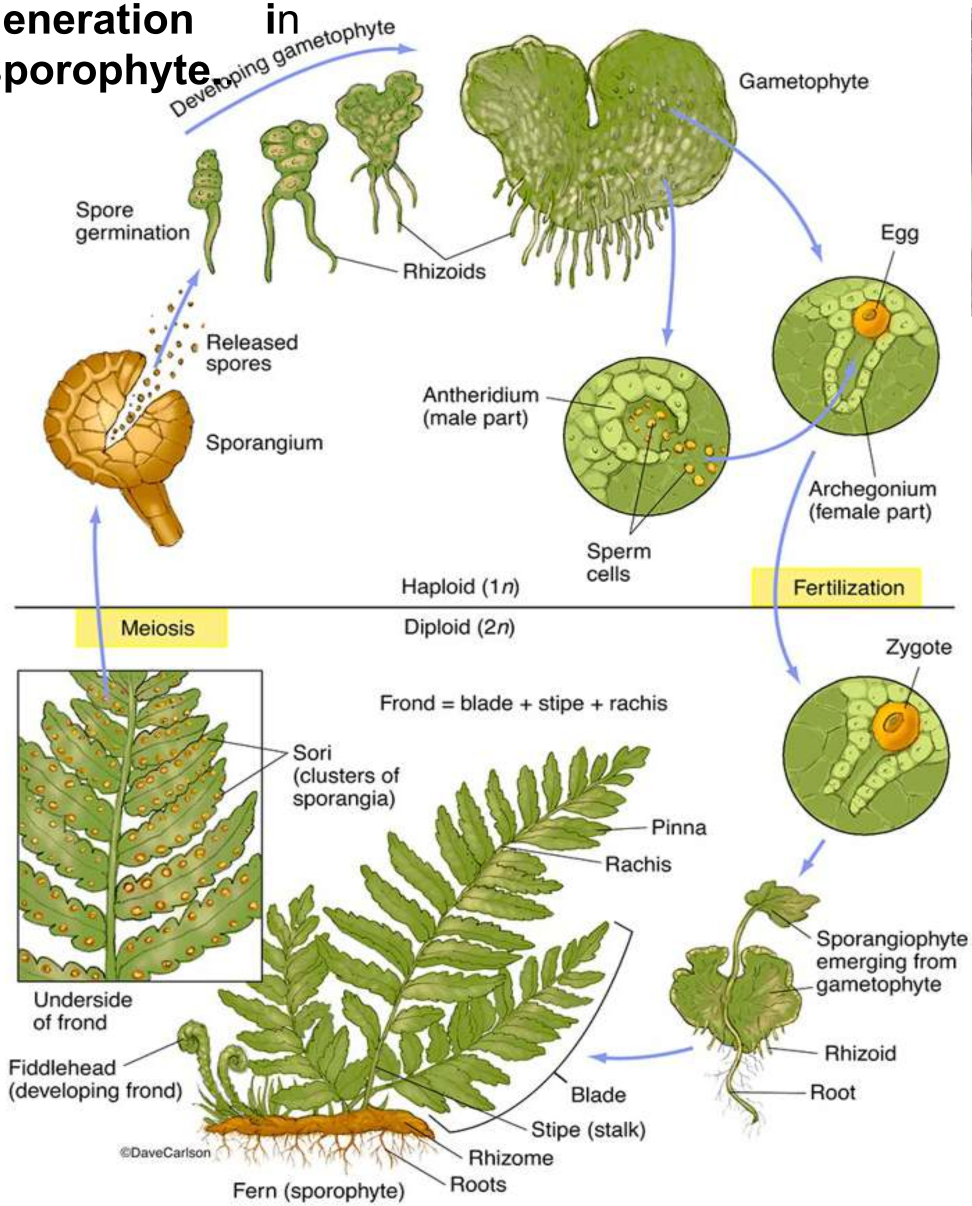
Sporic meiosis occurs during the life cycle of **pteridophytes** (also called **ferns**) so these plants show **alternation of generations**: one is haploid (gametophyte) while the other is diploid (sporophyte). The life cycle is therefore called **digenetic haplo-diploid**. It is also **heteromorphic** because gametophytes and sporophytes are morphologically distinct, with a **dominance of the sporophyte**.



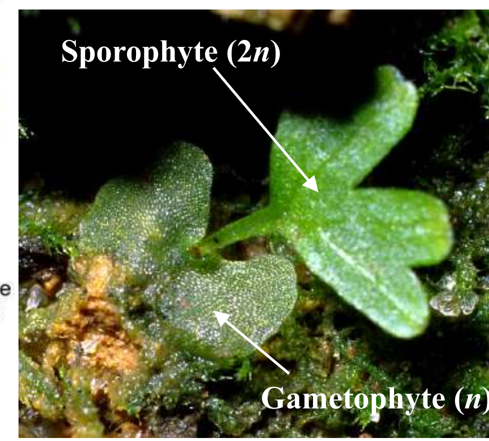
Vegetative and reproductive traits of pteridophytes: the **life cycle**

The **dominant generation in pteridophytes** is the **sporophyte**

Sporophyte (2*n*)



Gametophyte (*n*)



Vegetative and reproductive traits of pteridophytes

The stems of present-day pteridophytes may be **rhizomes** or **erect stems** with a columnar appearance reminiscent of palms (e.g. tree ferns). In most cases there is no secondary growth in thickness.

rhizome

Tree fern with a columnar stem

Vegetative and reproductive traits of pteridophytes

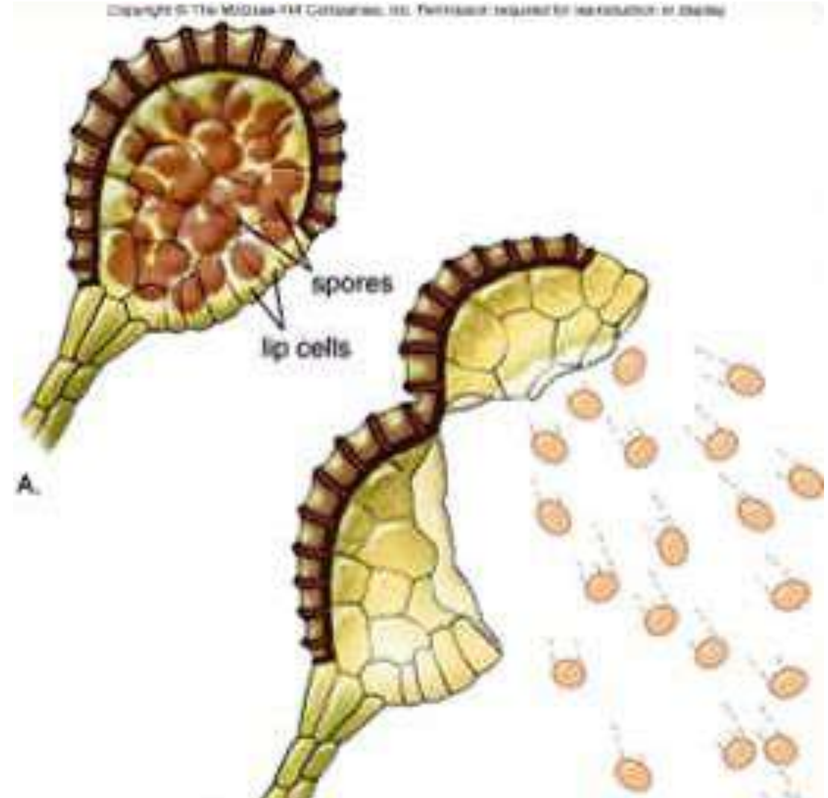
The dominant life cycle stage is the sporophyte, which develops true leaves. Two kinds of leaves in pteridophytes are defined according to their size and the abundance and arrangement of vascular vessels (bundles of xylem and phloem).

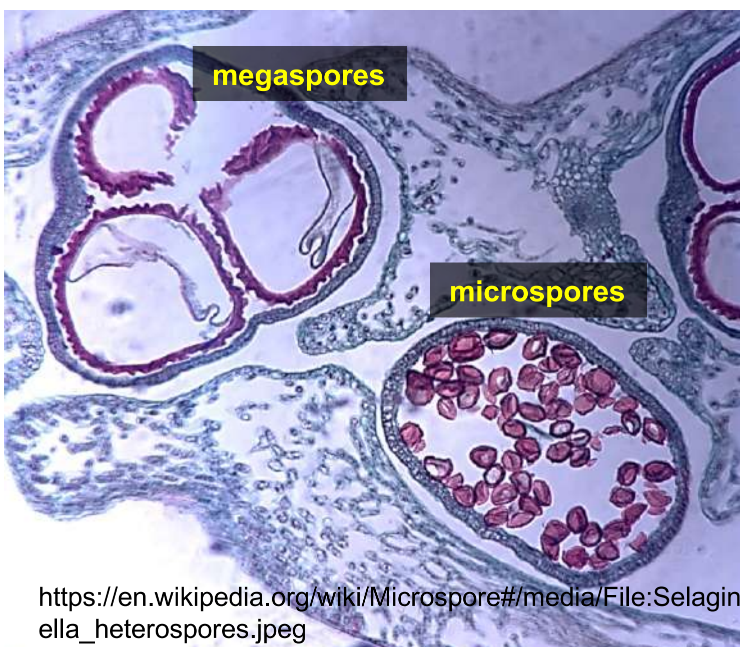
Vegetative and reproductive traits of pteridophytes

- **Sporophytes** produce **sporangia**, which produce **haploid spores** after **meiosis**.

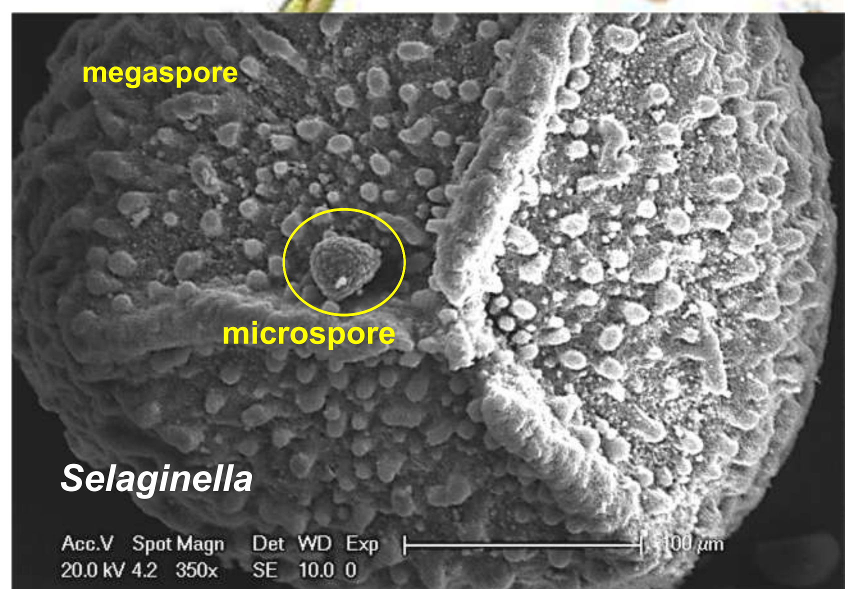
- The spores produced may be identical (**isosporic**) or different (**heterosporic**). There are therefore isosporic pteridophytes or heterosporic pteridophytes.

- The spores have a well-structured wall made up of **sporopollenin**.





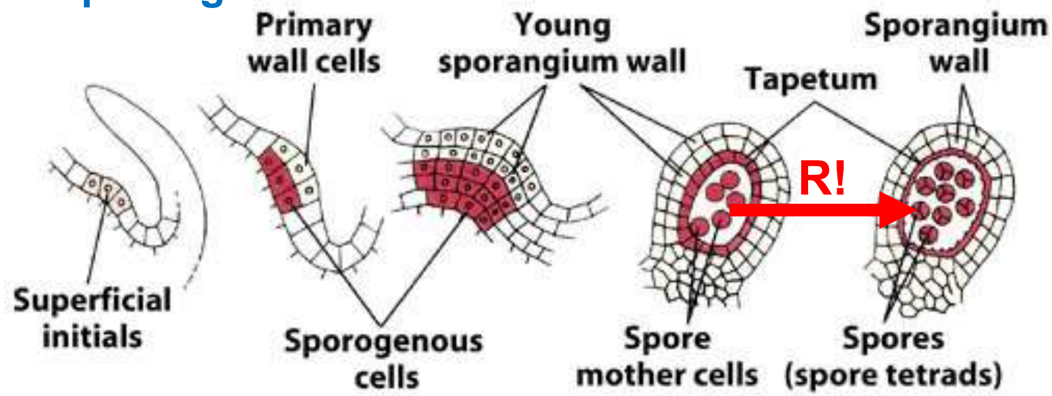
https://en.wikipedia.org/wiki/Microspore#/media/File:Selaginella_heterospores.jpeg

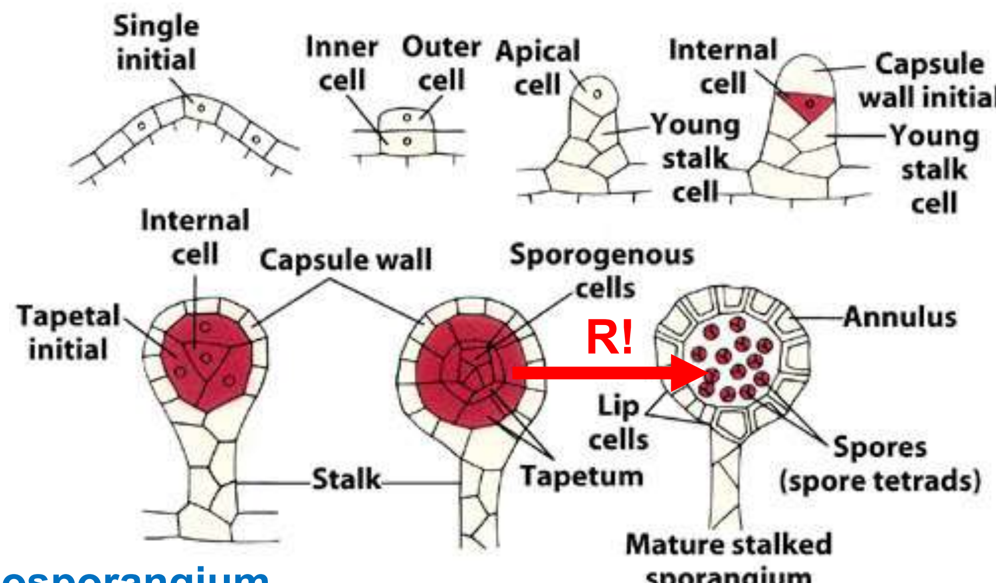


Vegetative and reproductive traits of pteridophytes

Sporophytes form sporangia, which, depending on their development, may be **eusporangiate** or **leptosporangiate**.

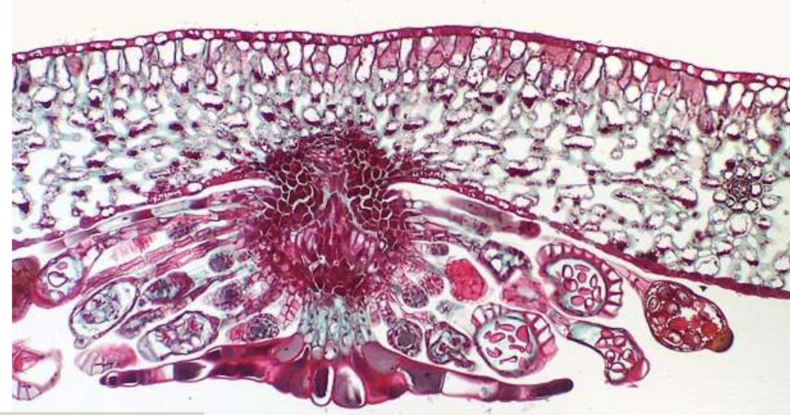
eusporangium

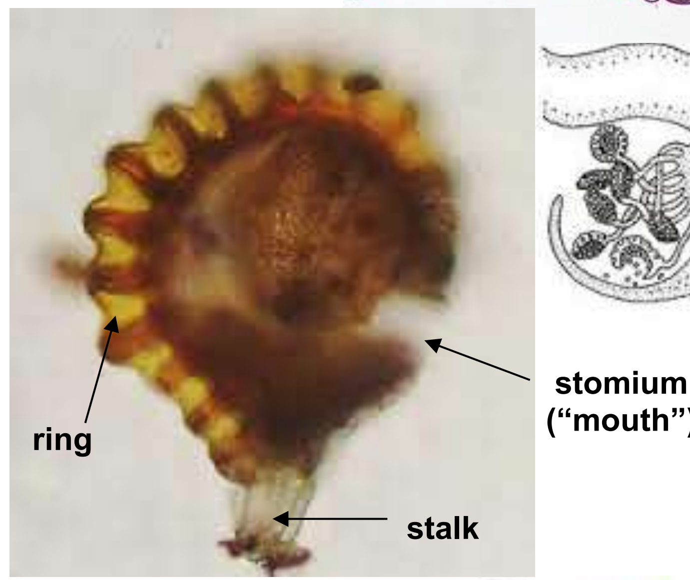


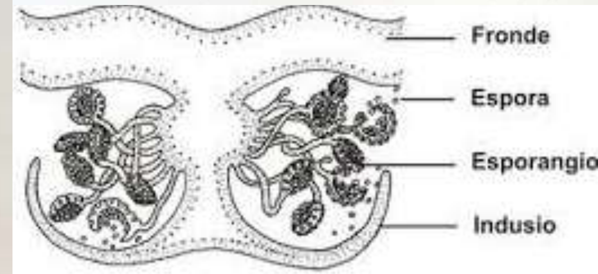


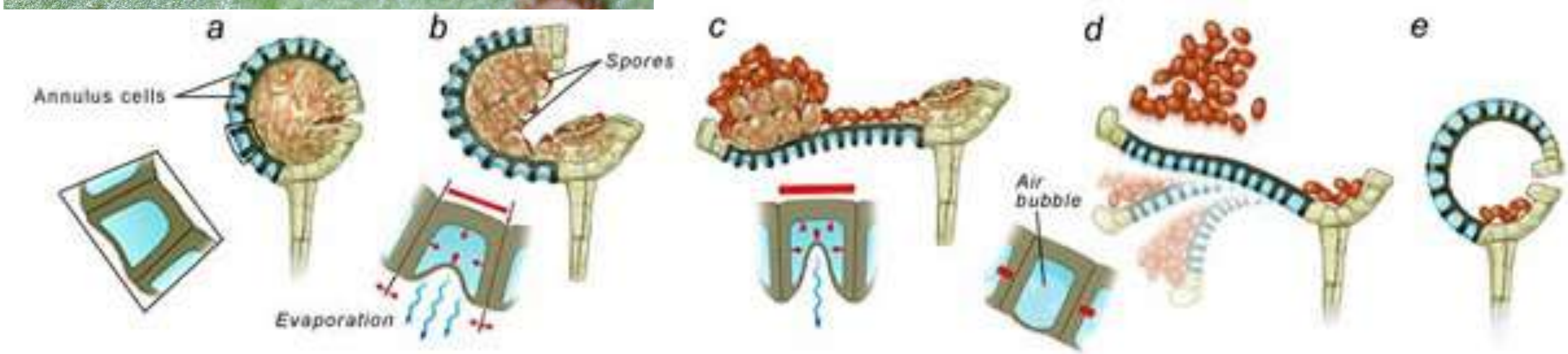
leptosporangium

In **leptosporangia** a cluster of cells forms the **annulus**. The sporangia are grouped in **sori** (sing. sorus) and may or may not be protected by the **indusium** (pl. indusia).









Different types of sori

Circular, naked sori of ***Polypodium cambricum***.

Linear sori with lateral indusium of ***Asplenium* sp**.

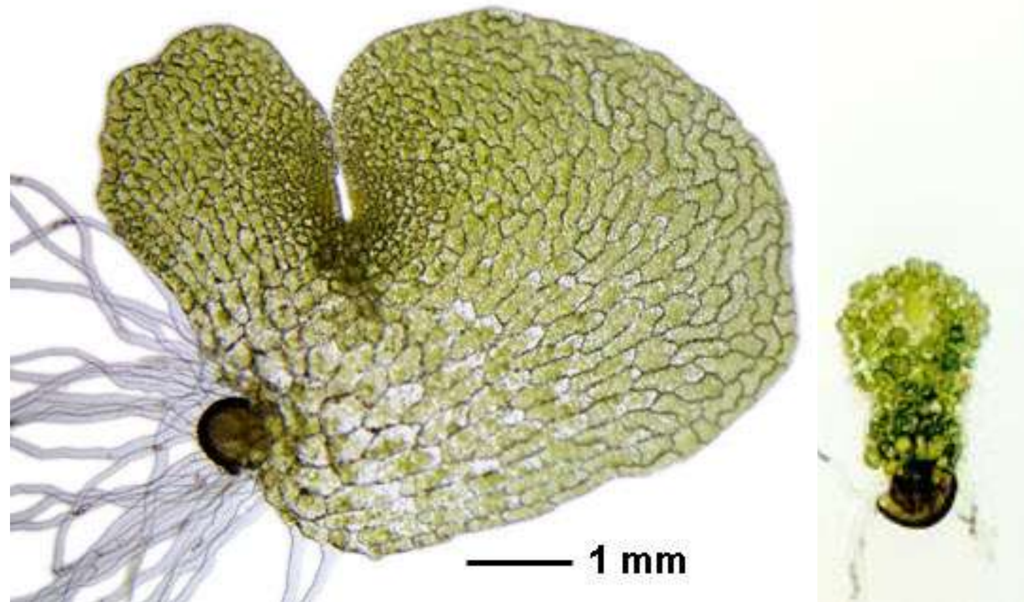
Circular sori with circular, peltate indusia of ***Cyrtomium falcatum.***

Marginal sori with false indusia of ***Adiantum capillus-veneris***.

Circular sori with kidney-shaped indusium of ***Dryopteris filix-mas.***

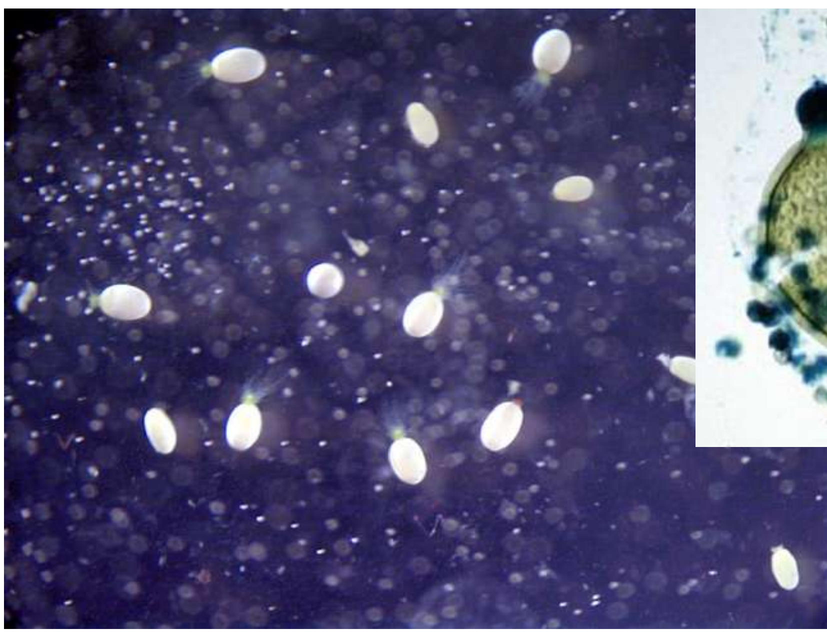
Vegetative and reproductive traits of pteridophytes

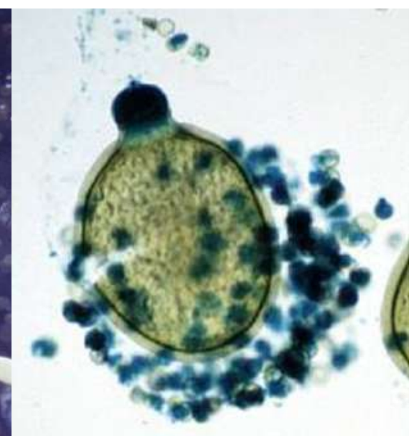
The gametophyte of a pteridophyte is called the PROTHALLUS



- <u>Most pteridophytes are isosporic.</u> In these cases, the prothalli are exosporic and monoecious.

- Heterosporic pteridophytes are rare. In this case, the prothalli are endosporic and dioecious.





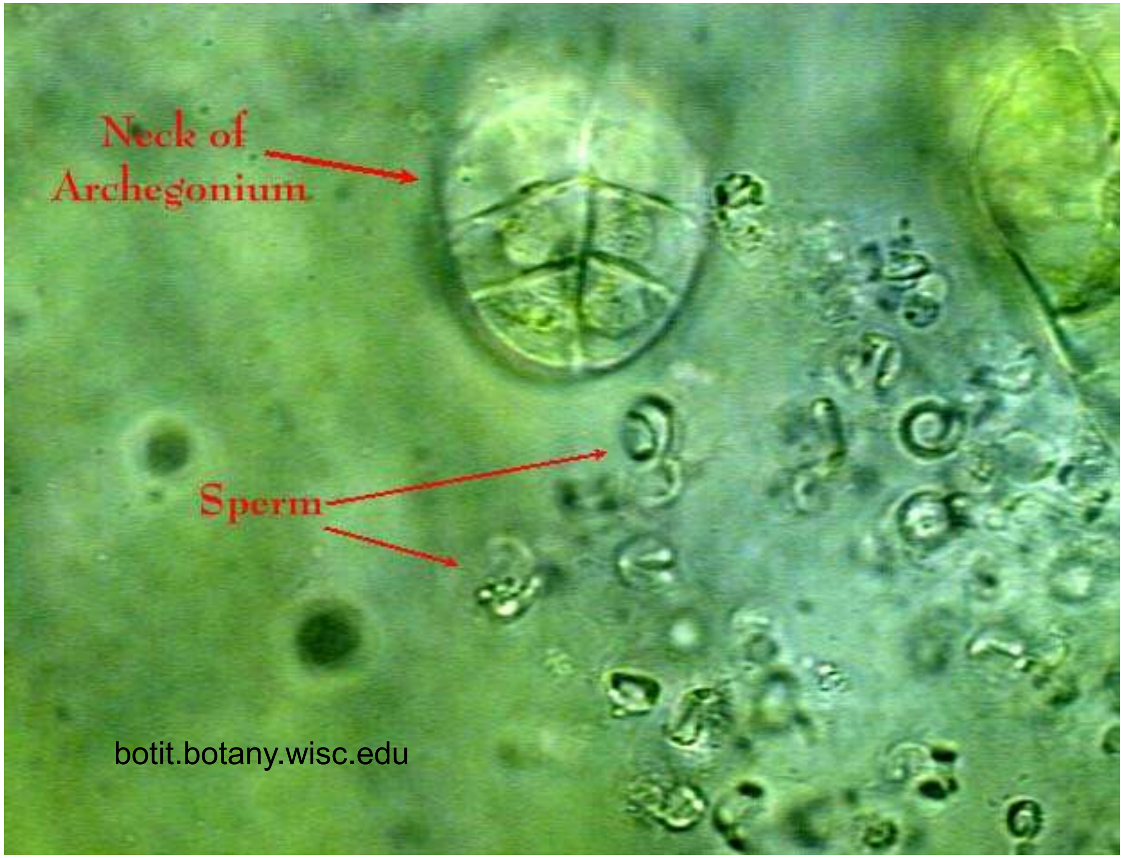
Marsilea
Microspores and macrospores.
Endosporic gametophytes.

Vegetative and reproductive traits of pteridophytes

Reproductive systems

In seedless vascular plants, fertilisation is via **oogamy** and the male gametes have to swim in a liquid medium.

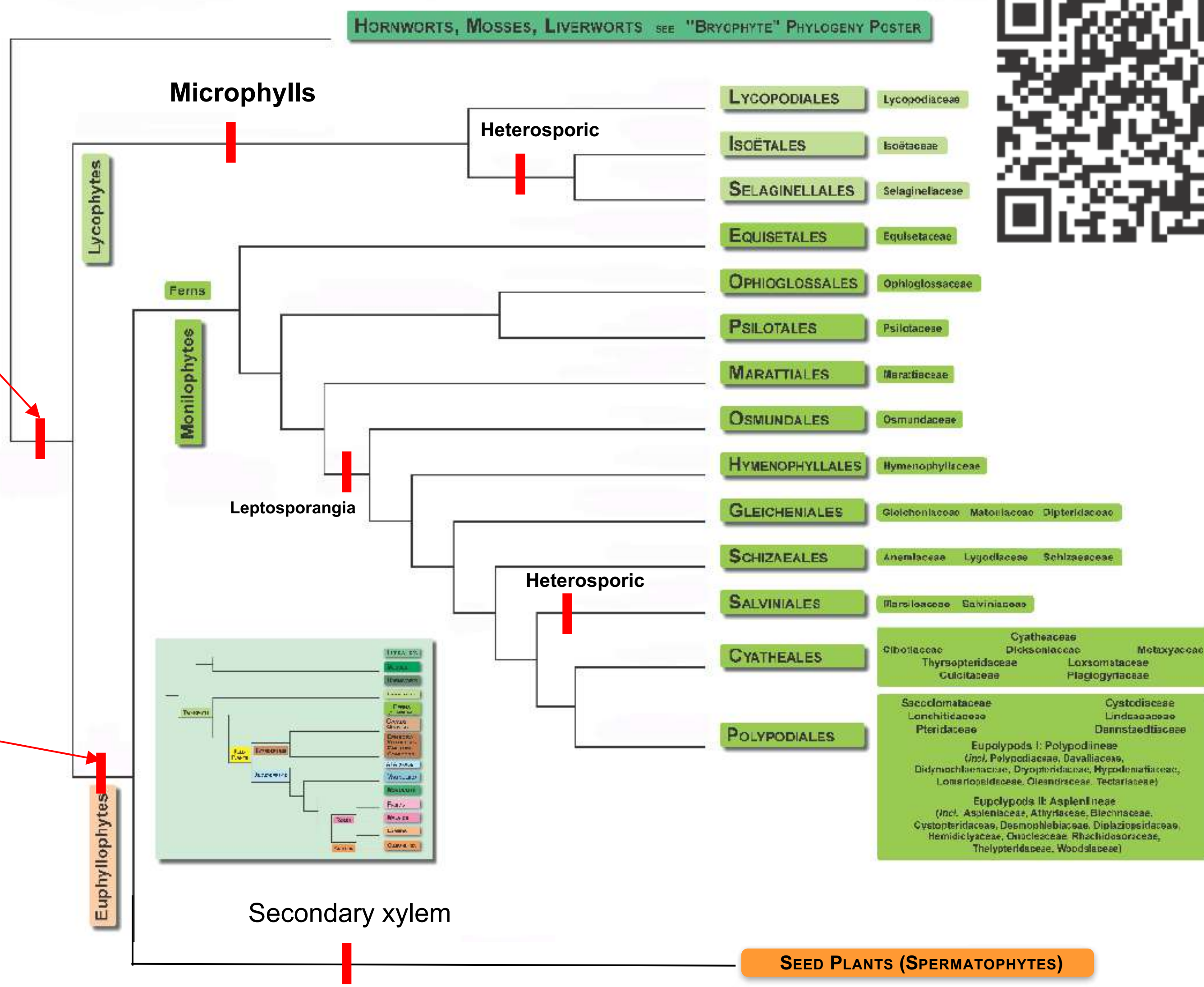
Although many gametophytes are monoecious, there is usually no self-fertilisation due to the temporary separation of the male and female phases (**dichogamy**).



Evolutionary relationships in ferns

Dominance of the sporophyte, which is branched and with many sporangia;
presence of vascular vessels (xylem & phloem) and, therefore, lignin.

Megaphylls.
Male gametes with multiple flagella.

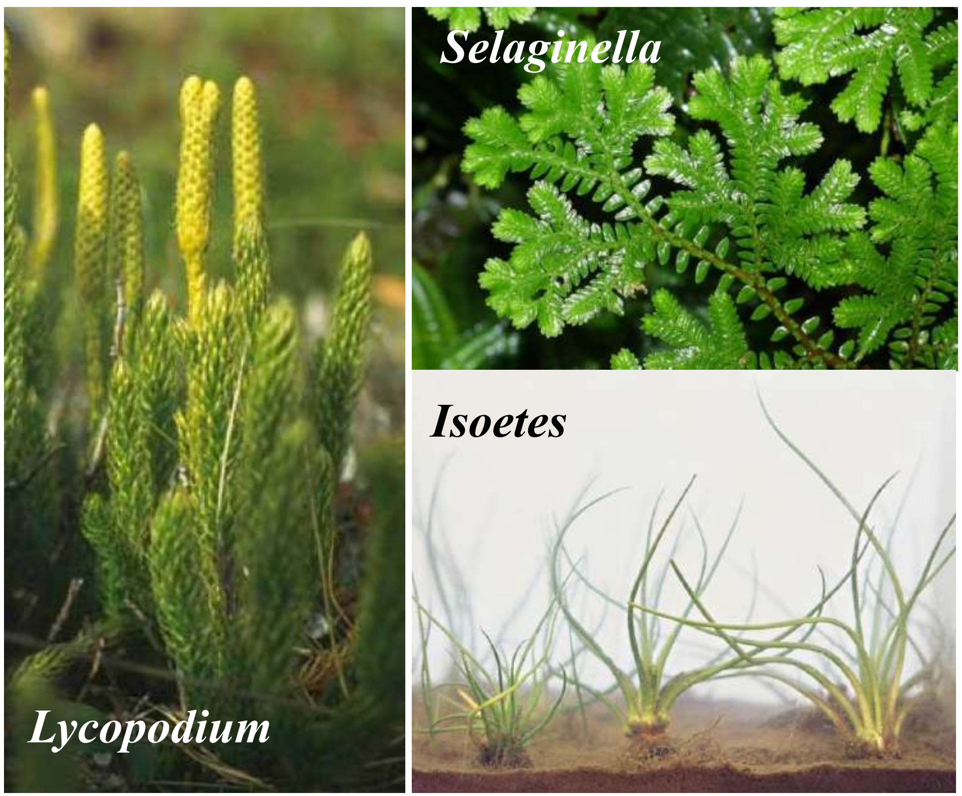


(Adapted from Cole *et al.*, 2019)

Updated circumscription of extant ferns

Extant ferns are included into two phyla:

Lycopodiophyta



Monilophyta

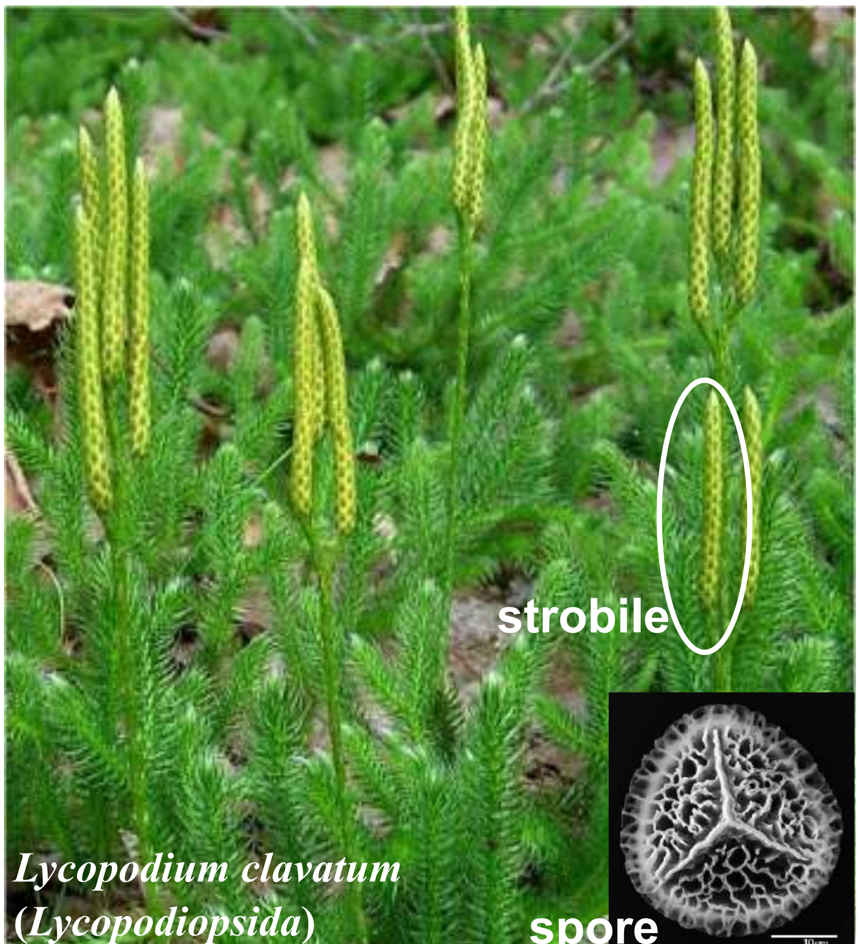
Main topics

The origin of cormophytes	Pteridophytes, or ferns
Phylum *Lycopodiophyta*	Phylum *Monilophyta*

Phylum *Lycopodiophyta*

- The sporophytes of extant species are **small plants**. The stem is bulbiform, or a rhizome from which erect sporangium-bearing branches arise; the leaves are **microphylls**.
- They may be isosporic or heterosporic.
- They include the classes *Lycopodiopsida* and *Isoetopsida*.

In ***Lycopodium* spp.**, which is isosporic, sporangia are gathered in terminal **strobiles**.



Lycopodium clavatum is commonly known as club moss, clubfoot moss, foxtail, ground pine, sulfer, and wolf's claw. It is a pteridophyte abundantly found in tropical, subtropical and in many European countries. In homeopathy, it is used in the treatment of aneurisms, constipation, fevers, and chronic lung and bronchial disorders. It also reduces gastric inflammation, simplifies digestion, and helps in treatments of chronic kidney disorders. Several studies support the analgesic, antioxidant, anticancer, antimicrobial, antiinflammatory, neuroprotective, immunomodulatory, and hepato-protective activity of this fern. It also can mitigate tiredness and chronic fatigue. The spores of *Lycopodium clavatum* are used routinely by native Americans in treating nose bleeds and in healing wound (Banerjee et al., 2014).

Phylum *Lycopodiophyta*

- The sporophytes of extant species are **small plants**. The stem is bulbiform, or a rhizome from which erect sporangium-bearing branches arise; the leaves are **microphylls**.
- They may be isosporic or heterosporic.
- They include the classes *Lycopodiopsida* and *Isoetopsida*.

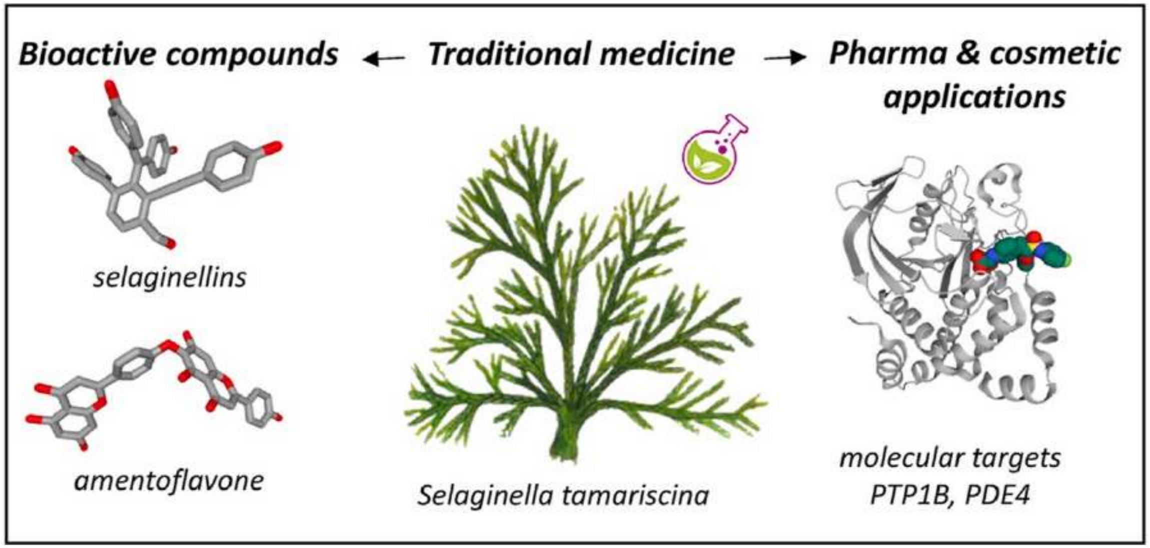
Huperzia selago (Lycopodiopsida)

Bioactive compounds of *Huperzia* spp. are alkaloids (e.g., Huperzine A), which have shown significant effects on preventing the development of Alzheimer Disease (AD) as it improves cognitive function. They are new promising compounds against AD due to their antioxidant, anti-inflammatory and acetylcholinesterase inhibitory activities in the neural system (Yang et al. 2013).

Probably, this alkaloid is produced by endophytic fungi (Su & Yang 2015).

Phylum *Lycopodiophyta*

- The sporophytes of extant species are **small plants**. The stem is bulbiform, or a rhizome from which erect sporangium-bearing branches arise; the leaves are **microphylls**.
- They may be isosporic or heterosporic.
- They include the classes *Lycopodiopsida* and *Isoetopsida*.



Selaginella species contain numerous bioactive natural products, including biflavonoids (chiefly amentoflavone), (neo)lignans, phenolic compounds (selaginellin derivatives) and alkaloids, which have promising pharmacological and cosmetic properties (Almeida et al., 2013; Bailly 2021). A recent analysis of eight *Selaginella* species revealed the presence of compounds with antioxidant, anti-inflammatory and immuno-regulatory properties, as well as a few cytotoxic activities (Křížkovská et al., 2020). Potent inhibitors of protein tyrosine phosphatase 1 B (PTP1B), phosphodiesterase-4 (PDE4), and repressor of pro-inflammatory cytokines expression have been also identified (Bailly 2021).

***Selaginella* spp. (*Isoetopsida*) are heterosporic.**

Phylum *Lycopodiophyta*

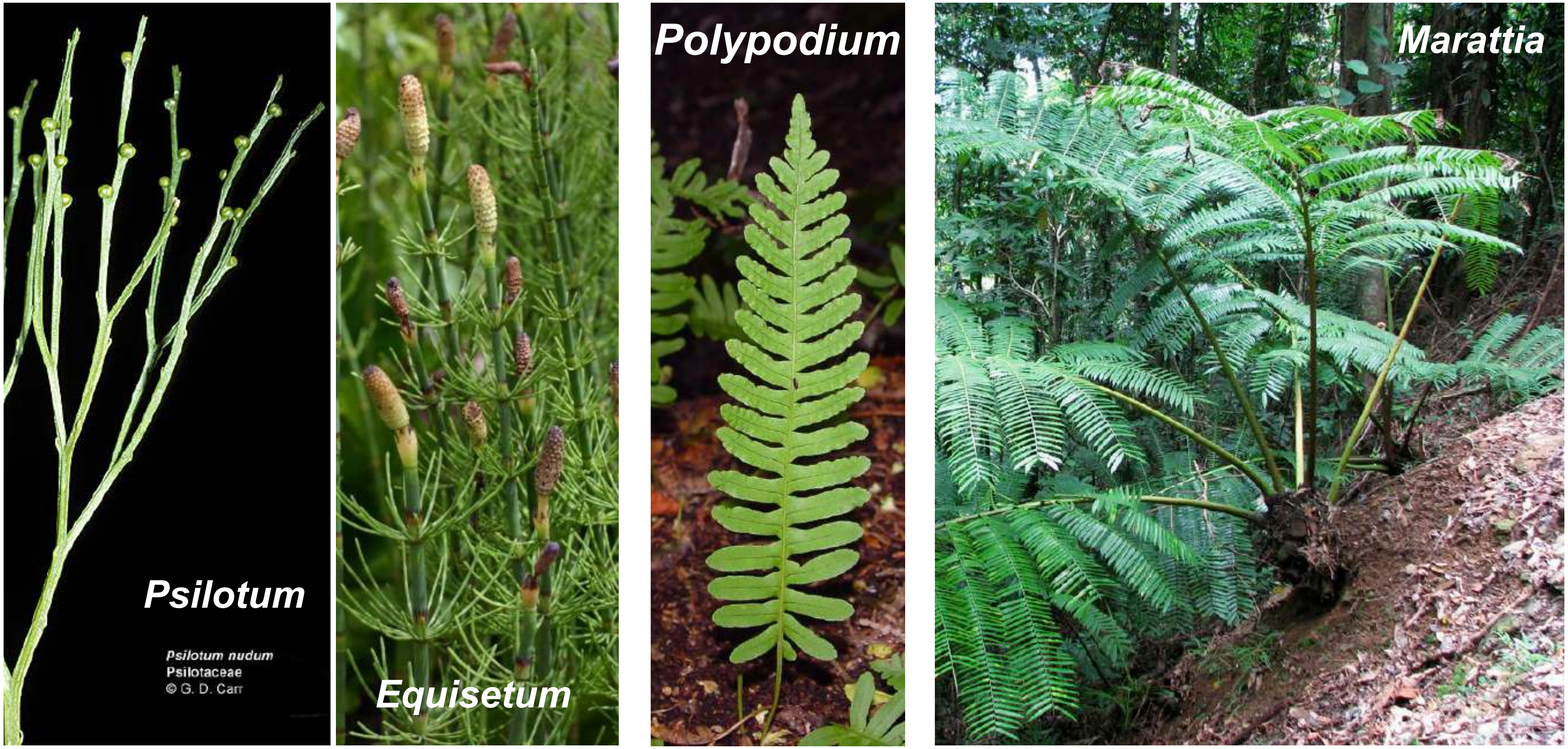
Selaginella lepidophylla is a species of desert fern known as a “resurrection plant“. This species is renowned for its ability to survive almost complete desiccation. During dry weather in its native habitat, its stems curl into a tight ball, uncurling only when exposed to moisture.

Main topics

The origin of cormophytes	Pteridophytes, or ferns
Phylum *Lycopodiophyta*	Phylum *Monilophyta*

Phylum *Monilophyta*

- The sporophytes of these species present a wide variety of morphologies, sizes and life forms. The stem is columnar or rhizomatous, with erect branches and **megaphylls**.
- They form **leptosporangia** and some groups of **eusporangia**, and may be **isosporic** or **heterosporic**.
- They include representatives distributed in the classes *Psilotopsida*, *Equisetopsida*, *Polypodiopsida* and *Marattiopsida*. Representatives of the first three are found in the Iberian Peninsula.



Phylum *Monilophyta*, class *Equisetopsida*

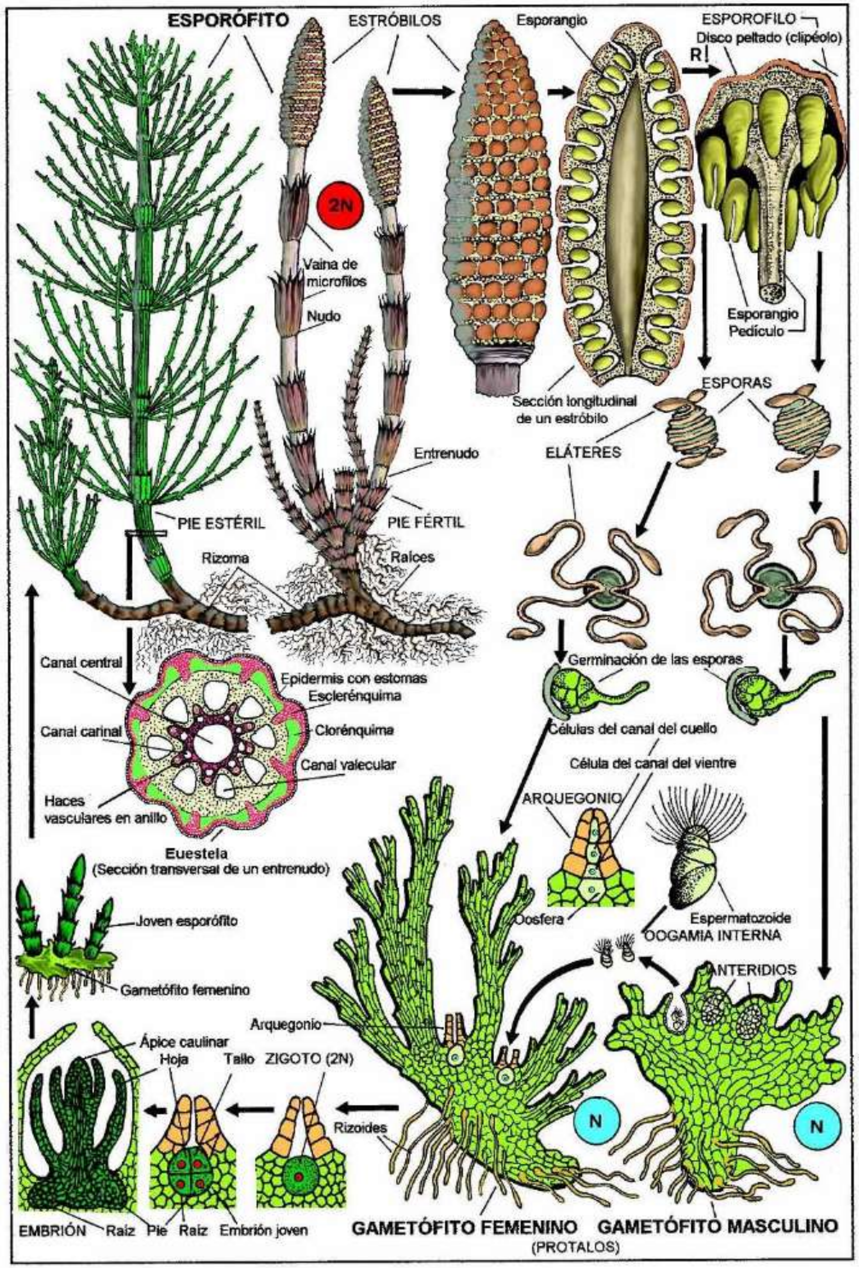
- These are **isosporic** and eusporangiate ferns.
- Extant species are herbaceous and belong to the genus ***Equisetum***.
- Their leaves are microphylls (secondarily derived from macrophylls).

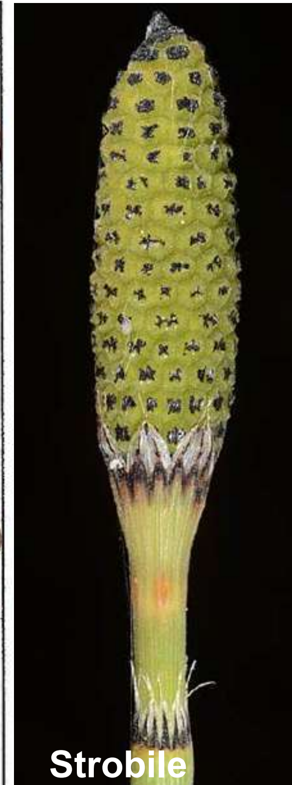
Horsetails (*Equisetum* spp.) have been used as herbal remedies since ancient Roman and Greek times. They were traditionally used to stop bleeding, heal ulcers and wounds, and treat tuberculosis and kidney problems. The name *Equisetum* is derived from the Latin roots *equus*, meaning “horse”, and *seta*, meaning “bristle”. Horsetails contain silicon, which helps strengthen bones. For this reason, some practitioners recommend horsetail as a treatment for osteoporosis. It is also used as a diuretic and as an ingredient in some cosmetics. It may cause vitamin B1 deficiency when used long-term.

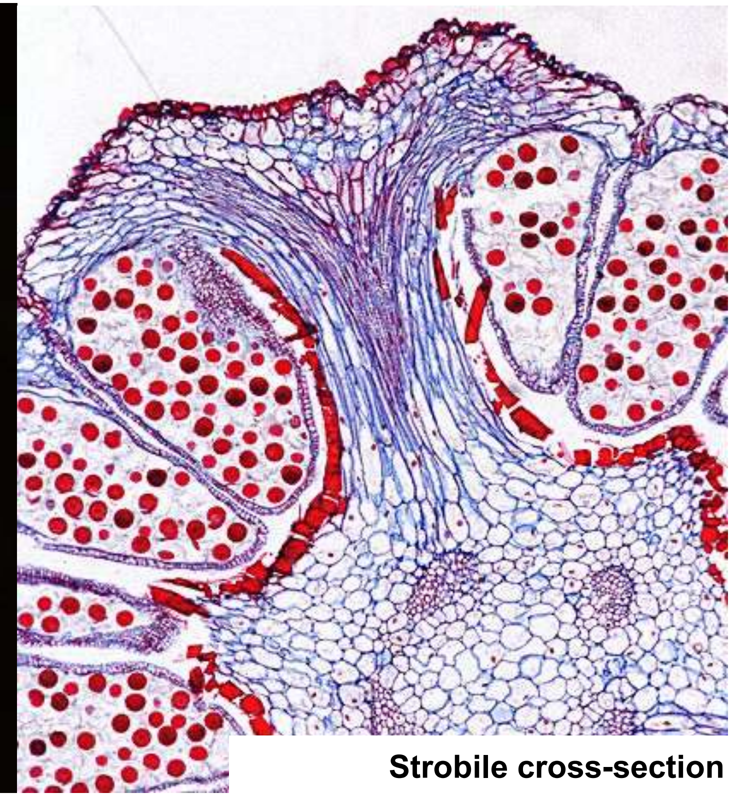
Equisetum telmateia

Stem, branches and leaves of *Equisetum*

Reproductive structures and life cycle of *Equisetum*







Phylum *Monilophyta*, class *Polypodiopsida*

- These are called true ferns.
- They are the most diverse and common group.
- They can live on the ground, in rock crevices, or as epiphytes.

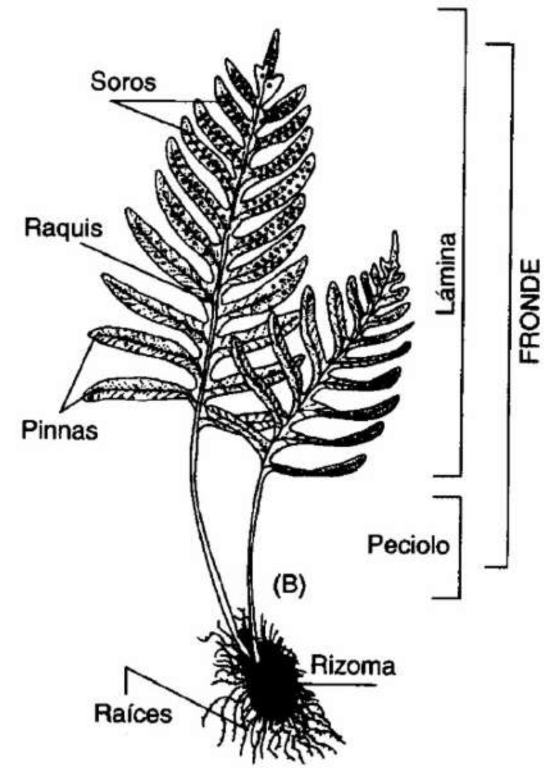
Ceterach officinarum

Polypodium cambricum

Pteridium aquilinum

Phylum *Monilophyta*, class *Polypodiopsida*

The sporophyte consists of a stem, which may be a rhizome or an erect, columnar structure (24 m in *Cyathea*). From this structure leaves called **fronds** (sing. frond) emerge that may be whole or divided. Each division of a divided leaf is called a **pinna**.



Phylum *Monilophyta*, class *Polypodiopsida*

The ubiquitous bracken fern (*Pteridium aquilinum*) is one of the most abundant plants on Earth. Due to its inherent toxin, bracken fern is known to cause various diseases in livestock that ingest large amounts of bracken or are fed bracken-containing fodder. Bracken fern toxin is used to illustrate inherent plant toxicants that may be excreted into milk. The milk of ruminants that graze on bracken-infested land can be an important source of carcinogenic **ptaquiloside** exposure in humans.

Phylum *Monilophyta*, class *Polypodiopsida*

Dryopteris filix-mas, commonly known as male fern, is an evergreen plant that grows up to 60-150 cm. It is found in streams, moist environments, open grounds, and stone or brick walls. Its leaf decoction is used by traditional healers to treat inflammation, rheumatoid arthritis, ulcers and wounds. Its reported pharmacological activities include antioxidant and cytotoxic, antimicrobial, antithelmintic, antidiarrheal and tocolytic activities.

Dryopteris filix-mas

Phylum *Monilophyta*, class *Polypodiopsida*

Blechnum spicant (hard fern)
The leaflets of hard fern have been chewed to treat internal cancer, lung disorders and stomach problems. The fronds are used externally as a medicine for skin sores. A decoction of the root has been used to treat diarrhoea.

Lecture 09

Spermatophytes: vascular plants with seeds

Main topics

Spermatophytes (main traits)	The seed primordium and its origin
Evolutionary success and diversity of spermatophytes	Fertilisation and seed development in gymnosperms
Fertilisation and seed development in angiosperms	Types of seeds and dormancy

Spermatophytes

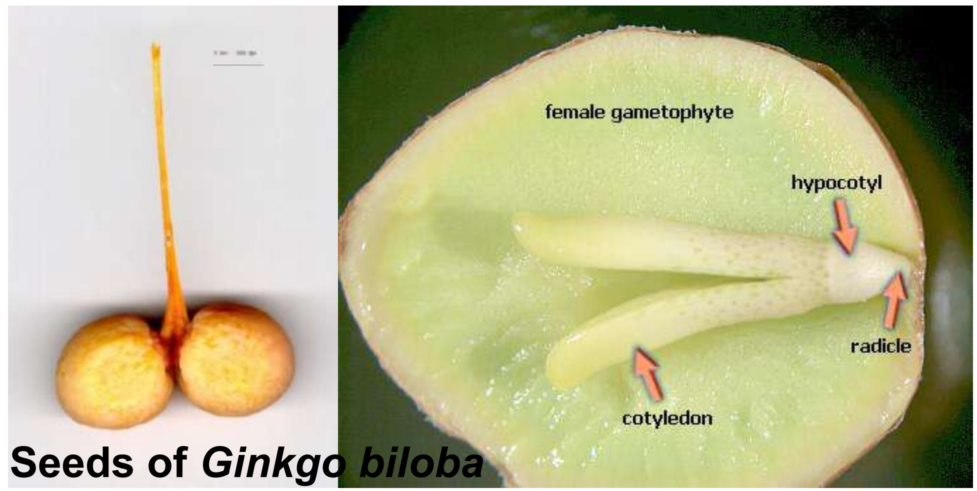
The emergence of **seeds** is one of the most momentous events in the history of life.

Seeds are the **main reason** why a recent group of organisms has undertaken such an **expansion** to become the **largest in terms of biomass** (among multicellular plants) and the most **dominant in terms of the number of environments**.

Seeds

Seeds are diploid **sporophytic organisms at the juvenile stage** enveloped by internal nutritive (**endosperm**) and external protective (**episperm**) layers that guarantee their autonomous life. They represent the mature and fertilised **seed primordium** in a variable stage of dehydration. When mature, most seeds are in a state of rest or **dormancy**.

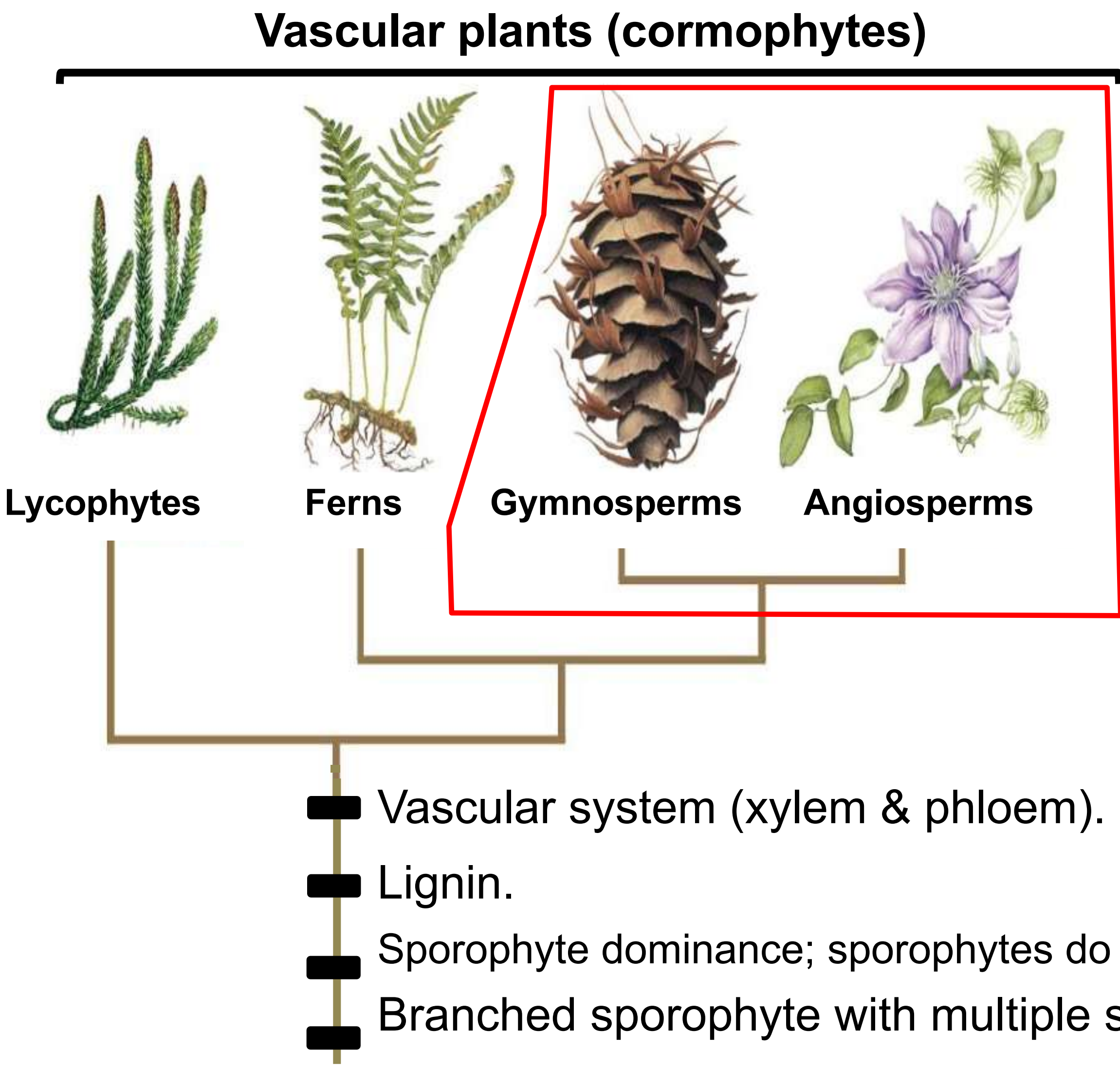
Seed of *Cycas* sp.



Seeds of *Ginkgo biloba*

Fruits and seeds of angiosperms

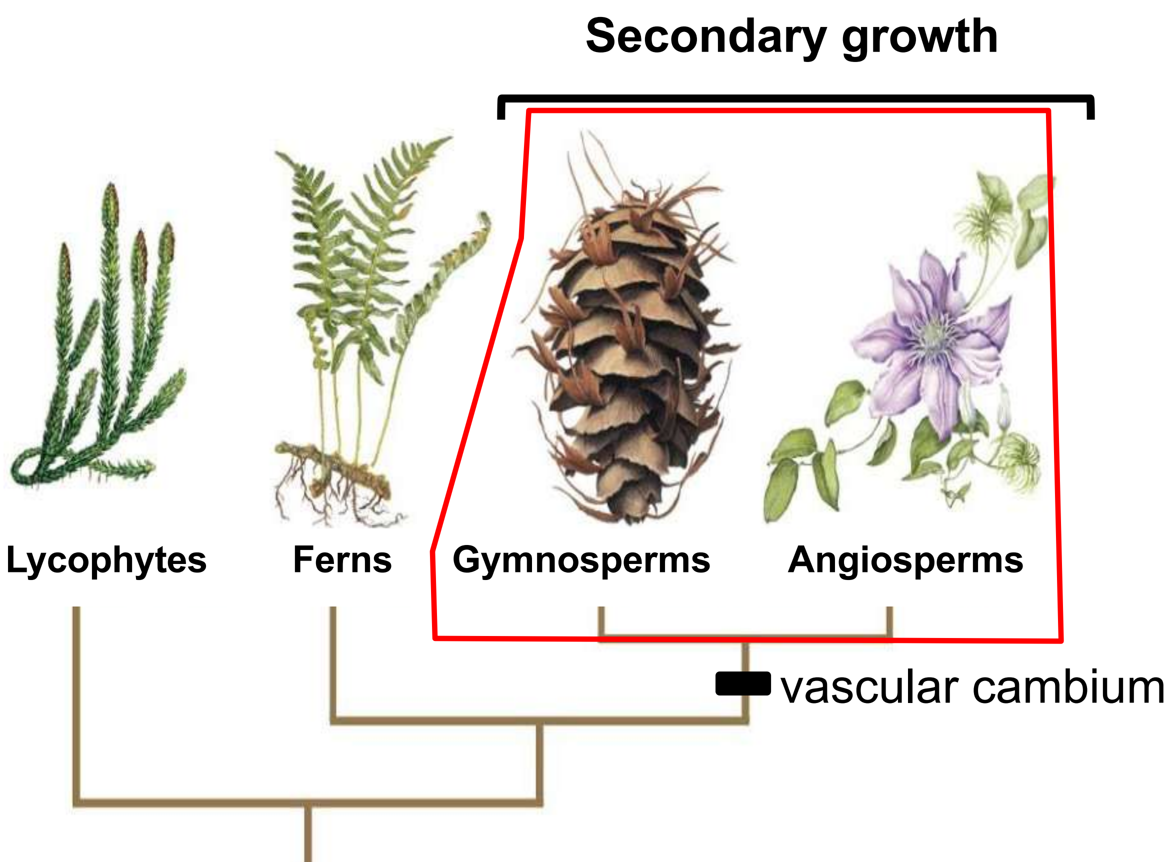
Vegetative traits of spermatophytes

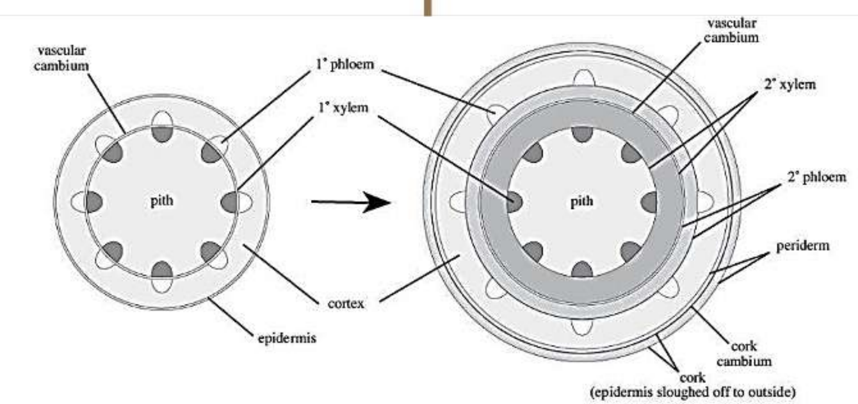


Spermatophytes are a group of **vascular plants**.

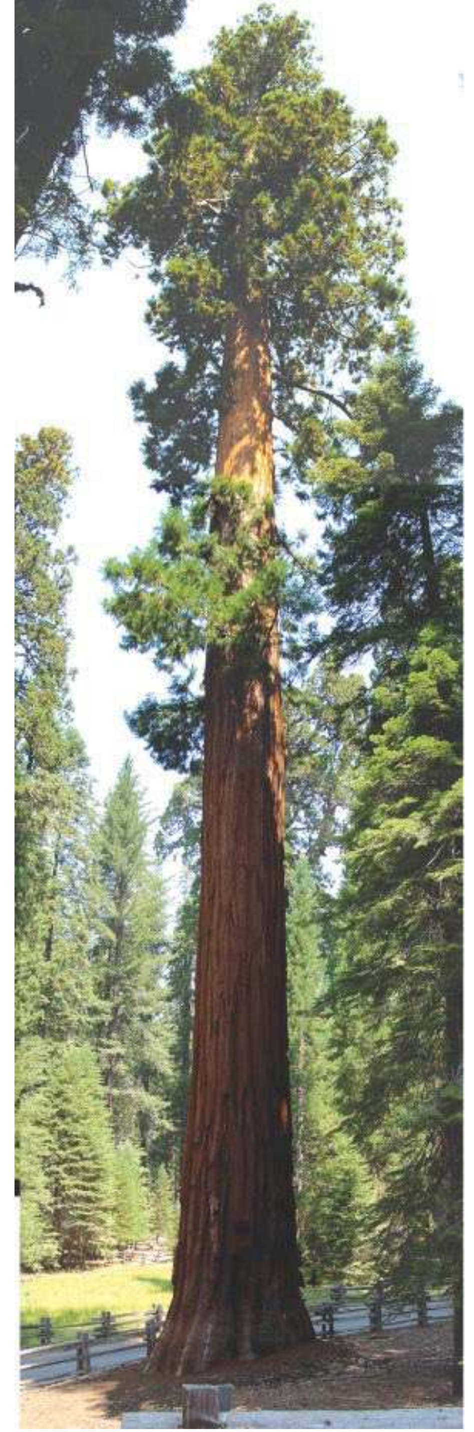
The life cycle is digenetic haplo-diploid and heteromorphic

Vegetative traits of spermatophytes



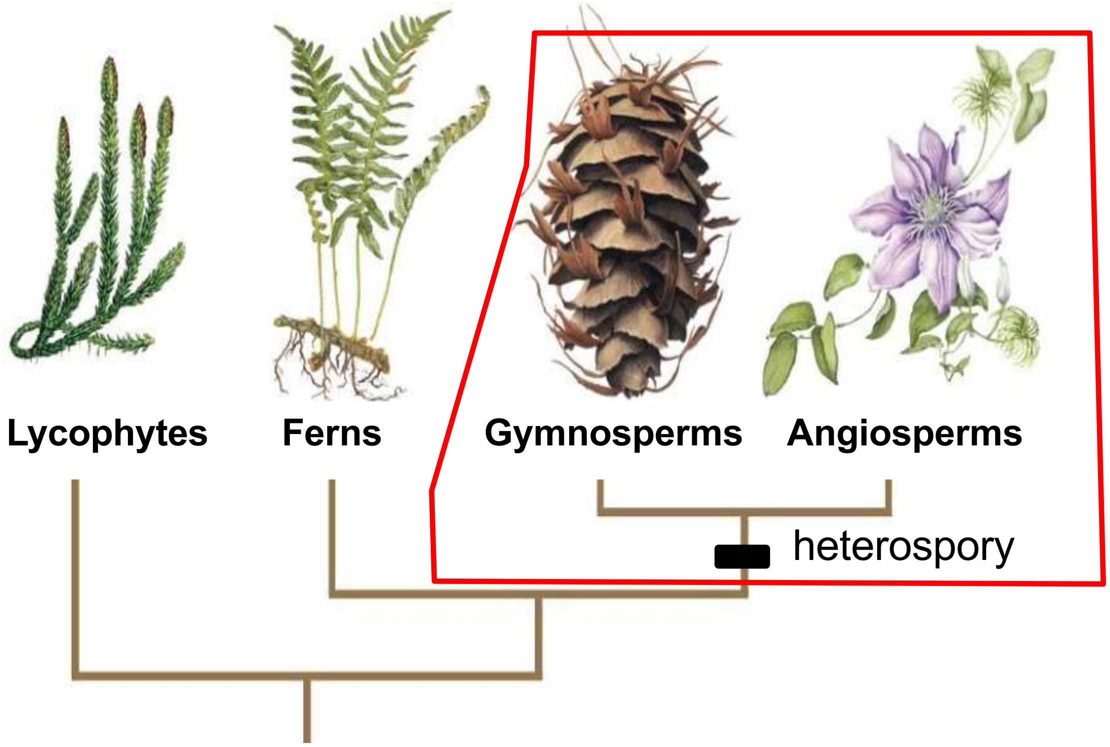


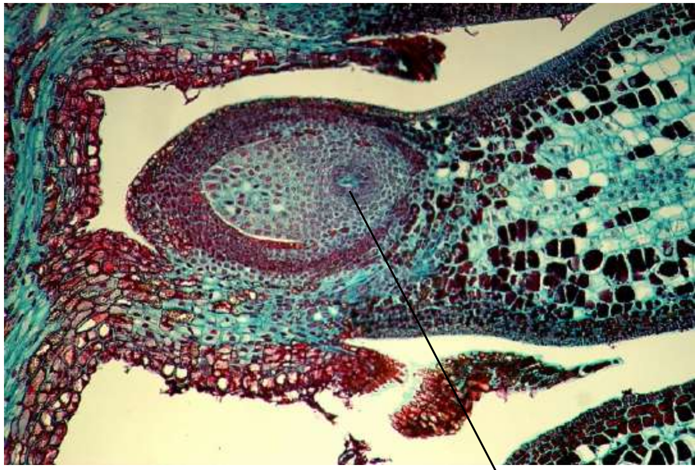
Secondary growth (in thickness)



Vegetative traits of spermatophytes

Spermatophytes are heterosporic.





Megaspore of a gymnosperm

Microspore (pollen grain) of a gymnosperm

Microspore (pollen grain) of an angiosperm

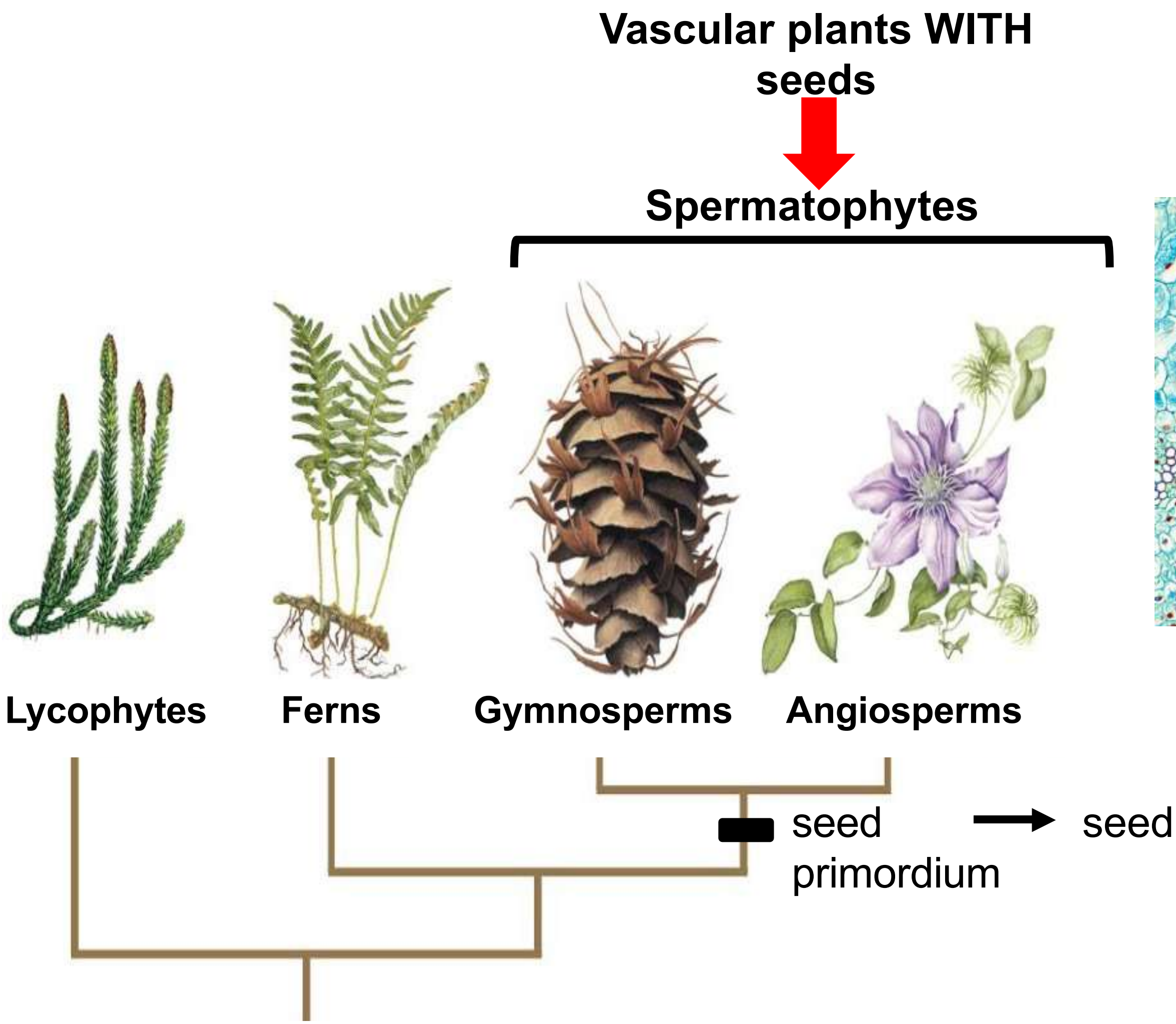
<u>Consequences of heterospory:</u>

-Reduction in gametophytic generation.

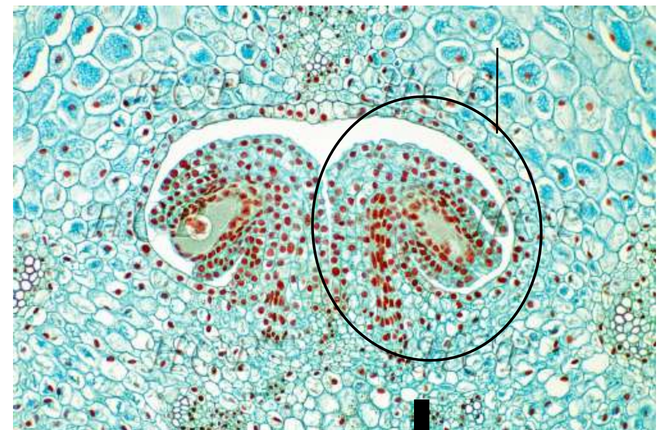
-Obligate dioecy of the gametophytic phase (unisexual gametophytes).

-Endospory.

Vegetative traits of spermatophytes



Seed primordium of an angiosperm



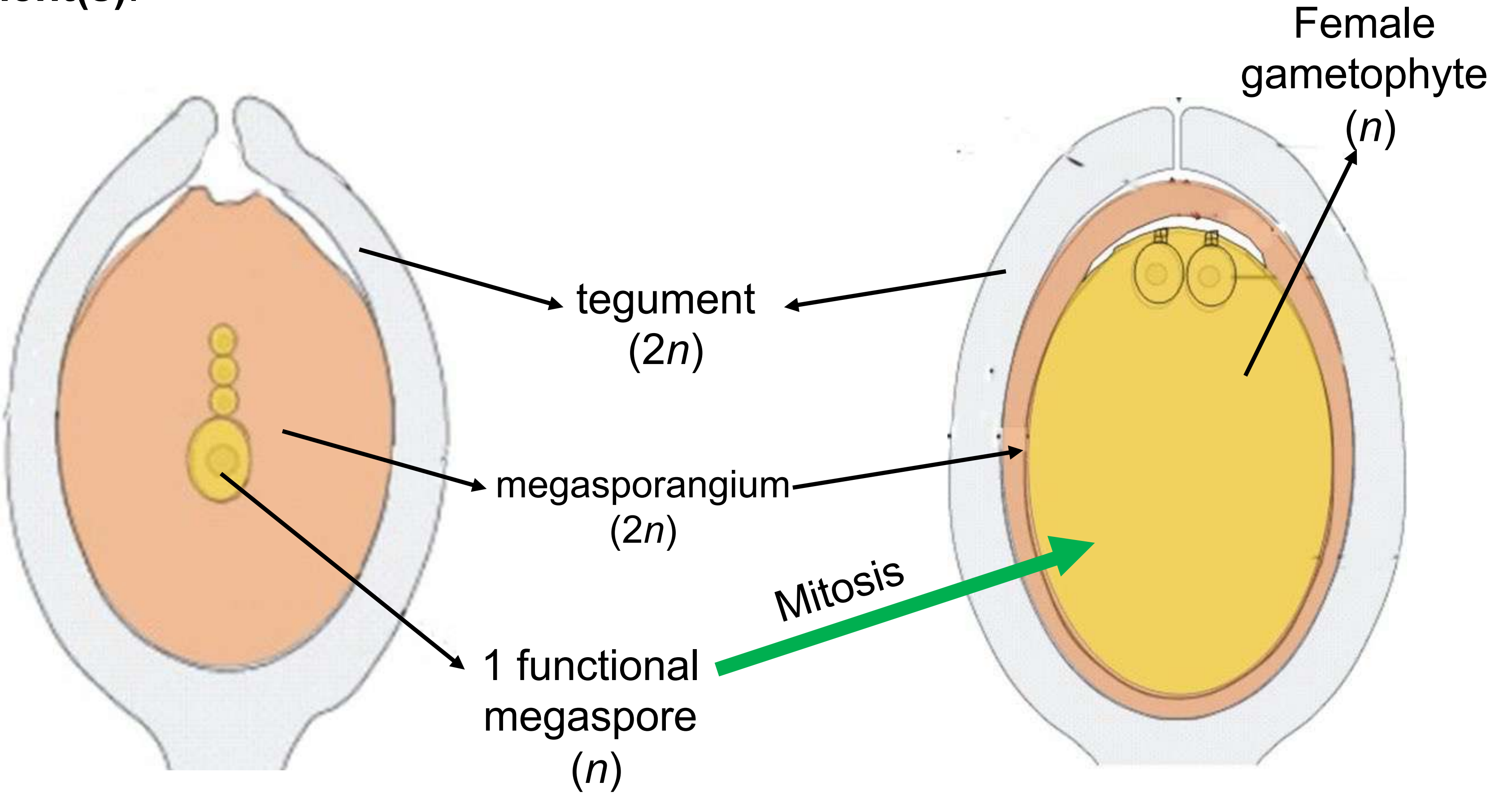
Seed of an angiosperm

Main topics

Spermatophytes (main traits)	The seed primordium and its origin
Evolutionary success and diversity of spermatophytes	Fertilisation and seed development in gymnosperms
Fertilisation and seed development in angiosperms	Types of seeds and dormancy

The seed primordium

In the first stage, the **seed primordium** is a **megasporangium** with a single functional **megaspore** enveloped by one or two **teguments**. Later it includes the **female gametophyte**, which is **endosporic** and also enveloped by the **tegument(s)**.

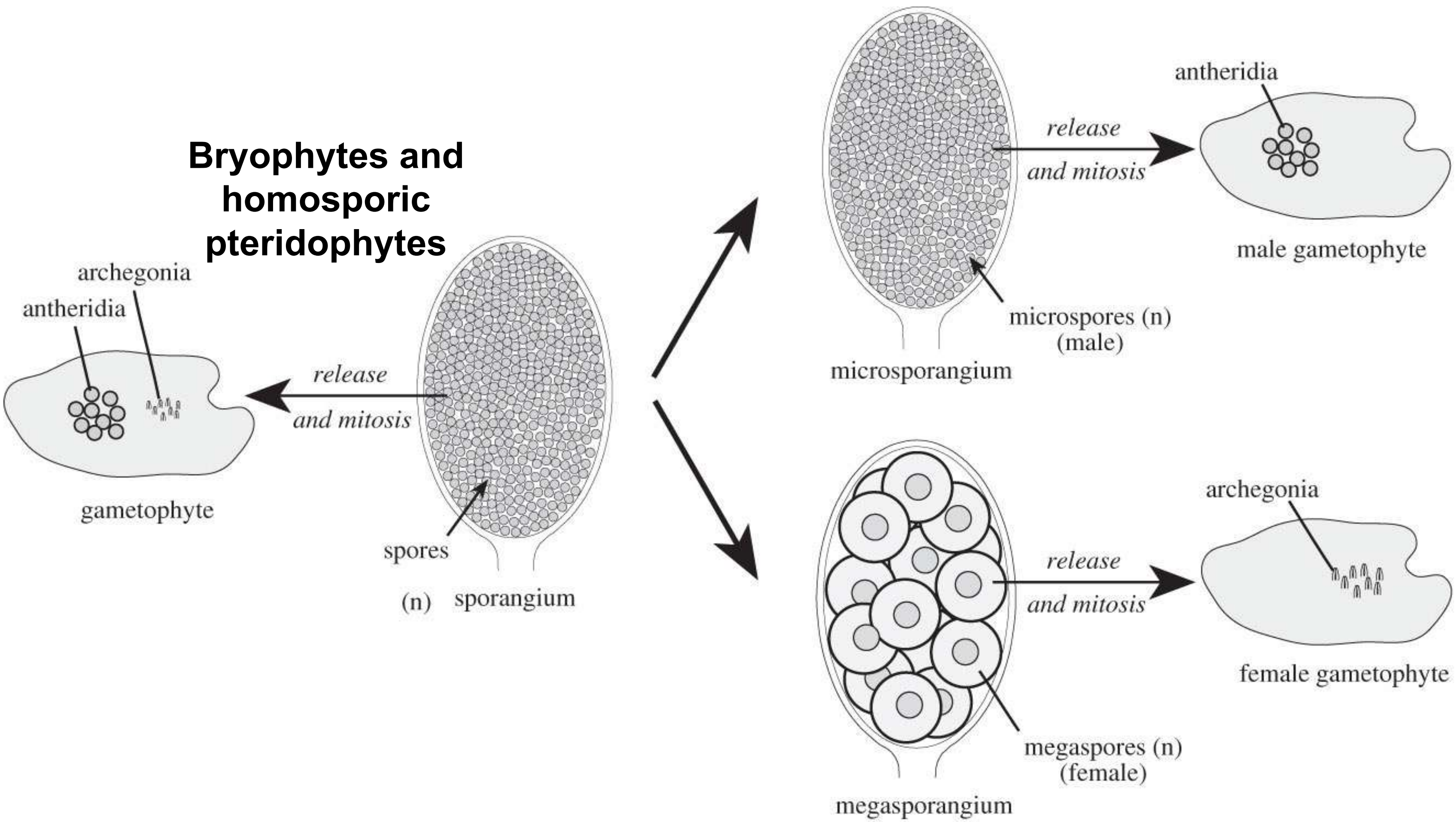


What evolutionary processes were necessary for the seed primordium to emerge?

Model of the evolutionary processes that led to the development of a seed primordium

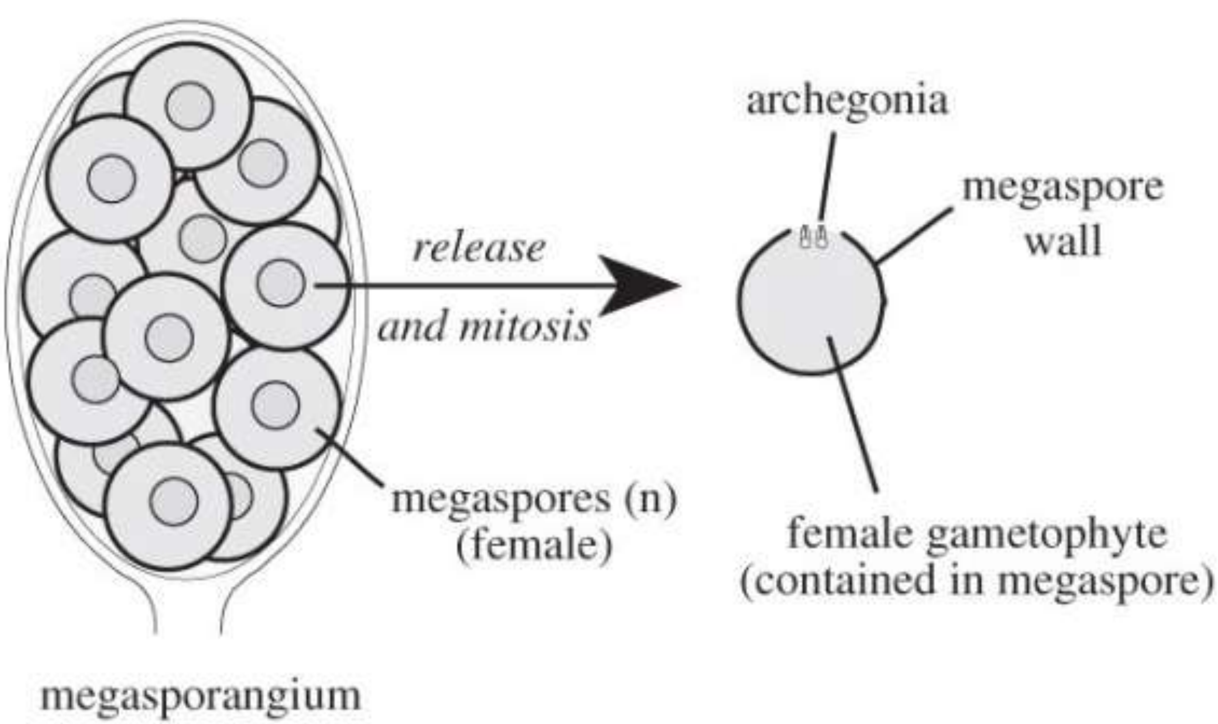
Step 1: Homospory → Heterospory

Bryophytes and homosporic pteridophytes



Model of the evolutionary processes that led to the development of a seed primordium

Step 2: endospory

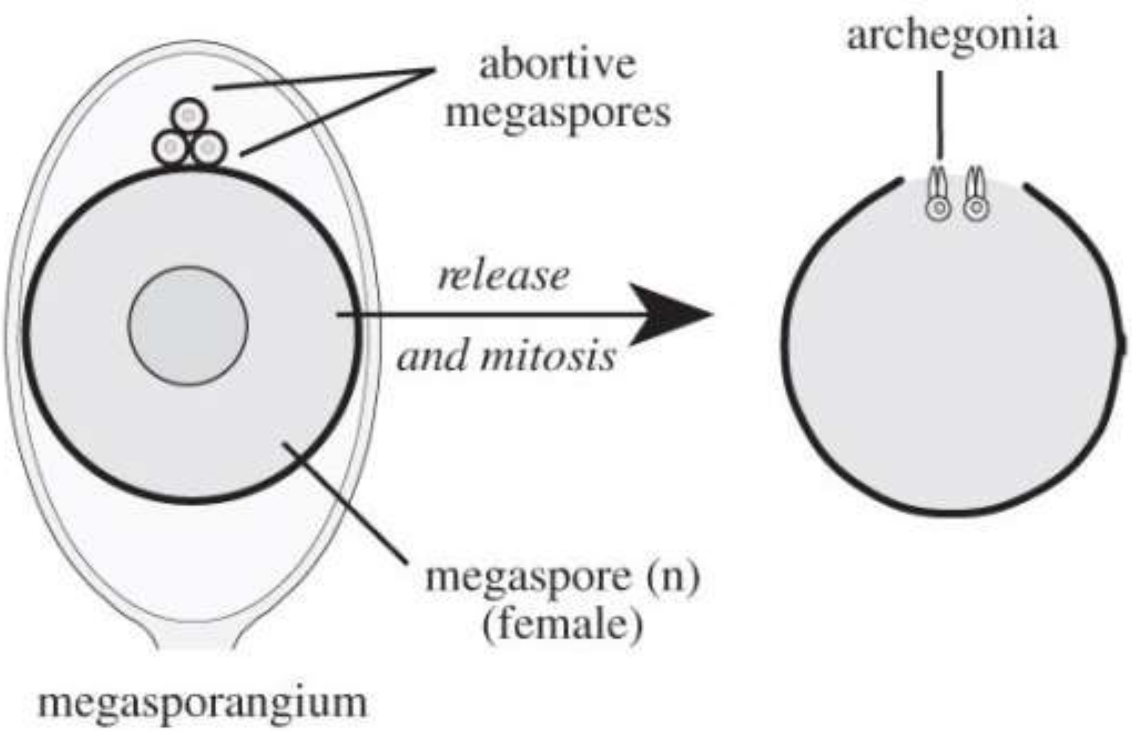


Formation of the **female gametophyte** surrounded by the megaspore wall (**endosporic gametophyte**).

This trait is present in heterosporic pteridophytes (*Selaginella*, *Isoëtes*, *Marsilea*). **In vascular plants, endospory is a consequence of heterospory.**

Model of the evolutionary processes that led to the development of a seed primordium

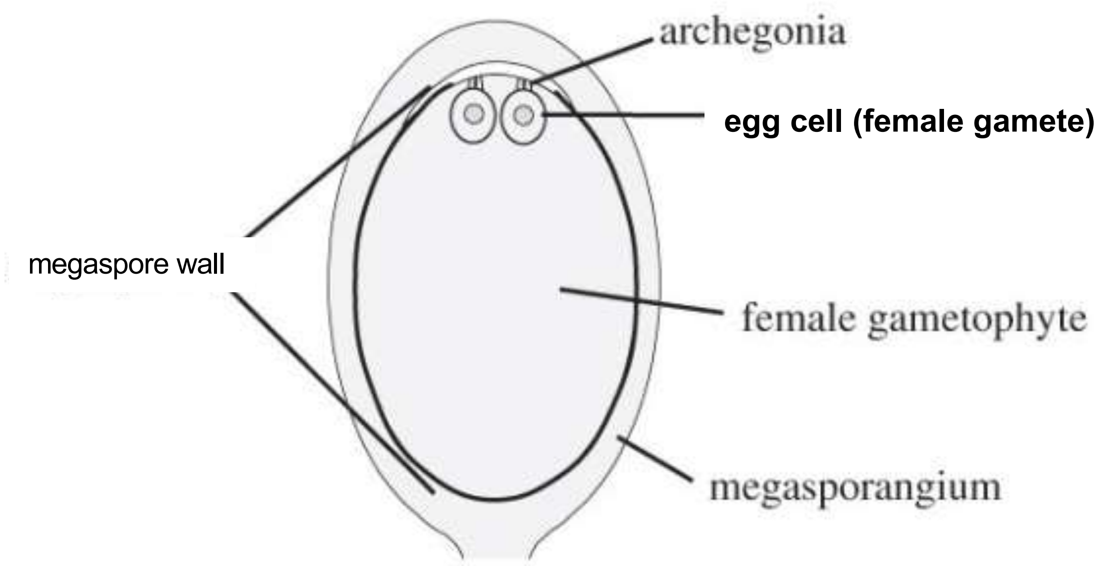
Step 3: reduction in the number of megaspores to just one



Only one functional megaspore in each megasporangium.

Model of the evolutionary processes that led to the development of a seed primordium

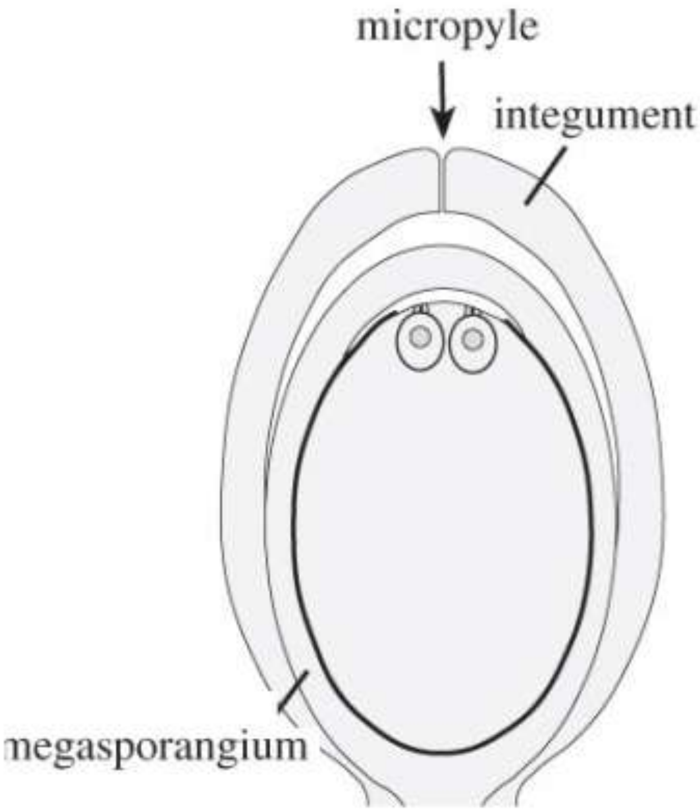
Step 4: megaspore retention



The megaspore is retained (not released) in the sporangium, so the **female gametophyte becomes sporophyte-dependent** and is retained in the sporangium.

Model of the evolutionary processes that led to the development of a seed primordium

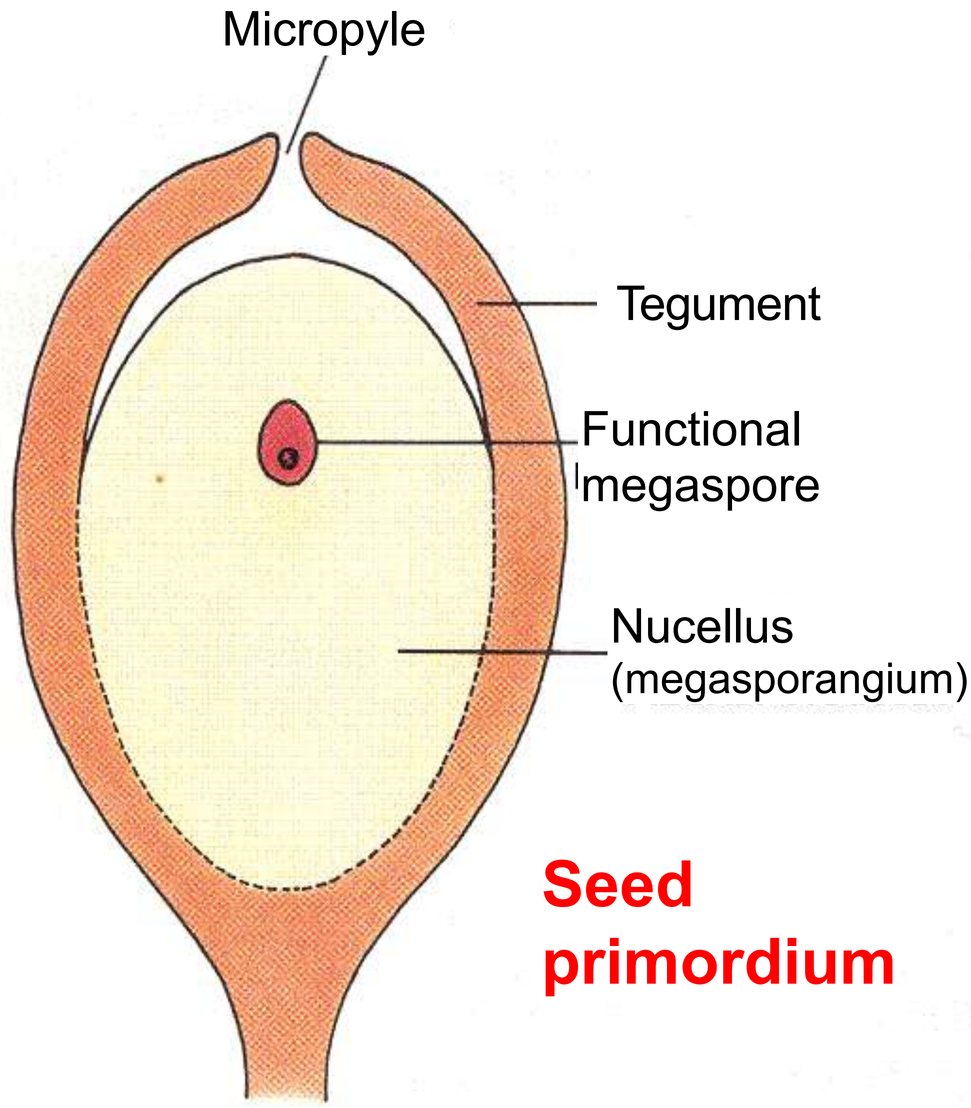
Step 5: development of the megasporangium coatings



The sporangium is covered by the **teguments**, leaving only one opening for communication with the outside (the **micropyle**).

Model of the evolutionary processes that led to the development of a seed primordium

- The megasporangium becomes **fleshy** and is called the **nucellus**; it is enveloped by coverings called **teguments**.
- Together they form the **seed primordium**.



Main topics

Spermatophytes (main traits)	The seed primordium and its origin
Evolutionary success and diversity of spermatophytes	Fertilisation and seed development in gymnosperms
Fertilisation and seed development in angiosperms	Types of seeds and dormancy

The evolutionary success of seed plants

The spread of seed plants occurred when the climate became progressively more arid.

In this environment, seed-dispersing plants had an advantage: they were **independent of water for the fertilisation process**.

The seed can remain in the soil for some time until **conditions are suitable for germination**.

The **seed increases the survivability of the new generation** (protection, storage material, dispersal).

Plants with seeds (spermatophyte groups)

At present there are 5(6) phyla of seed plants with living representatives on our planet. They derive from the large group of progymnosperms, which lived during the Devonian-Carboniferous.

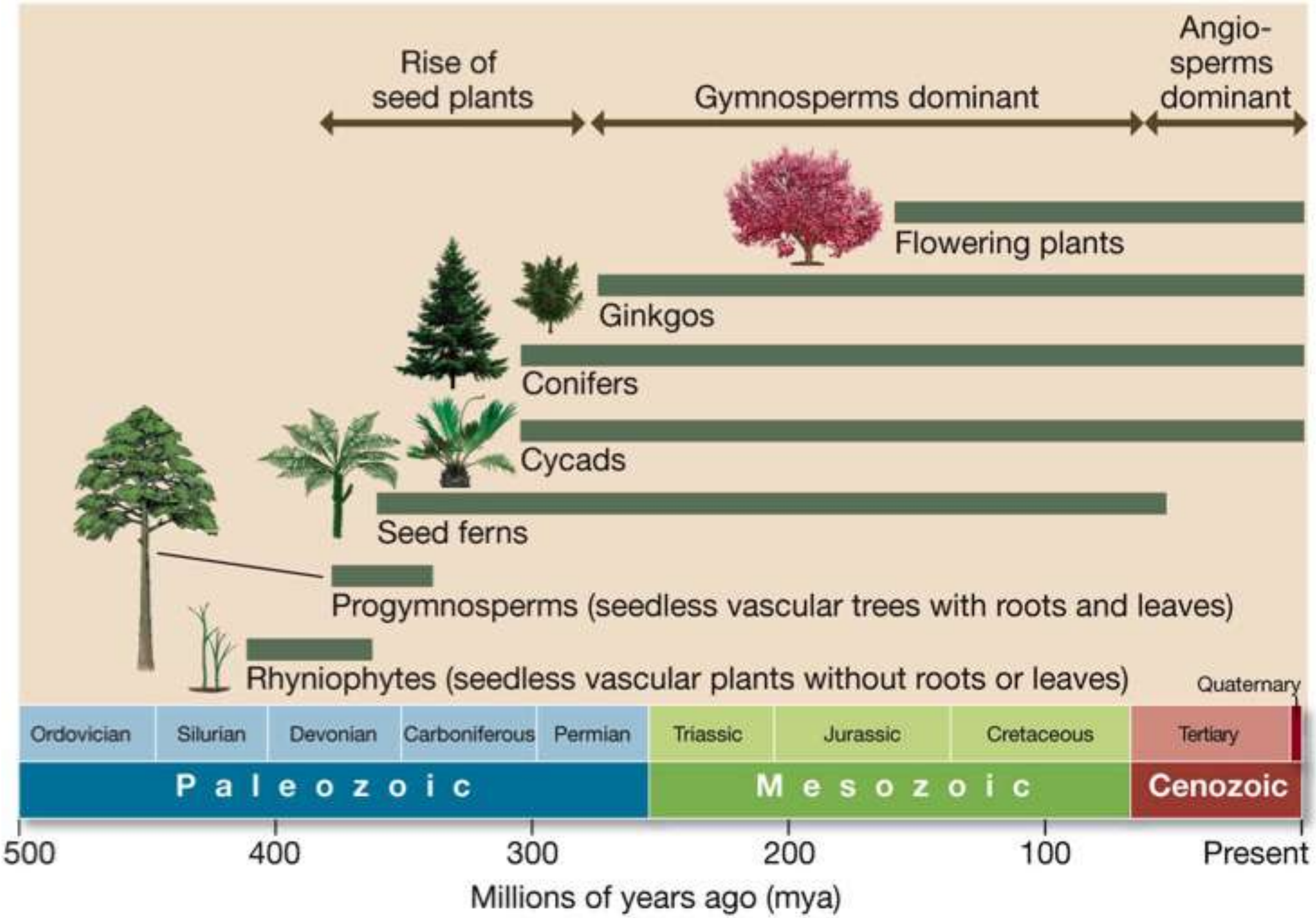
4(5) **Gymnosperm phyla**

1 **Angiosperm phylum**

Magnoliophyta

Plants with seeds (spermatophyte groups)

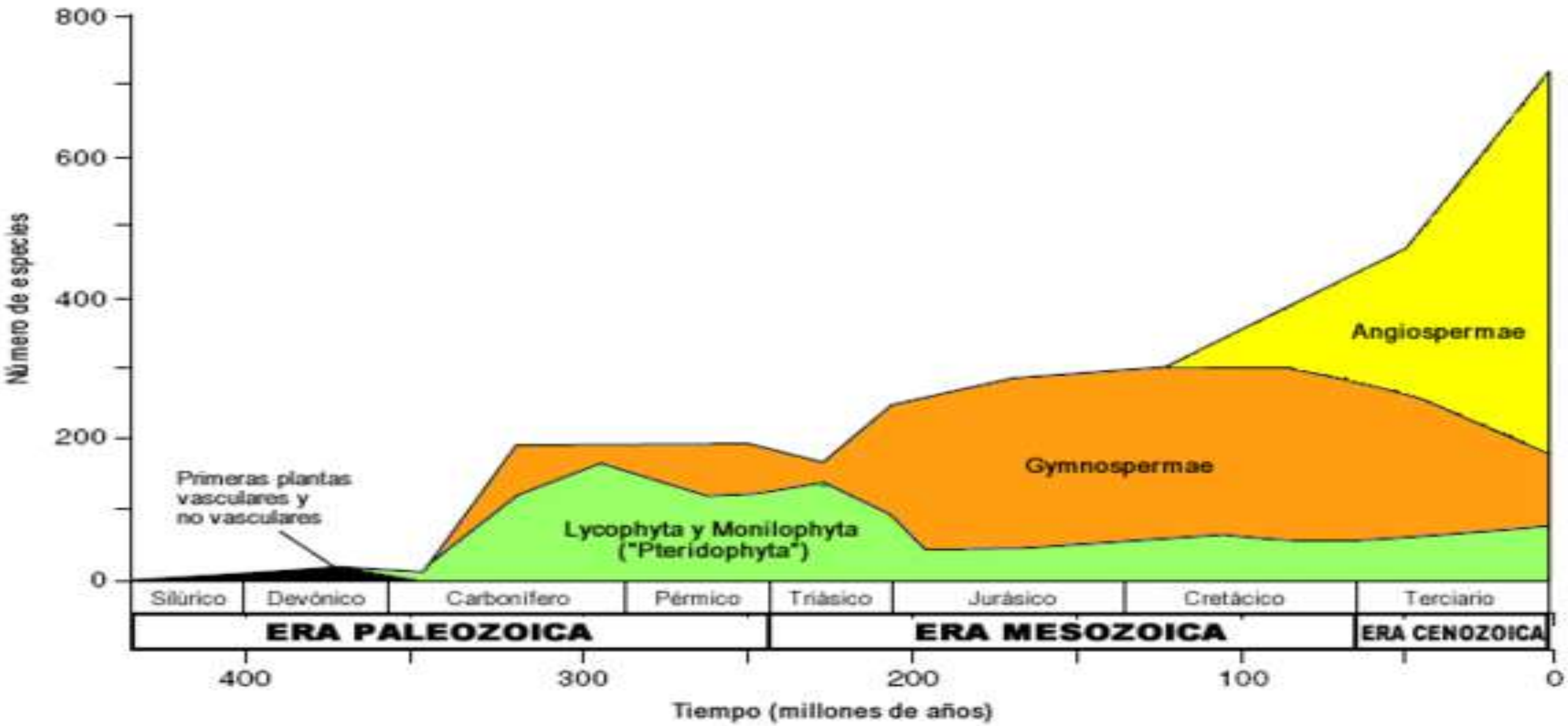
Seed plants evolved along different lines: **gymnosperms**, with **naked seed primordia**, dominated terrestrial floras until roughly 100 million years ago.



LIFE 9e, **Figure 29.1**

Plants with seeds (spermatophyte groups)

Angiosperms, with **protected seed primordia**, appeared in the fossil record roughly 140 million years ago and became dominant roughly 60 million years ago.



Dibujado y traducido a partir de Willis y McElwain (2002)

Main topics

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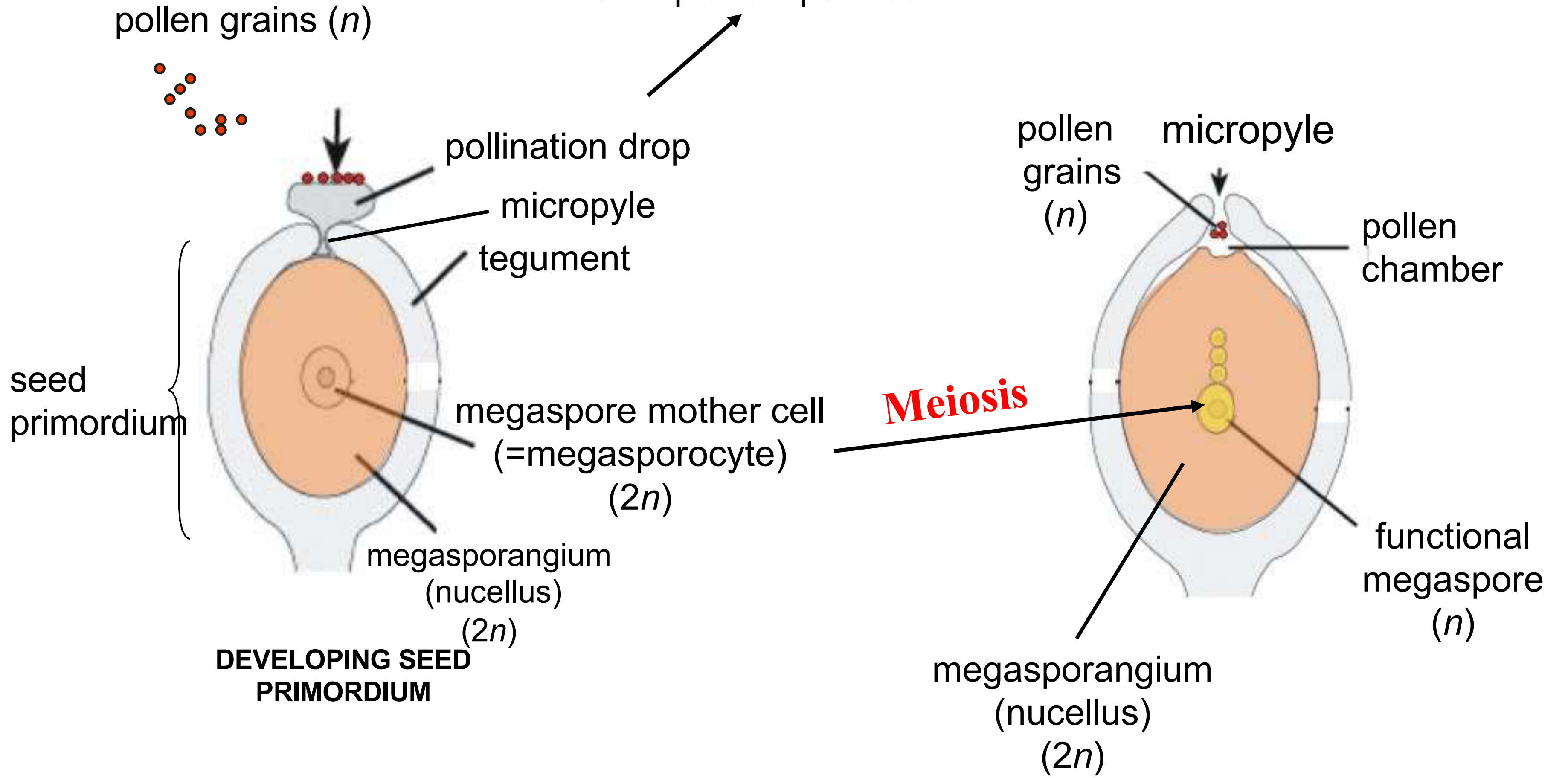
The seed primordium must be fertilised for the seed to develop

GYMNOSPERMS

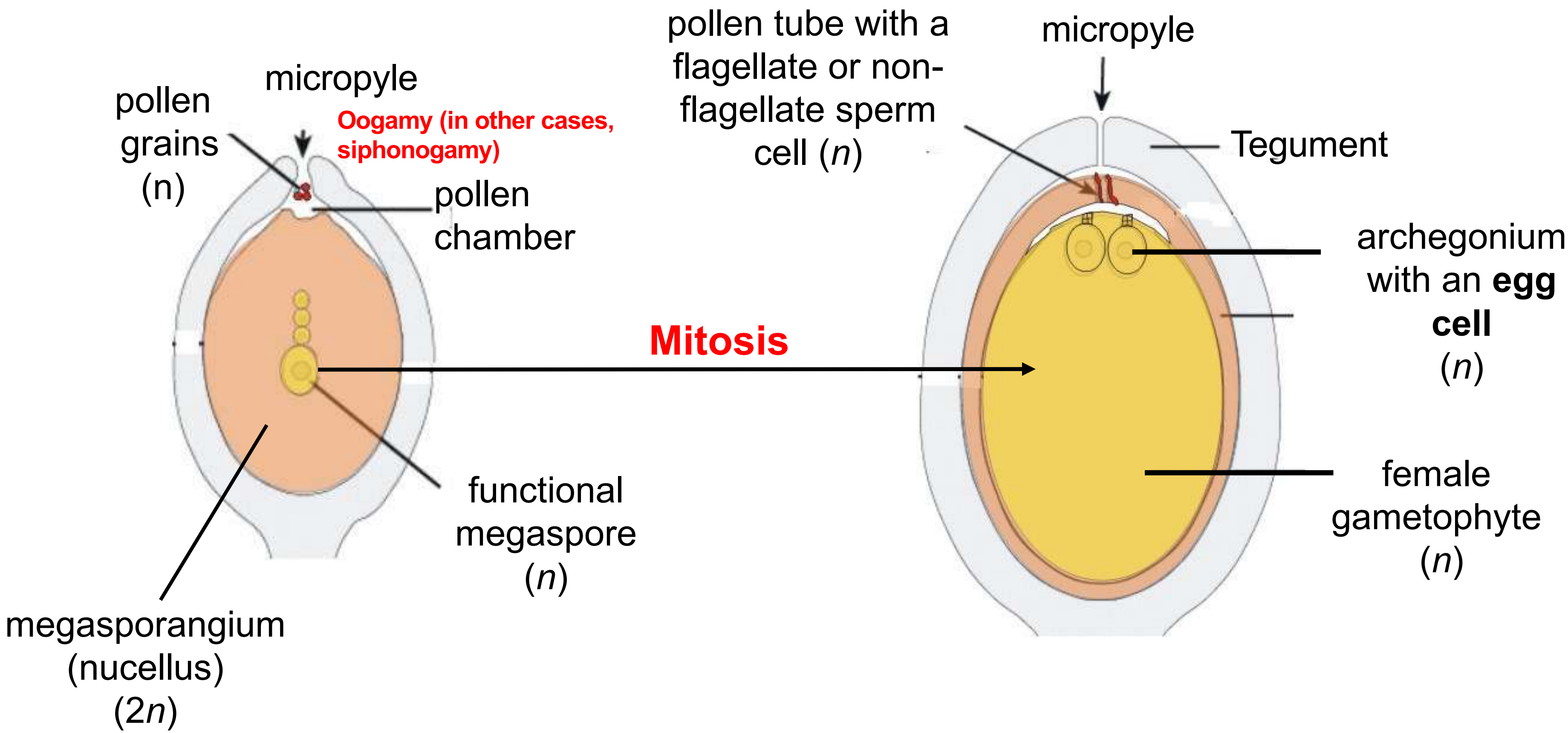
The pollination drop is secreted through the micropyle; pollen grains adhere and are absorbed inside the primordium as the droplet evaporates.



Pollen grain= microspore, which, by mitosis, subsequently gives rise to the endosporic male gametophyte (*n*).

The seed primordium must be fertilised for the seed to develop

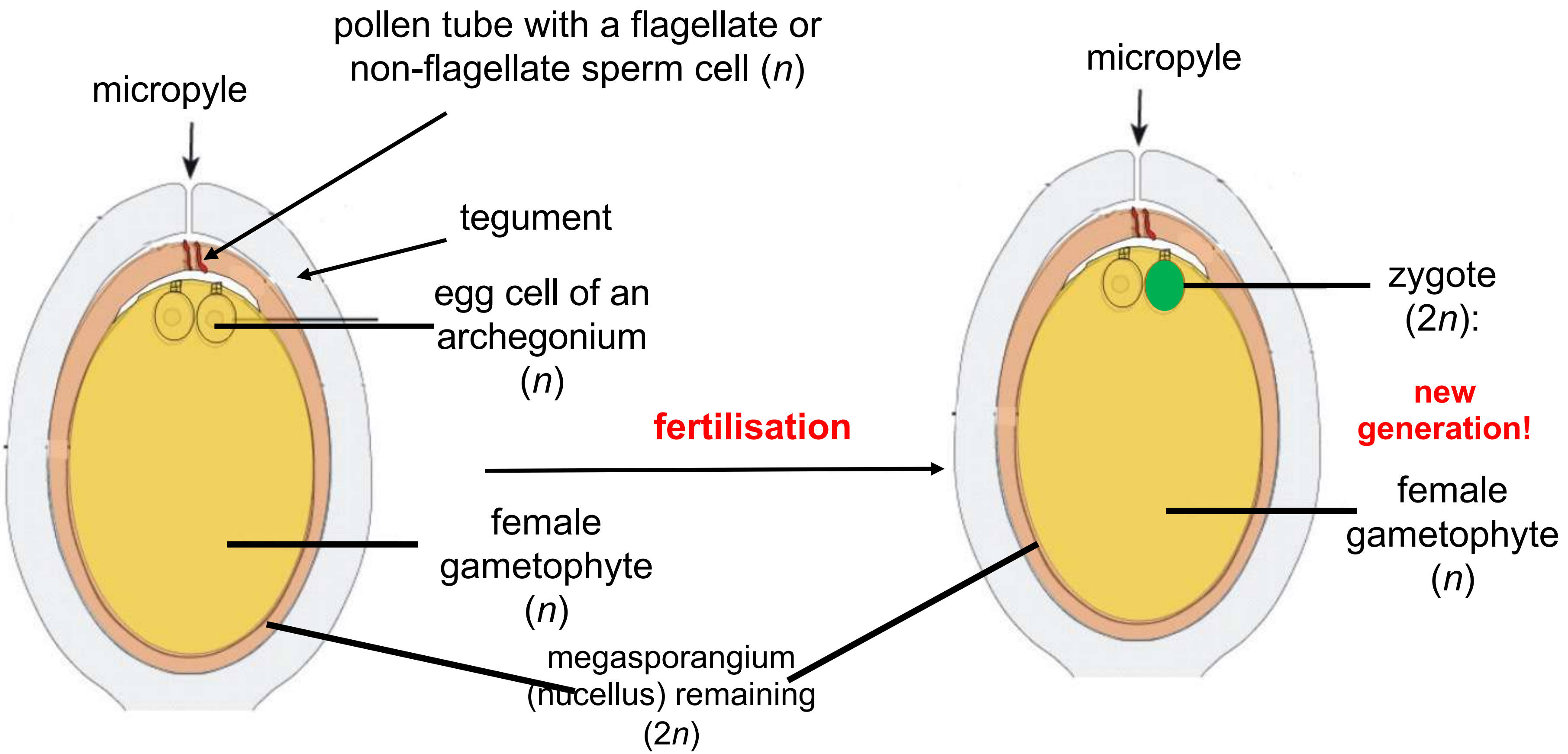
GYMNOSPERMS



The megaspore develops, thus giving rise to the female gametophyte. This produces archegonia; each archegonium hosts a female gamete (egg cell).

The seed primordium must be fertilised for the seed to develop

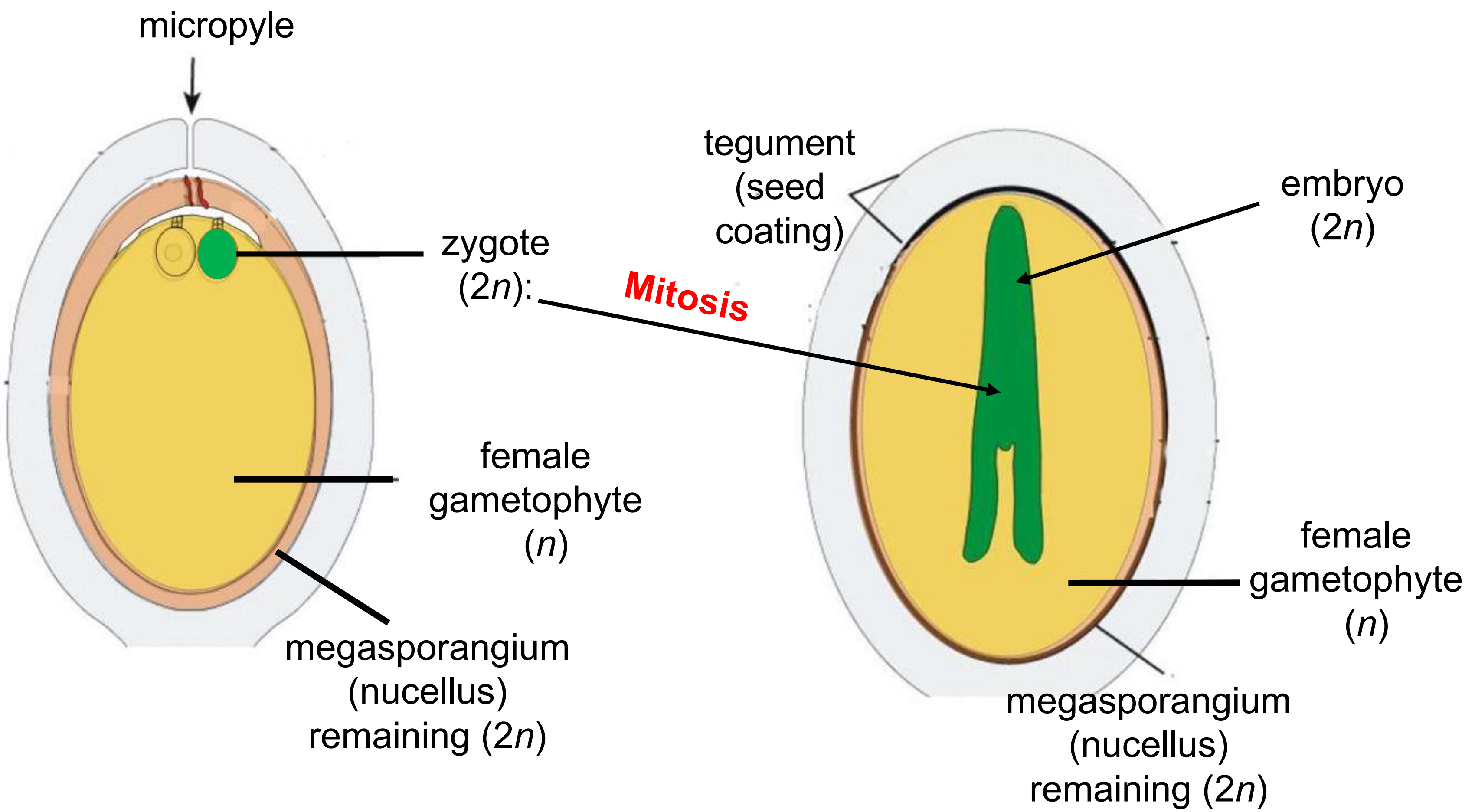
GYMNOSPERMS



In gymnosperms fertilisation is generally simple: the sperm cell (flagellated or otherwise) fertilises the egg cell.

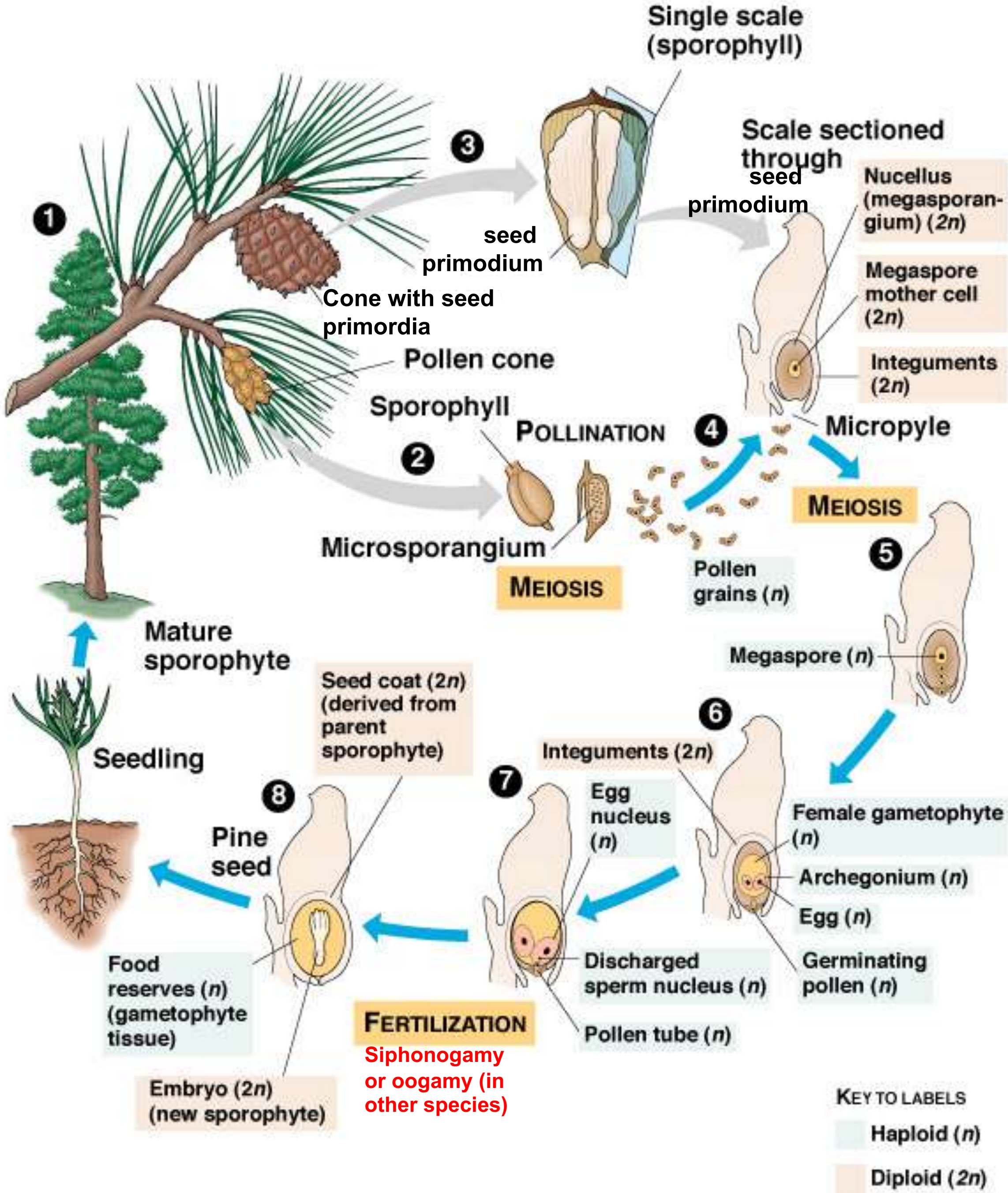
The seed primordium must be fertilised for the seed to develop

GYMNOSPERMS



The storage material of gymnosperm seeds is the female gametophyte = PRIMARY ENDOSPERM.

The life cycle of *Pinus*



Main topics

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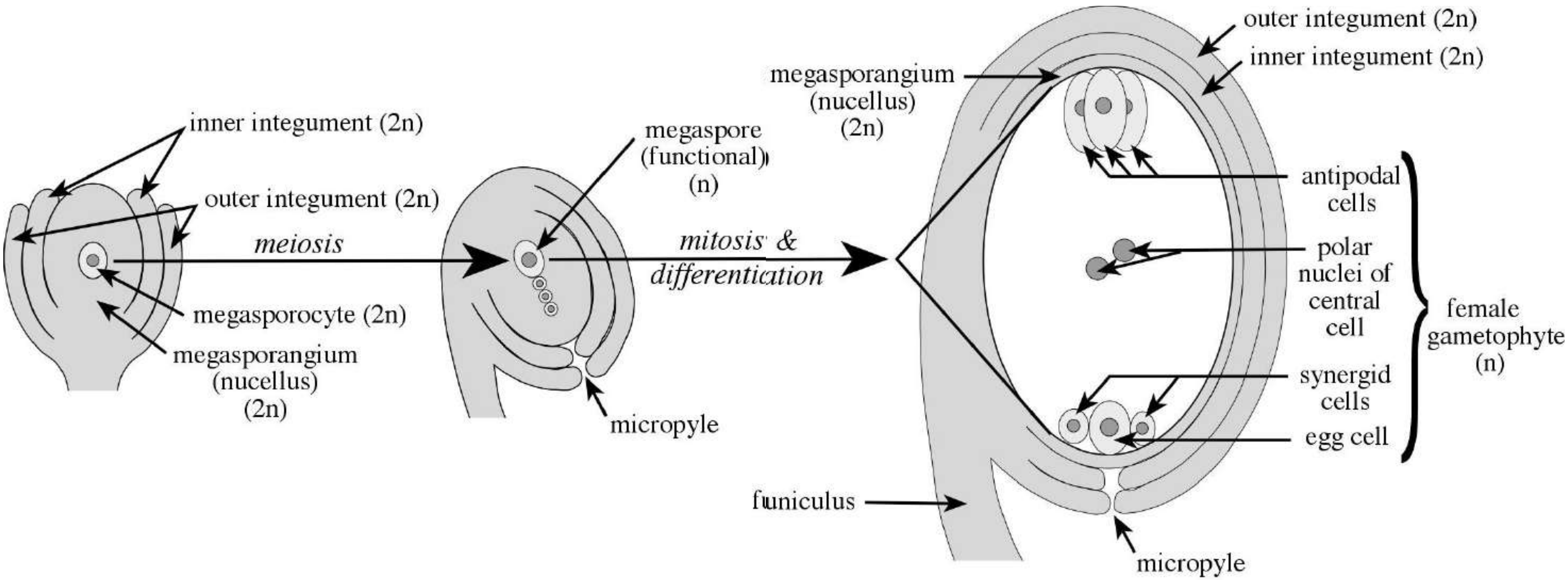
Fertilisation and seed development in angiosperms	Types of seeds and dormancy

The seed primordium must be fertilised for the seed to develop

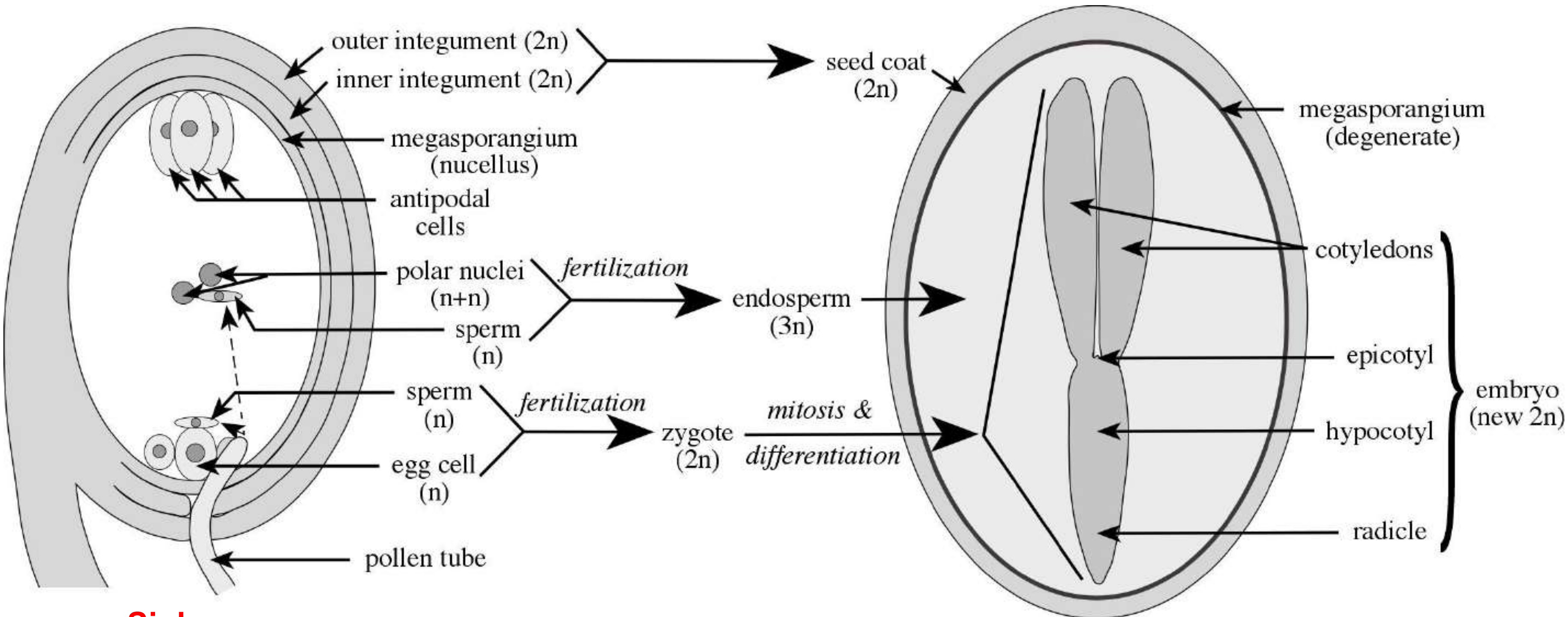
ANGIOSPERMS



The female gametophyte of angiosperms is reduced to a few cells (no archegonia are formed).

The seed primordium must be fertilised for the seed to develop

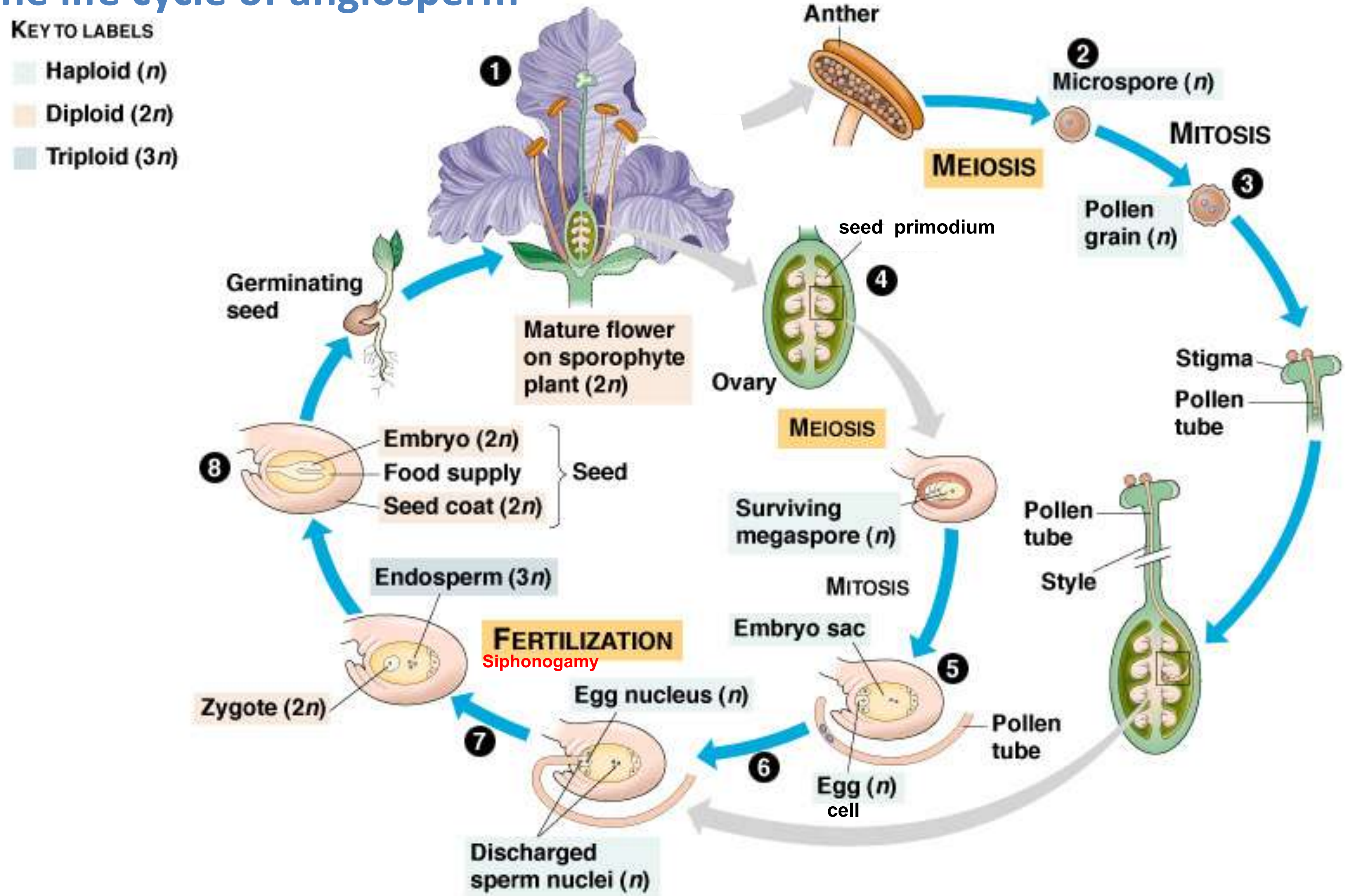
ANGIOSPERMS



Siphonogamy

In angiosperms, fertilisation is double: one sperm nucleus fertilises the egg cell and the other fuses with the two polar nuclei to form the SECONDARY ENDOSPERM (triploid reserve tissue, *3n*).

The life cycle of angiosperm



Main topics

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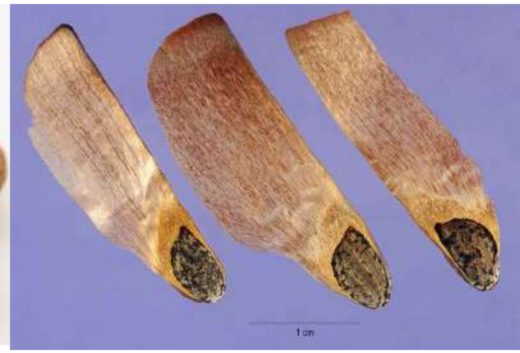
Types of seeds according to the “speed” of germination

Orthodox seeds: the seed completes its development by reducing its water content (dehydration), acquires a quiescent state, and metabolically slows down, which allows it to remain viable for a variable time.


Recalcitrant seeds: the seeds of some species do not pass through this dehydration phase and should therefore germinate as quickly as possible since their viability is rapidly reduced over time (e.g. many tropical plants, *Quercus*, citrus, etc.).

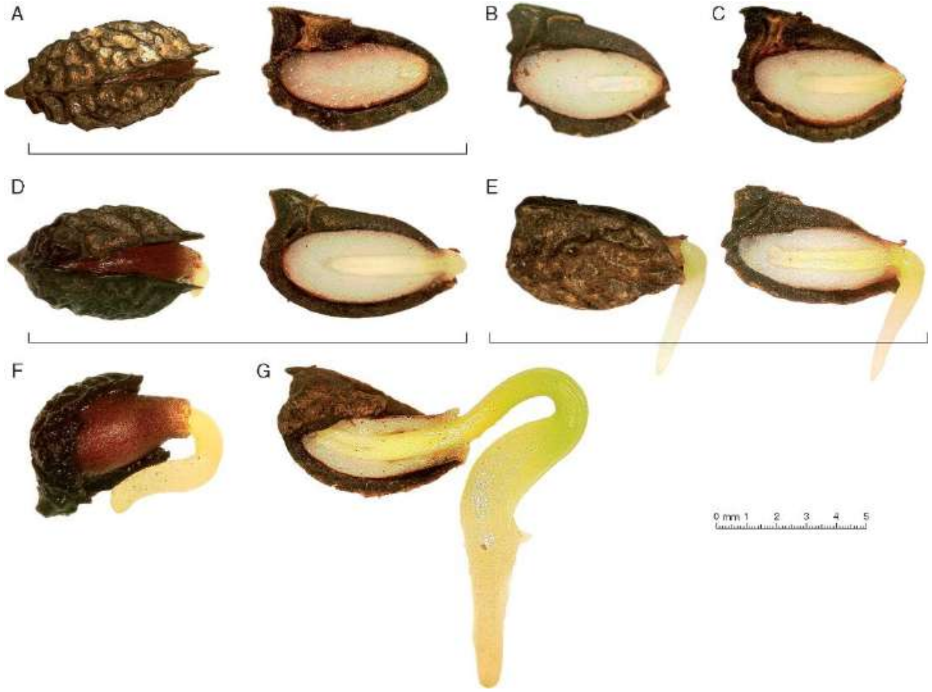


Seed dormancy

Seed dormancy is defined as an **intrinsic obstruction to the complete germination** of a viable seed under favourable conditions for the germination (e.g. temperature, humidity, light) of the corresponding non-dormant seed. Seed dormancy controls germination timing in response to the seasons and plays an important role in seed plant evolution and its adaptation to climatic changes.

Types of seed dormancy are physiological, morphological and physical, or a combination of these types.

Morphological dormancy in *Amborella trichopoda*



Advantages of seeds for plants

- The whole process of reproduction occurs on the sporophyte, which is the diploid and dominant generation.

- The dispersal unit is a small plant ($2n$) of cormophytic organisation.

- The seedling will begin to develop when it has suitable conditions and the rest period (dormancy) has been overcome.

Key differences in the reproduction of plants from seeds

Gymnosperms	Angiosperms
Scales ("*escamas*")	Complex flowers
Flowering takes place after many years	May bloom in their first year of life
Pollination is often by the wind	Pollination is often by animals
Slow life cycle (up to 2 years)	Rapid life cycle (1 year)
Gametophytes made up of many cells	Gametophytes made up of few cells
Naked seed primordia (not inside an ovary)	Protected seed primordia within the ovary
Simple fertilisation	Double fertilisation
Haploid seed endosperm (female gametophyte)	"*De novo*" formation of a triploid (*3n*) endosperm
Seeds naked seed (not within the fruit)	Seeds within the fruit

Seed plant (gymnosperms vs. angiosperms) structures (GLOSSARY)

	Gymnosperms / Angiosperms
Sporophyte (2*n*)	Plant
Megasporophyll (2*n*)	Scale / Carpel
Megasporangium (2*n*)	Nucellus (within a seed primordium)
Megasporangium + coatings (2*n*)	Seed primordium (it may be called ovule as well)
Megaspore (*n*)	Megaspore
Female gametophyte (*n*)	Primary endosperm (many cells, archegonia) / Embryo sac (7 cells, 8 nuclei, no archegonia)
Female gamete (*n*)	Egg cell
Microsporophyll (2*n*)	Scale / Stamen
Microsporangium (2*n*)	Pollen sac
Microspore (*n*)	Unicellular pollen grain
Male gametophyte (*n*)	Multicellular pollen grain
Male gamete (*n*)	Sperm nucleus

Lecture 10

Gymnosperms

Main traits

Spermatophytes

- Spermatophytes reached their highest importance in the Mesozoic (250-65 Mya).
- There are 83 genera and roughly 1,080 living species, though there are numerous fossil genera.
- Spermatophytes are included in **4(5) phyla,** whose members share the following characters:

1. They are **always woody plants** (trees or shrubs) with **monopodic branching** with a secondary growth in thickness.
2. Their **leaves** are generally **acicular (needle-like)** or **scaled**.
3. Their **reproductive structures** are **always unisexual**.
4. They are **dioecious or monoecious plants** with **simple sporophyll clusters** and mostly with a **scale bearing seed primordia** or **pollen sacs**. Their sporophylls are often grouped in **strobili** or pine **cones**.

Main traits

5. Their **seed primordia** are totally or partially **naked** (no fruit formation)**.**

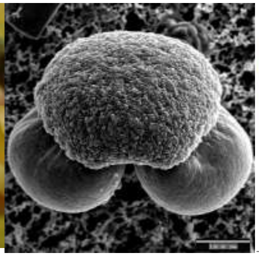
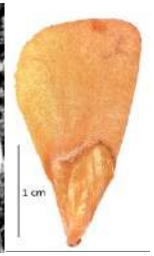
6. Their life cycle is **digenetic haplo-diploid** and **heteromorphic** with a clear **dominance** of the **sporophytic phase** (heterosporic-endosporic).

7. Female gametophytes are formed by **many cells**, which in most cases produce several archegonia.

8. Male gametophytes (multicellular pollen grains) have an endosporic development. Exceptionally, male gametophytes can originate mobile male gametes (**oogamy**), though they usually form gametic nuclei that reach the female gamete through a **pollen tube** (**siphonogamy**).

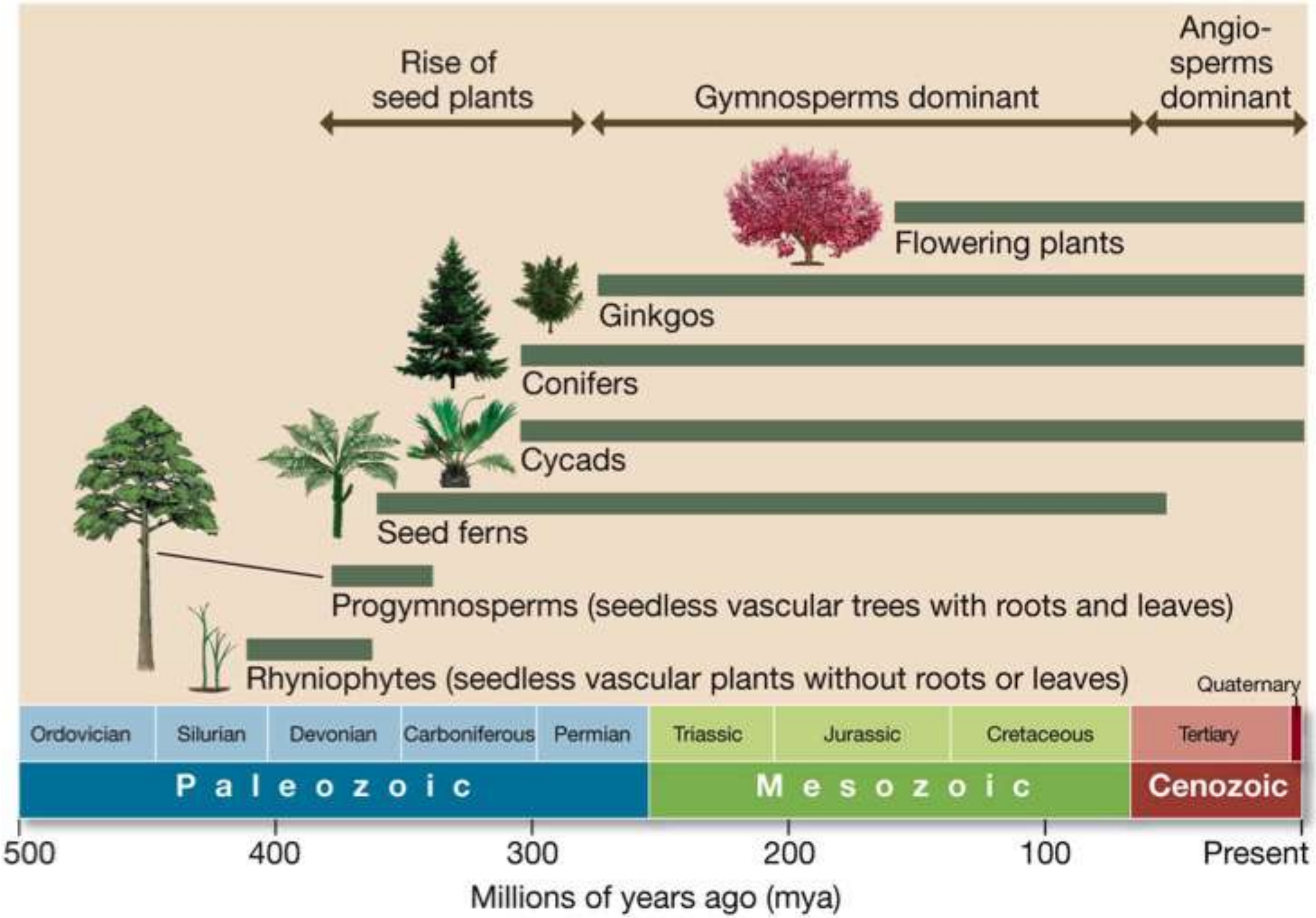
9. Seeds develop after fertilisation of the female gamete inside the seed primordium, are of variable appearance and size, and have a **storage tissue of gametophytic origin** (**primary endosperm**).



Diversity and phylogeny

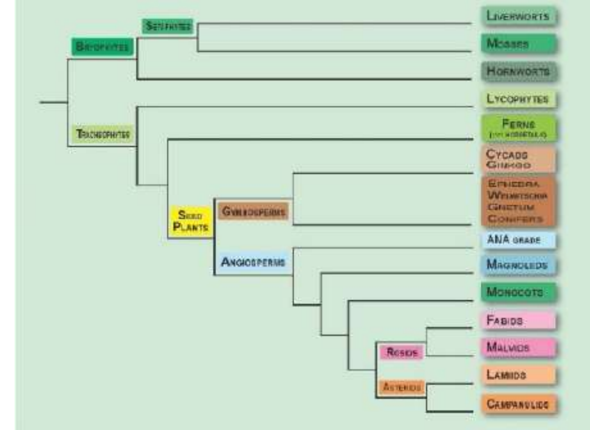
Gymnosperms, with **naked seed primordia**, dominated terrestrial floras until about 100 million years ago. They probably originated in the Devonian from an extinct group of plants with spore reproduction and secondary growth in thickness traditionally called "Progymnosperms".

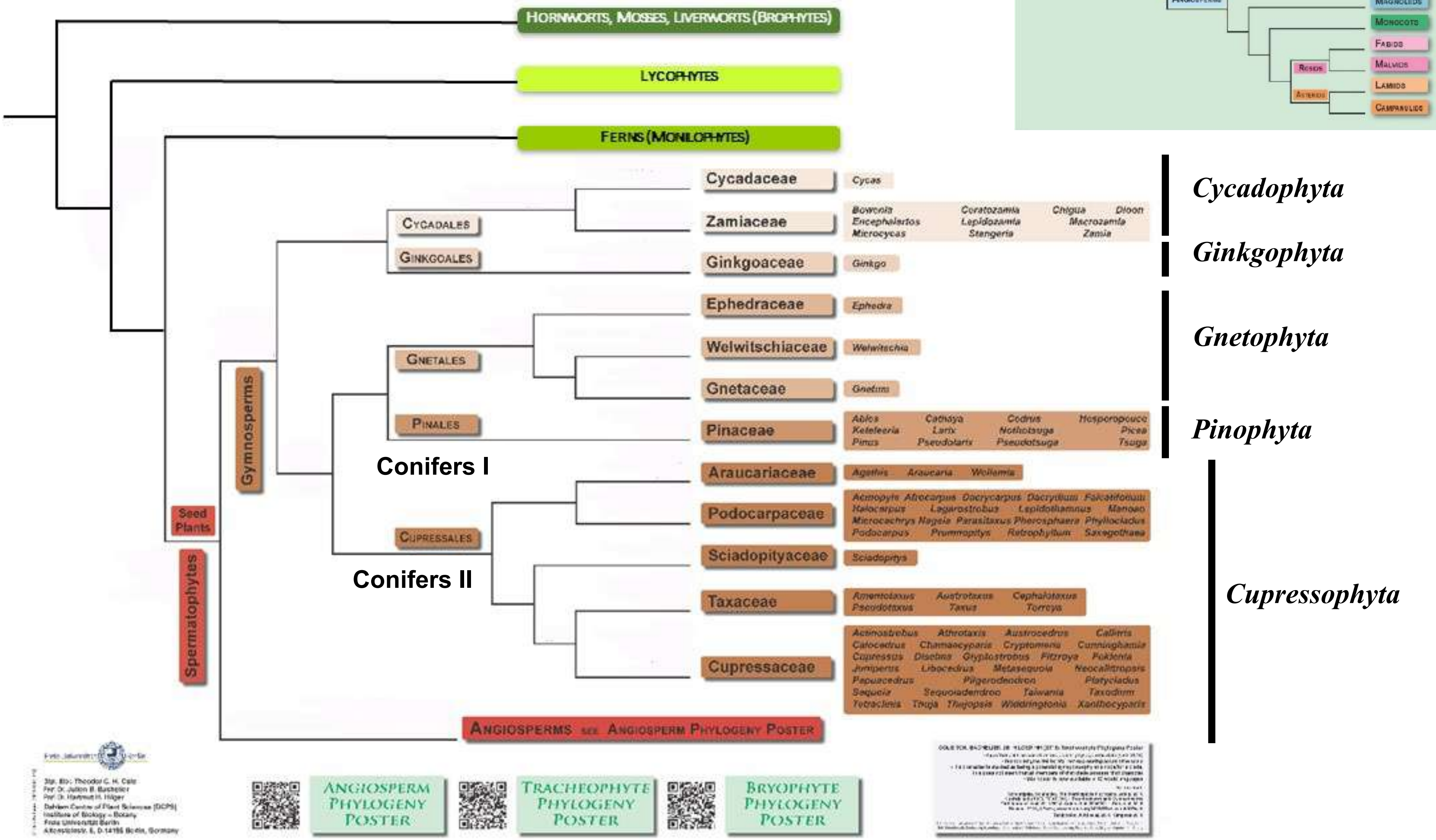


LIFE 9e, **Figure 29.1**

Diversity and phylogeny

The most recent molecular data support the **monophyly of the gymnosperms**. *Gnetales* are sisters of the *Pinales*, so **conifers become paraphyletic**.





Adapted from Cole *et al*. (2019)

Diversity and phylogeny

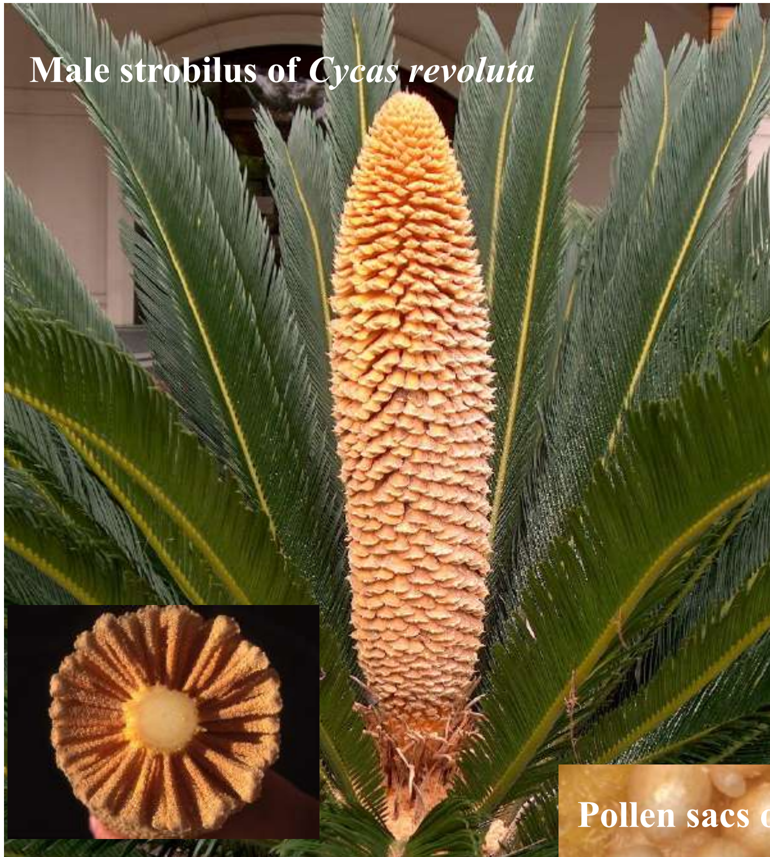
- **Classification: there are 4 (5) living groups:**
  - Phylum ***Cycadophyta***
  - Phylum ***Ginkgophyta***
  - **Conifers** (paraphyletic) including phylum ***Pinophyta*** and phylum ***Cupressophyta***
  - Phylum ***Gnetophyta***

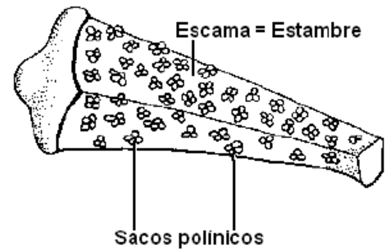
Phylum *Cycadophyta*

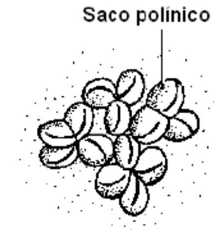
- **Minor group** with only **two families** (*Cycadaceae* and *Zamiaceae*) that comprise 10 genera (*Cycas*, *Dioon*, *Encephalartos*, *Zamia*, etc.) and 337 species.
- Probable origin in the Carboniferous, though the reliable fossil record is from the Permian. Greater diversity in the Mesozoic. They constitute **the oldest lineage of the current gymnosperms**.
- The stem is generally simple, slow growing, and topped by a tuft of pinnate, **palm-like leaves**.
- Dioecious plants.

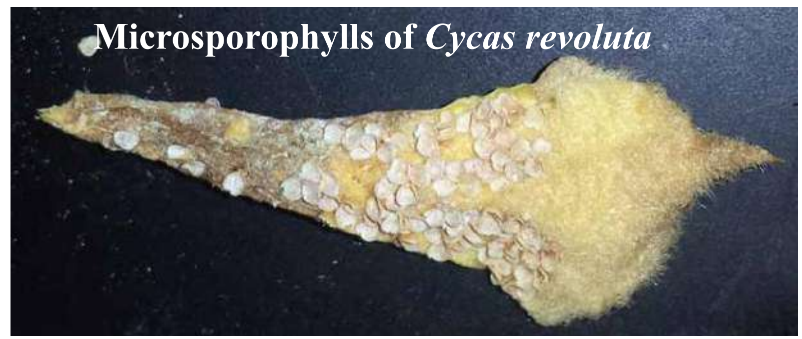
Phylum *Cycadophyta*

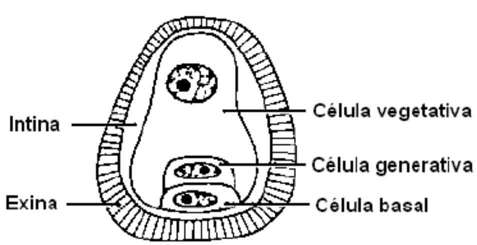
Male reproductive structures are grouped in **strobili**.



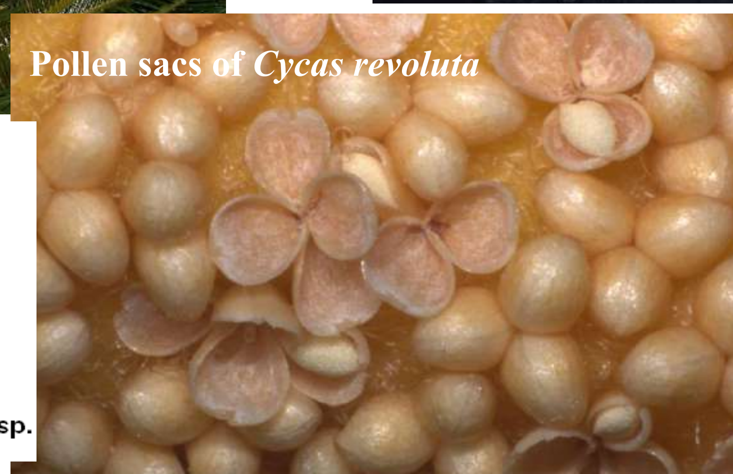


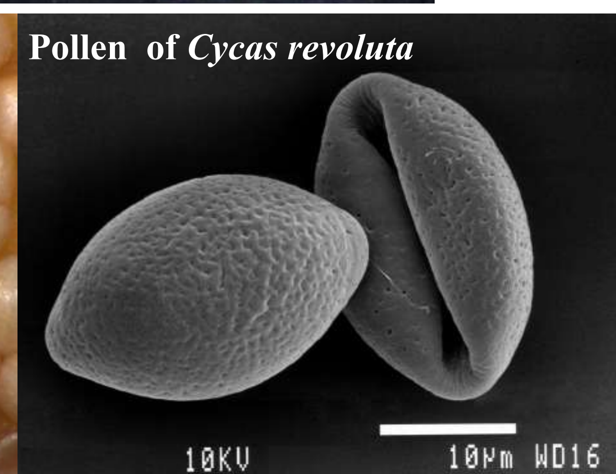






Organización del grano de polen de *Cycas* sp.





Phylum *Cycadophyta* Female reproductive structures

Megasporophyll clusters (may also be named strobili).


Cycas revoluta


Cycas platyphylla

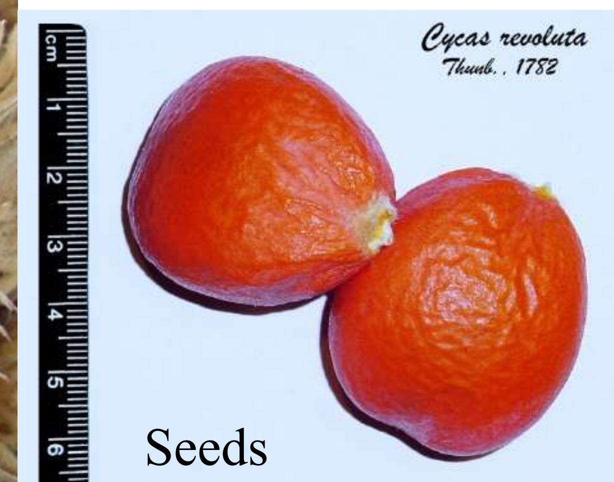
Female strobili


Zamia altensteinii


Megasporophyll and seed primordia of *Cycas*


Seed primordium of *Cycas*

Phylum *Cycadophyta*



Cycasin is a carcinogenic and neurotoxic glucoside found in cycads such as *Cycas revoluta* and *Zamia pumila*. Symptoms of poisoning include vomiting, diarrhoea, weakness, seizures, and **hepatotoxicity**. It induces hepatotoxicity and *Zamia* stagger, a fatal nervous disease affecting cattle resulting from browsing on the leaves or other parts of cycads.

Phylum *Ginkgophyta*

Family ***Ginkgoaceae***

-There is only one living species: *Ginkgo biloba.*

-This relict tree of Chinese origin (see map) is cultivated as an ornamental. This group of plants spread throughout the world during the Paleozoic. Nowadays it is planted in the parks and gardens of many cities because of **its resistance to pollution and insects**.

-**Edible seeds** (endosperm).

-It has a **pharmaceutical interest** due to its **flavonoid content**: anti-radicals and brain oxygenation enhancers.

Conifers: main traits

- Like the two previous phyla, conifers are usually **trees** (or shrubs) with a fossil record from the Carboniferous. Unlike those, however, they have an important participation in **terrestrial vegetation** (**6 families** with some **629 species**), especially in **extratropical areas**.

- These **woody**, slow-growing plants can reach a large size.

- Except for *Taxaceae*, they have seed primordia on bracts that form **strobili** or “**cones**” (“*piñas*”).

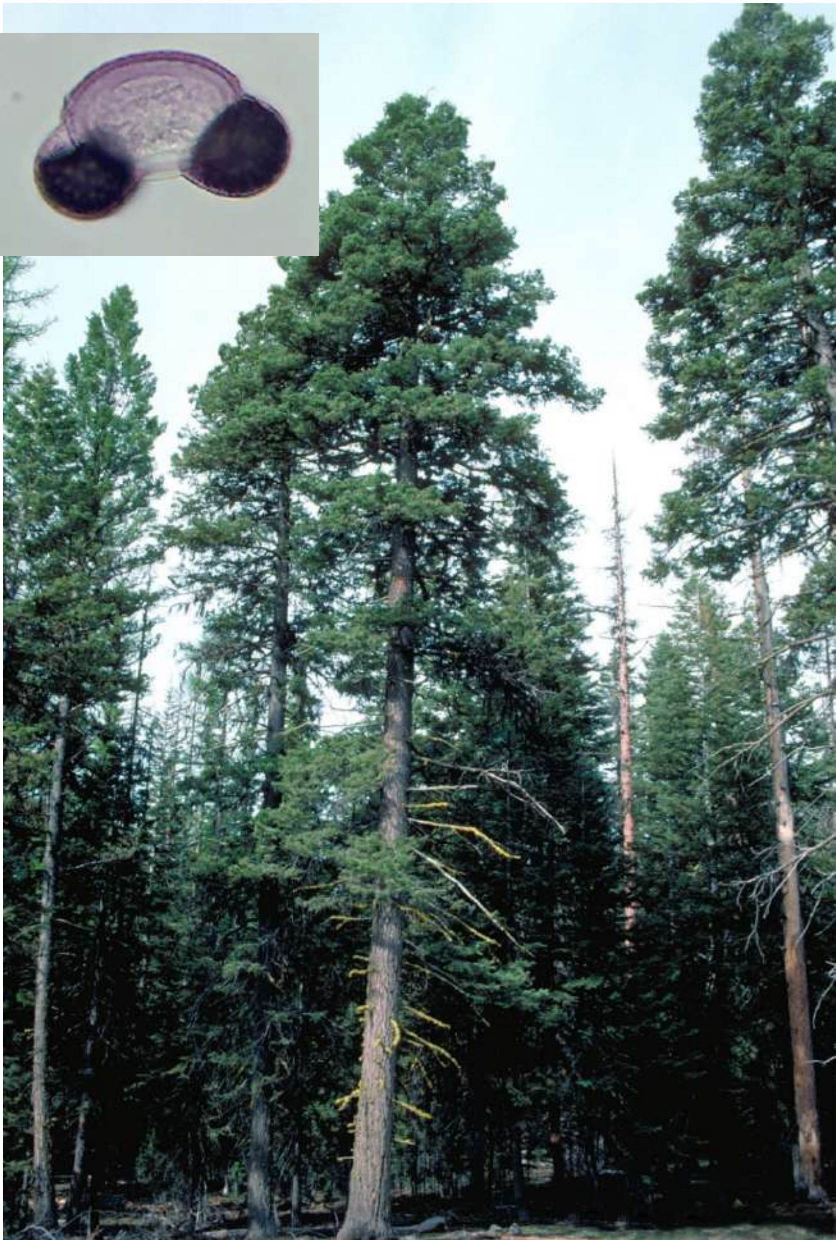
- They have generally acicular or scaled leaves.

- They pollinate by wind (anemophily).

- They reproduce sexually by siphonogamy.

- They constitute a paraphyletic group.

Conifers: Phylum *Pinophyta*, Order *Pinales*, Family *Pinaceae*



11 genera and 228 species.

Monoecious trees, **resiniferous**, with solitary **acicular leaves** or grouped in fascicles of 2-6 (in *Pinus*).

Microsporophylls with two pollen sacs. **Pollen with air vesicles**.

Female cones with persistent or deciduous scales.

The seeds are generally winged.

Conifers (I): Phylum *Pinophyta*, Order *Pinales*, Family *Pinaceae*

- Acicular leaves. Classification based on leaf arrangement:

- Leaves only on macroblasts:

Abies alba (white fir): Atlantic, timber, ornamental and resin production.

Abies balsamea: source of Canada balsam.

Abies pinsapo ("pinsapo"): endemic to the Betic mountain ranges (Spain).

Picea abies ("pinabeto"): wood.

- Leaves on macro- and brachyblasts:

Cedrus sp. pl. (cedars): wood and ornamental.

Cedrus libani (Lebanon cedar): supramediterranean, eastern Mediterranean.

Cedrus atlantica (Atlas cedar): supramediterranean, western Mediterranean.

Larix decidua (larch): deciduous, source of resin.

Conifers (I): Phylum *Pinophyta*, Order *Pinales*, Family *Pinaceae*

-Leaves only on brachyblasts:

Pinus sp. pl. (pines). Many species of interest in forestry and also in pharmaceuticals:

With two needle-like leaves in each brachyblast:

– ***P. sylvestris*** (Scots pine): wood, febrifuge and immunostimulant buds.
– ***P. pinaster*** (resin pine): wood, resin source (turpentine & rosin/colophony).
– ***P. halepensis*** ("pino carrasco"): restocking.
– ***P. pinea*** ("pino piñonero"): source of edible pine seeds.
– ***P. nigra*** ("pino negro"): restocking.

With three needle-like leaves in each brachyblast:

- ***P*. *canariensis*** (Canary pine): adapted to volcanism.

Abies alba Miller

Order ***Pinales***

Large **conical trees**, with branches regularly arranged in whorls along the main trunk, straight. **Leaves in macroblasts**, isolated, **linear**, flattened or subquadrangular. **Cones** in the upper part of the crown, **erect**, cylindrical or almost cylindrical, formed by deciduous scales that when detached leave in the tree the axes of the pine cones, with protruding scales. **Winged, triangular seeds**. Central and southern Europe.

Abies pinsapo Boiss.

Order ***Pinales***

This differs from *Abies alba* in its smaller size and its shorter, stiffer and concolorous leaves. Cones with non-protruding scales.

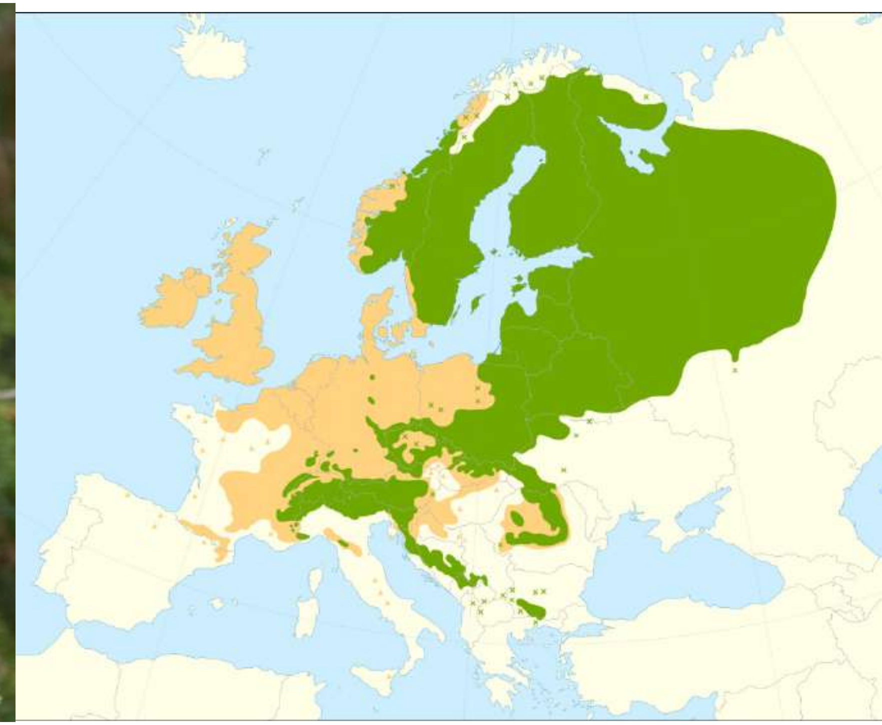
Calcareous or serpentine soil.

Southern Iberian Peninsula and northern Morocco.

“Pinsapar” from Sierra de las Nieves (Málaga)

Picea abies (L.) H.Karst.

Order ***Pinales***



Large conical trees, branches arranged horizontally or ascending along the main trunk, straight. Leaves in macroblasts, isolated, linear, quadrangular or rhomboidal. **Pine cones at the end of the branches**, cylindrical, **pendulous**, not disarticulate at maturity, non-protruding scales. Northern and central Europe.

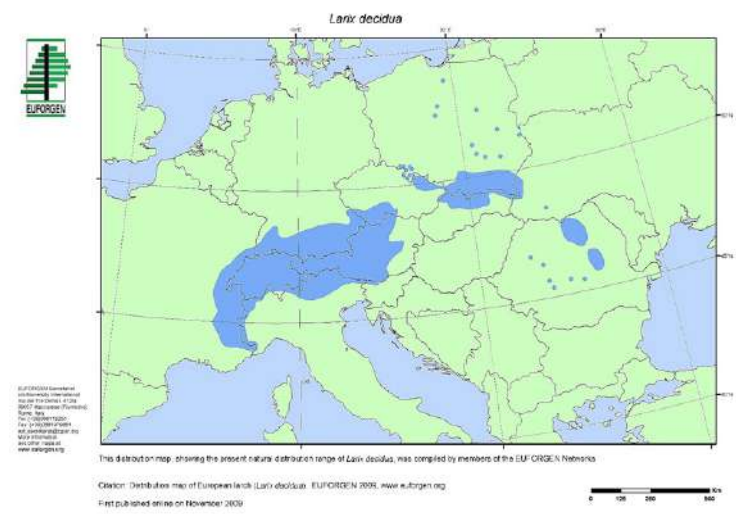
Cedrus sp. pl.

Order ***Pinales***

Four species. **Large trees** with thick trunks. Leaves in macroblasts, isolated and mainly **fasciculated** in linear brachyblasts, rigid. Cones ovoid or doliform, erect, disarticulate at maturity, non-protruding scales. Africa, Middle East and the Himalayas.

Larix decidua Mill.

Order ***Pinales***



Large trees with thick trunks. **Leaves** in macroblasts, isolated and mainly fasciculated in linear brachyblasts, rigid, **deciduous**. **Annual maturing cones**, small, erect, not disarticulated at maturity, non-protruding scales. **Highly resistant to low temperatures**. **These trees mark the upper altitudinal limit of trees**. Used for their wood and resin (**production of turpentine**). Central Europe, the Alps and the Carpathians.

Pinus

113 species

Order ***Pinales***

Monoecious and resin-producing trees.
Needle-like leaves grouped in clusters of 2-6.

Microsporophylls with 2 pollen sacs. Pollen with **air vesicles**.

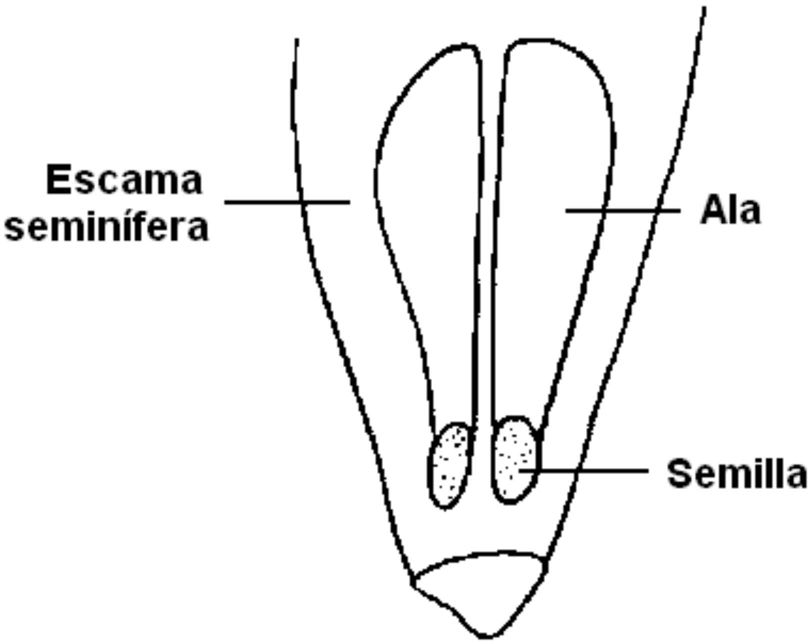
Female cones with a diverse morphology and size: conical, and cylindrical with **persistent scales**.

Winged seeds (sometimes with narrow and deciduous wings).

Distributed throughout the family’s geographic range.

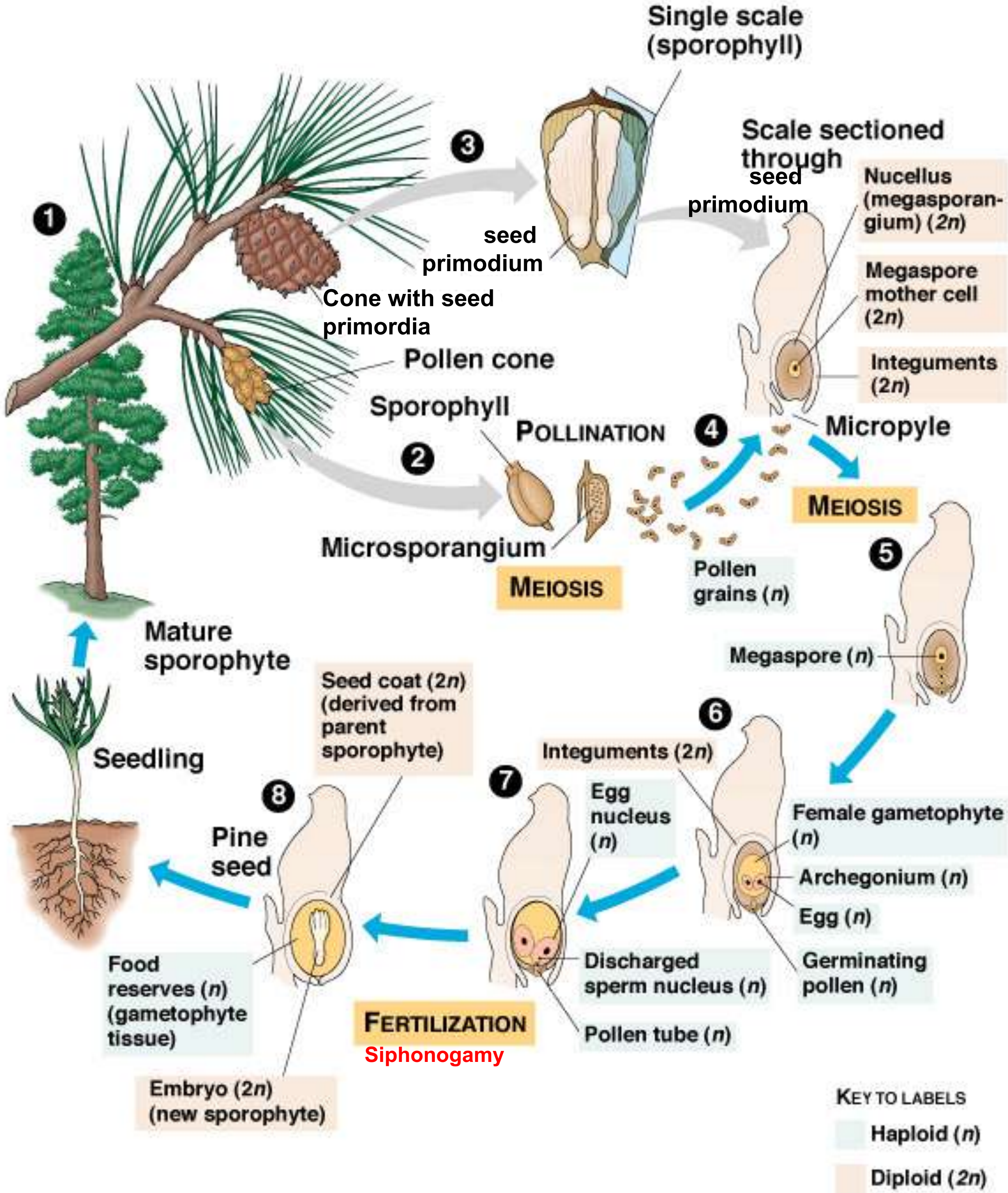
Pinus sp.

In some pines the seed is accompanied by a **wing** from the seminiferous scale.



Semillas aladas de pino
sobre la escama seminífera

Life cycle of *Pinus*



Pinus

Order ***Pinales***

The genus *Pinus* holds the **record for longevity** among the planet's organisms.

Pinus longaeva: the oldest inhabitant on Earth is "Methuselah", which is 4,850 years old (after its congener Prometheus, which by now would be 5,059 years old, was cut down). This tree has lived over a thousand years longer than any other.

Pinus halepensis Miller

Order ***Pinales***

Monoecious, widely branched tree with a greyish bark, not very dense foliage, acicular leaves, in pairs. Female strobiles conical, persistent, pedunculate. Winged seeds. Calcareous, siliceous, sandy soils. Thermo-mesomediterranean. Mediterranean basin up to Israel.

Pinus pinaster Aiton

Order ***Pinales***






Monoecious, sparsely branched tree with greyish-reddish bark, sparse foliage, long acicular leaves, thick, stiff and pointed, in pairs. Female strobiles, conical, not pedunculate, with scales with raised pyramidal apophyses. Winged seeds. Siliceous, sandy soils. Thermo-supramediterranean.
Western Mediterranean.

Pinus sylvestris L.

Order ***Pinales***

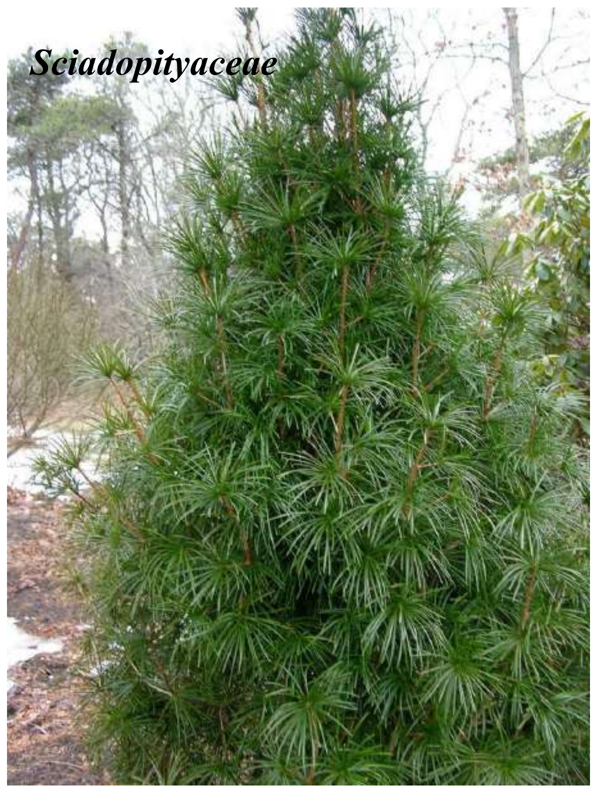
Monoecious tree, slender, greyish bark on the lower part that flakes off at the top leaving the trunk orange, short acicular leaves, flexible, in pairs. Female strobiles conical, not pedunculate, small, with scales with curved apophyses. Winged seeds. Calcareous and siliceous soils. Supra-oromediterranean and alpine. Eurasian.

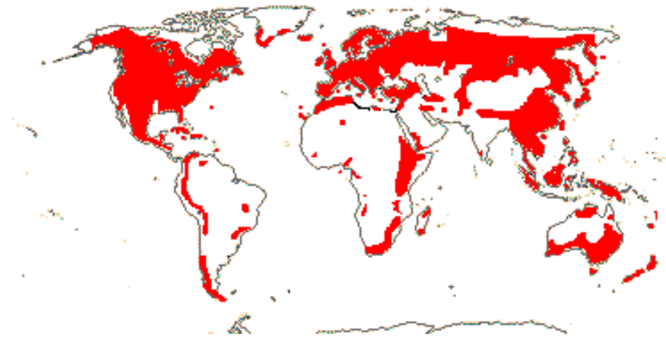
Pinus pinea L.

Order ***Pinales***

Monoecious tree, rounded crown, straight trunk, branched at the top, greyish bark with broad reddish plates, long acicular leaves, flexible, in pairs. Female cones conico-ovoid, globose, non-pedunculate, with scales with polygonal apophyses, not protruding. Seeds with very short and deciduous wing, appearing apterous. Generally sandy soils. Thermo-supramediterranean. Western Mediterranean. **Widely cultivated for pine nuts**.

Conifers (II): Phylum *Cupressophyta*





1 order, 5 families, 58 genera and 401 species.

Trees or shrubs **with or without resin**.

Acicular or scaled leaves, usually in macroblasts, alternate or verticillate.

Wide variety of female strobiles, elongated, globose, woody and fleshy (**galbules**).

Winged or apterous seeds.

Distributed throughout the family's geographic range.

Family *Araucariaceae*

Order ***Cupressales***

Agathis australis
(Tane Mahuta)

Wollemia nobilis

Araucaria araucana

3 genera (*Araucaria*, *Agathis* and *Wollemia*) and 37 species.

Long-lived trees, resinous, with *straight* trunk and whorled branches (in *Araucaria* and *Wollemia*), triangular, rigid and thick, prickly, persistent (>25 years), or lanceolate and coriaceous leaves, in macroblasts and brachyblasts.

Cylindrical male cones, each microsporophyll with 4-20 pollen sacs.

Large female cones mature in the second or third year. Winged or non-winged seeds.

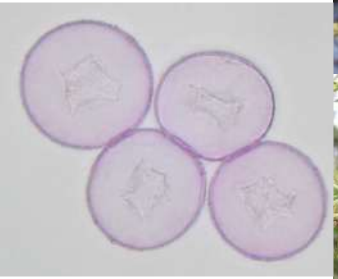
Southern Hemisphere: southeast Asia to Australia, New Zealand, and southern South America.

Family ***Cupressaceae***

Order ***Cupressales***

29 genera, 149 species.
Trees or shrubs, woody, with resin, needle-like or scaled leaves.
Monoecious or dioecious.
Male strobili with scales holding 3-7 pollen sacs. Spherical pollen grains without openings.
Female strobiles with variable number of pieces each with 2–24 seed primordia, woody or fleshy (**galbules**).
Boreal and more discontinuous in southern temperate areas.

- **Woody strobili:**
  - ***Cupressus sempervirens*** (cypress): ornamental, **venotonic strobili**
  - ***Platycladus orientalis*** (thuja): ornamental.
  - ***Tetraclinis articulata:*** rare species from the southeast of the Iberian Peninsula and North Africa.
  - ***Sequioadendron giganteum***
  - ***Sequoia sempervirens***



- **Fleshy strobili**: ***Juniperus*** sp. pl.

Junipers: needle-like leaves.

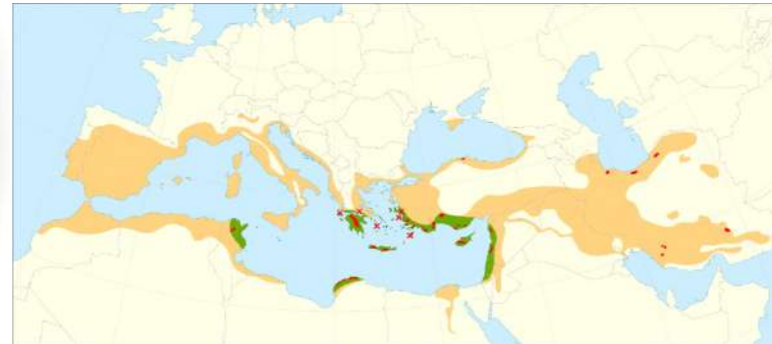
- ***J. communis*** (juniper): **gin flavoring, antiseptic, diuretic**.
- ***J. oxycedrus***.

Sabines: scaled leaves.

- ***J. sabina***: toxic.
- ***J. thurifera*****:** mainly in the Iberian Peninsula.
- ***J. phoenicea***: toxic.

Cupressus sempervirens L.

Order ***Cupressales***



Monoecious tree, pyramidal crown in cultivated varieties, straight trunk, greyish bark, scaled leaves, dark green. Female strobili woody, rounded, with 8-14 seminiferous scales with inconspicuous mucro. Seeds without wings. Generally sandy soils. Thermo-supramediterranean.
Eastern Mediterranean. Widely cultivated as an ornamental.

Tetraclinis articulata (Vahl) Masters

Order ***Cupressales***





Small, monoecious tree, rounded crown, greyish-brown bark, young stems articulated, scaled leaves, glaucous green. Female strobili, woody, small, with 4 seminiferous scales. Winged seeds. Generally sandy soils. Thermo-mesomediterranean.
North Africa and Iberian Peninsula (Murcia).

Platycladus orientalis (L.) Franco

Order ***Cupressales***

Small, monoecious tree, irregularly pyramidal crown, compressed branches, arranged in vertical planes, scaled leaves. Female strobili woody, annual maturing, small, with 6-8 seminiferous scales, with a hooked dorsal appendage. Seeds without wings.
Asiatic. Cultivated as an ornamental.

Sequoia sempervirens Endl.

Order ***Cupressales***

Tree that can reach a height of over 100 m (**gymnosperm of greater height**) and ages of 3,000 years. Straight, reddish, longitudinally furrowed trunk. Leaves dimorphic, in macroblasts and brachyblasts, those of vegetative stems distichous, flattened, decurrent, those of fertile stems scaled, acute. Female cones small <3 cm, annual maturing.

Soils, siliceous. Western USA and Canada

Sequoiadendron giganteum (Lindl.) J.Buchholz   Order ***Cupressales***

Tree that rarely reaches 100 m in height but has a much larger volume than the previous species (**it is the largest organism on the planet**) and lives for over 3,000 years. It differs from the previous tree by presenting leaves in macroblasts, acute scaled leaves and cones of greater size (up to 8 cm). Female cones of biannual maturation. The seeds can remain enclosed in the cones for 20 years, being released after fires.
Western USA.

Taxodium distichum (L.) Rich.

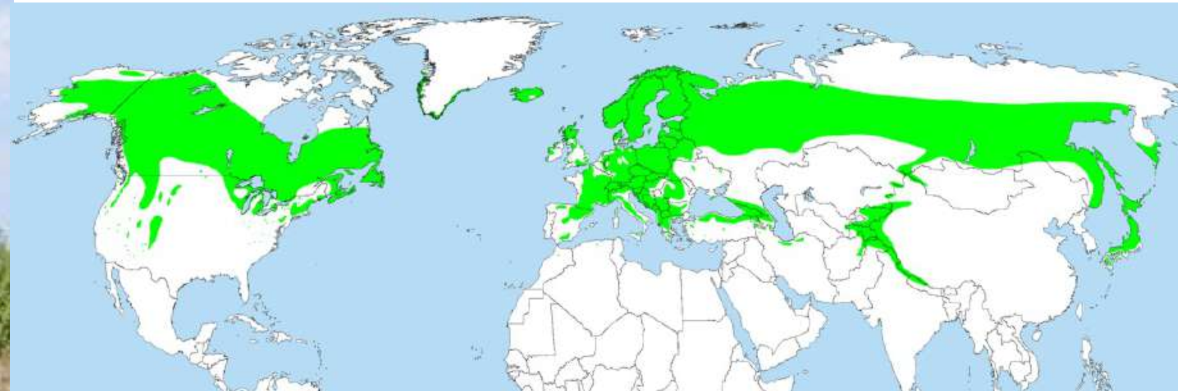
Order ***Cupressales***

Deciduous, monoecious tree with linear, flattened leaves in macroblasts and brachyblasts (which give the appearance of a divided leaf). Spherical strobili, < 4cm, with 20-30 seminiferous scales, annual maturation.
This tree inhabits humid, waterlogged areas, and swamps. **It has the only gymnosperm capable of withstanding permanent flooding.** It develops pneumatophores for root aeration.
Southeastern USA.

Temperate Rain forest, Vancouver Island

Juniperus communis L.

Order ***Cupressales***



Dioecious shrub, bush or tree, much branched, acicular leaves in whorls of three, **each with a stomatal band on the upper side**. Female strobili (**galbules**) mature, **bluish**. Calcareous, siliceous and sandy soils. Supra-oromediterranean. Circumboreal.

Juniperus oxycedrus L.

Order ***Cupressales***

Dioecious shrub, bush or tree, much branched, acicular leaves in whorls of three, each with **two stomatal bands on the upper side**. Female strobili (**galbules**) mature, **reddish-brown**. Calcareous, siliceous and sandy soils. Thermo-supramediterranean.
Mediterranean Basin to Iran.

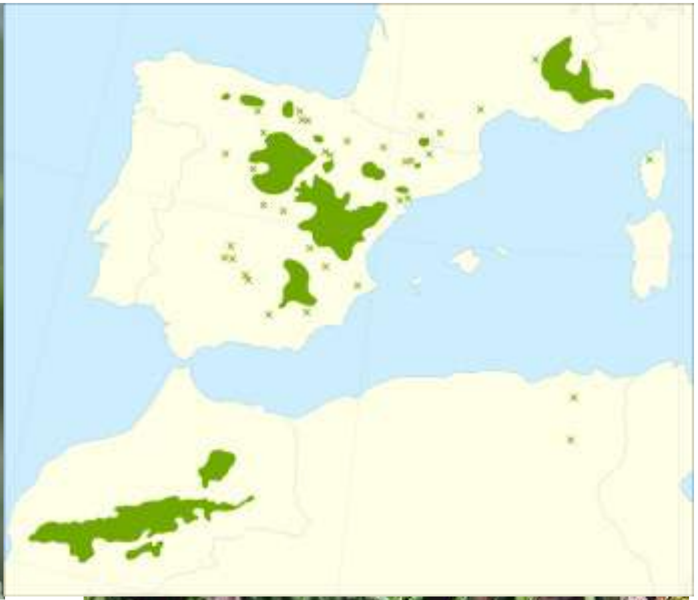
Juniperus sabina L.

Order ***Cupressales***

Dioecious shrub, usually **prostrate**, scaled leaves, with mature, bluish female strobili (**galbules**). Calcareous soils of high Mediterranean mountains.
Supra-oromediterranean.
Central and southern Europe, Algeria and Turkey.

Juniperus thurifera L.

Order ***Cupressales***



Dioecious **tree**, roughly 12 m tall, scaled leaves, with mature female strobili (**galbules**) **blue-grey**. Calcareous soils, sometimes siliceous and chalky.
Supra-oromediterranean.

Juniperus phoenicea L.

Order ***Cupressales***

Monoecious shrub sometimes of considerable size, very branched from the base, scaled leaves, female strobili (**galbules**) mature, **brownish**.
Thermo-supramediterranean.

Family *Taxaceae*

Order ***Cupressales***

6 genera and 27 species.

Dioecious trees or shrubs.

Linear, flattened leaves.

Female flowers not clustered in strobili, formed by isolated seed primordia.

Seeds that when ripe present a red **fleshy aril** (bird dispersal vectors).

Distributed throughout the Northern Hemisphere and Southeast Asia.

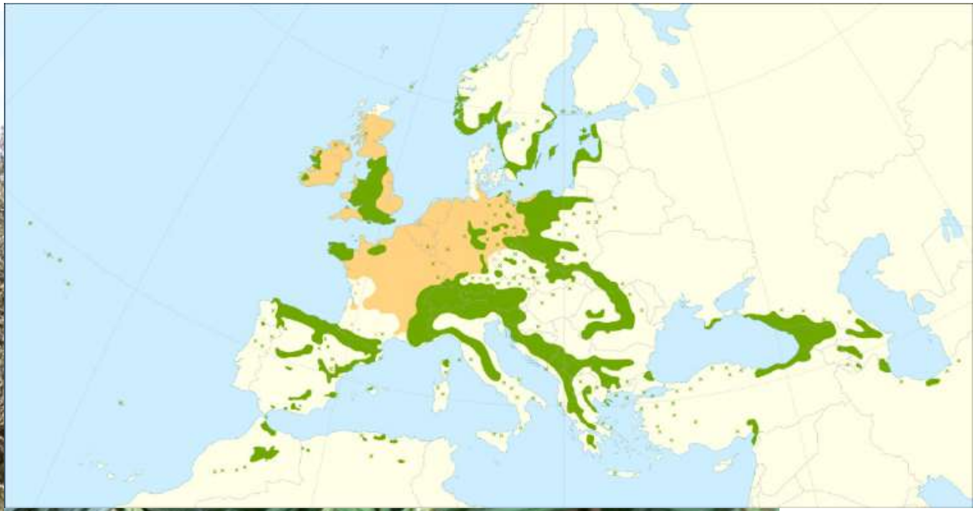
Spherical pollen grain without openings

Red arils

Taxus baccata L. (yew)

Order ***Cupressales***

Taxus baccata (Mas de Tetuán, Parque Natural del Carrascar de la Font Roja (Alicante)).



The whole plant is toxic (except the seed aril) due to its alkaloid **taxol** content. It is used as an anticancer agent.

Phylum *Gnetophyta*, order *Gnetales*

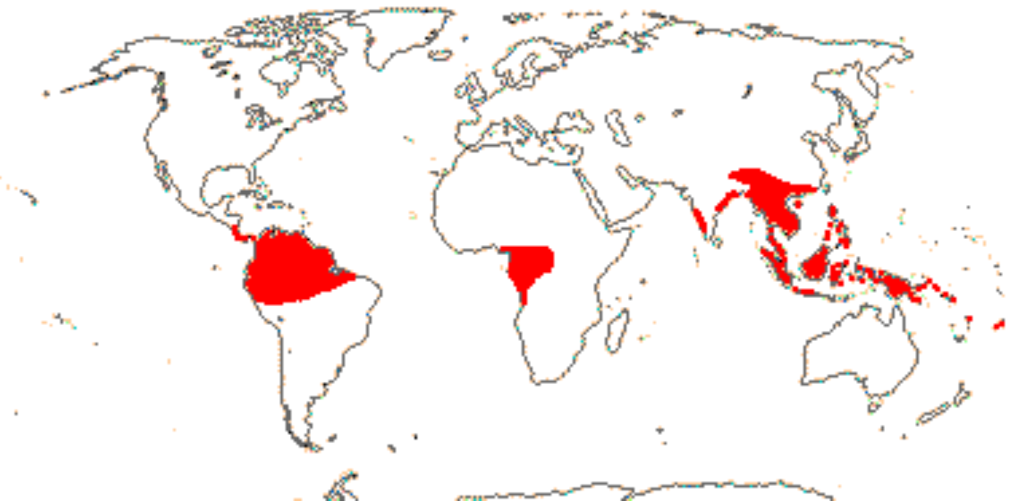
- Minor group with only 112 species grouped in 3 genera: *Gnetum*, *Ephedra* and *Welwitschia*.

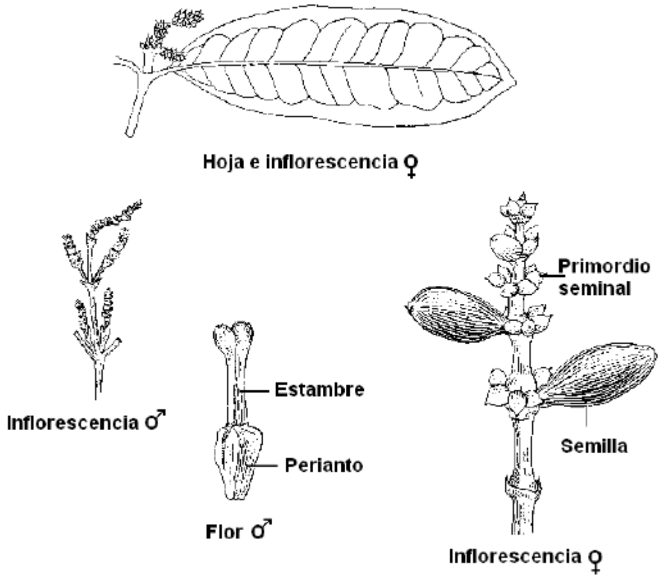
- Fossils are known from the Cretaceous. Because of their "floral" characteristics, they are considered very close to angiosperms:

  - Double fertilisation (in some cases).
  - Wide leaf blades like angiosperms (*Gnetum*).
  - Existence of tracheae in the xylem and cribose tubes in the phloem (*Gnetum*).
  - The "flowers" have bracts partially surrounding the seed primordia.
  - There is a reduction in the number of cells that gametophytes comprise with respect to the other gymnosperms; the female gametophyte sometimes no longer forms archegonia and the male is reduced to three cells.

Family *Gnetaceae*

Order ***Gnetales***





Gnetum gnemon

Only one genus with 43 species.

Monoecious or dioecious trees, shrubs or lianas. Leaves reminiscent of dicotyledons. In addition, they have tracheae in the xylem, do not produce archegonia and, during reproduction, double fertilisation occurs, though without the development of secondary endosperm.
Distributed in tropical regions.

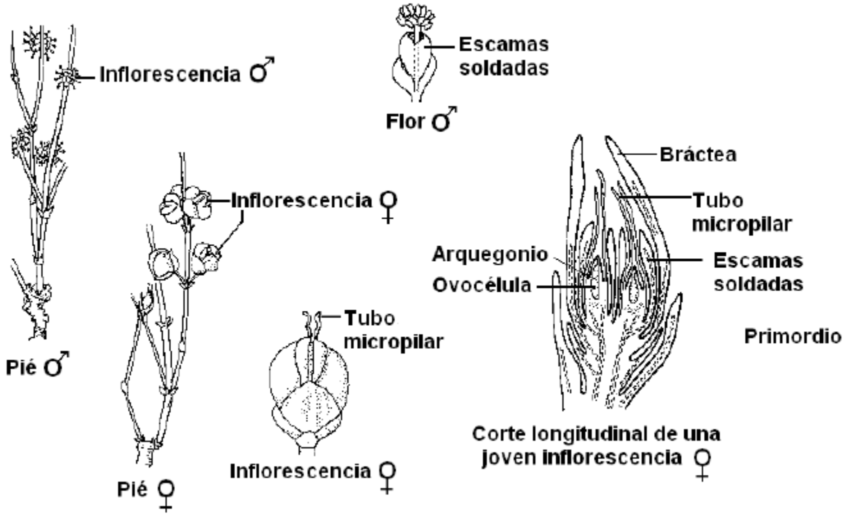
Family *Ephedraceae*

Order ***Gnetales***

Only one genus with 68 species.

Monoecious or dioecious, xeromorphic shrubs of arid zones, with photosynthetic, articulated stems and very small leaves.

Reproductive structures are grouped in strobili.



Ephedra distachya

Family *Ephedraceae*

Order ***Gnetales***

Pollen grains

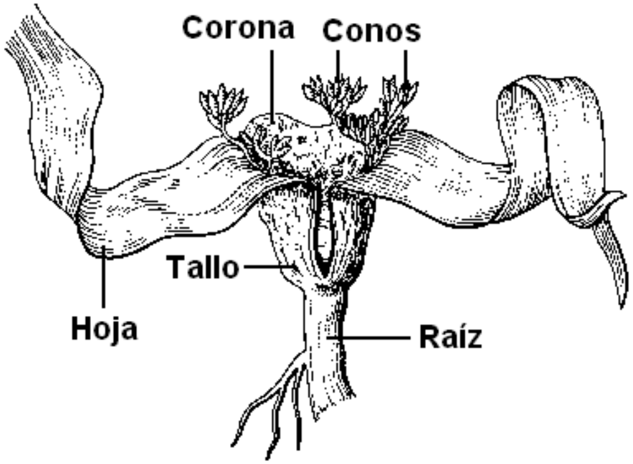
Pollination is by insects.

These plants have alkaloids: **ephedrine** and **pseudoephedrine** of medicinal use.

Family *Welwitschiaceae*

Family with one genus and one species Order ***Gnetales***

Welwitschia mirabilis



Female specimen

Male specimen

Male cone

Lecture 11

Angiosperms (Phylum *Magnoliophyta*)

Topics

- **Introduction**
- **Flowers, inflorescences, androecium and gynoecium**
- **Pollination and fertilisation**
- **Seeds and fruits**

Main traits of angiosperms

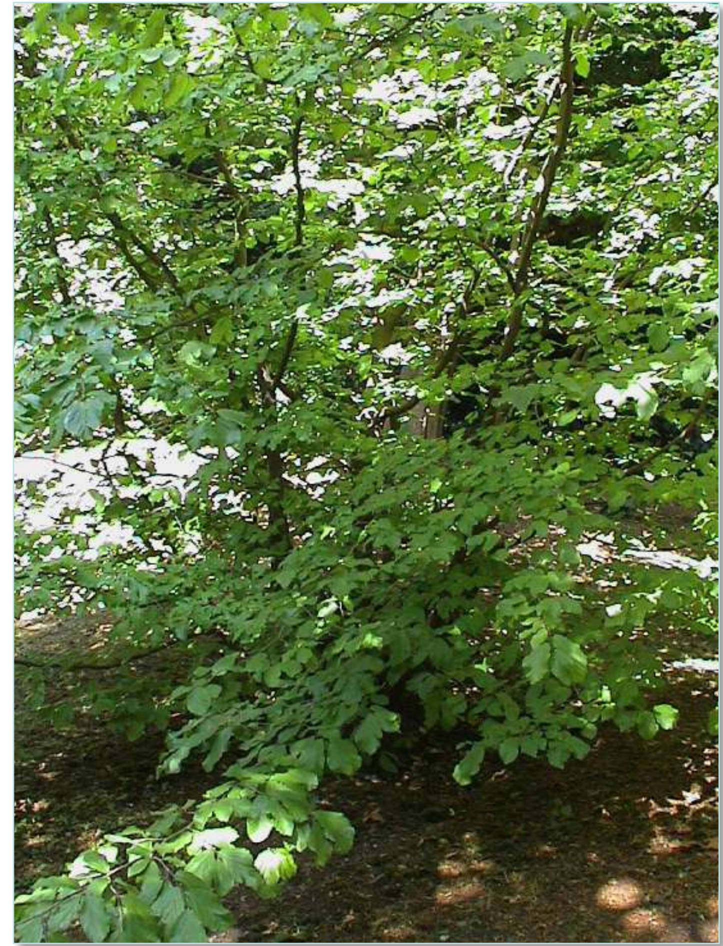
- Angiosperms are the most **numerous group of plants**, comprising some 300,000 species.
- Although they **dominate terrestrial environments**, some have adapted to live in marine or continental aquatic habitats.
- Most are autotrophic but roughly 3,000 are parasitic and also **mycoheterotrophic** (i.e. they have an obligate relationship with a mycorrhizal fungus that is in turn connected to an autotrophic plant that transfers carbohydrates to it).
- **Digenetic** haplo-diploid and heteromorphic **life cycle**, in which the **sporophyte** is the **dominant** generation.

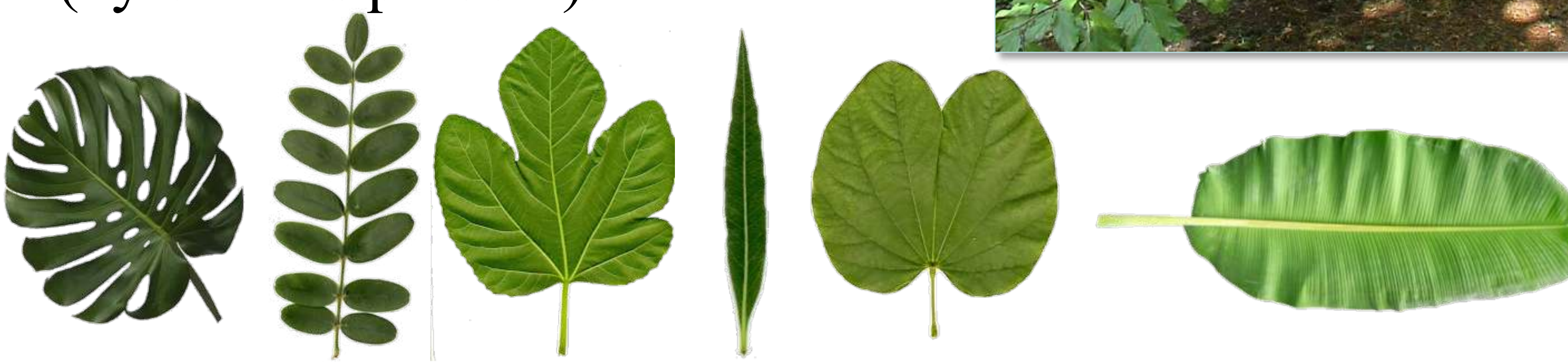
Monotropa sp.

Raflessia arnoldii

Main traits of angiosperms

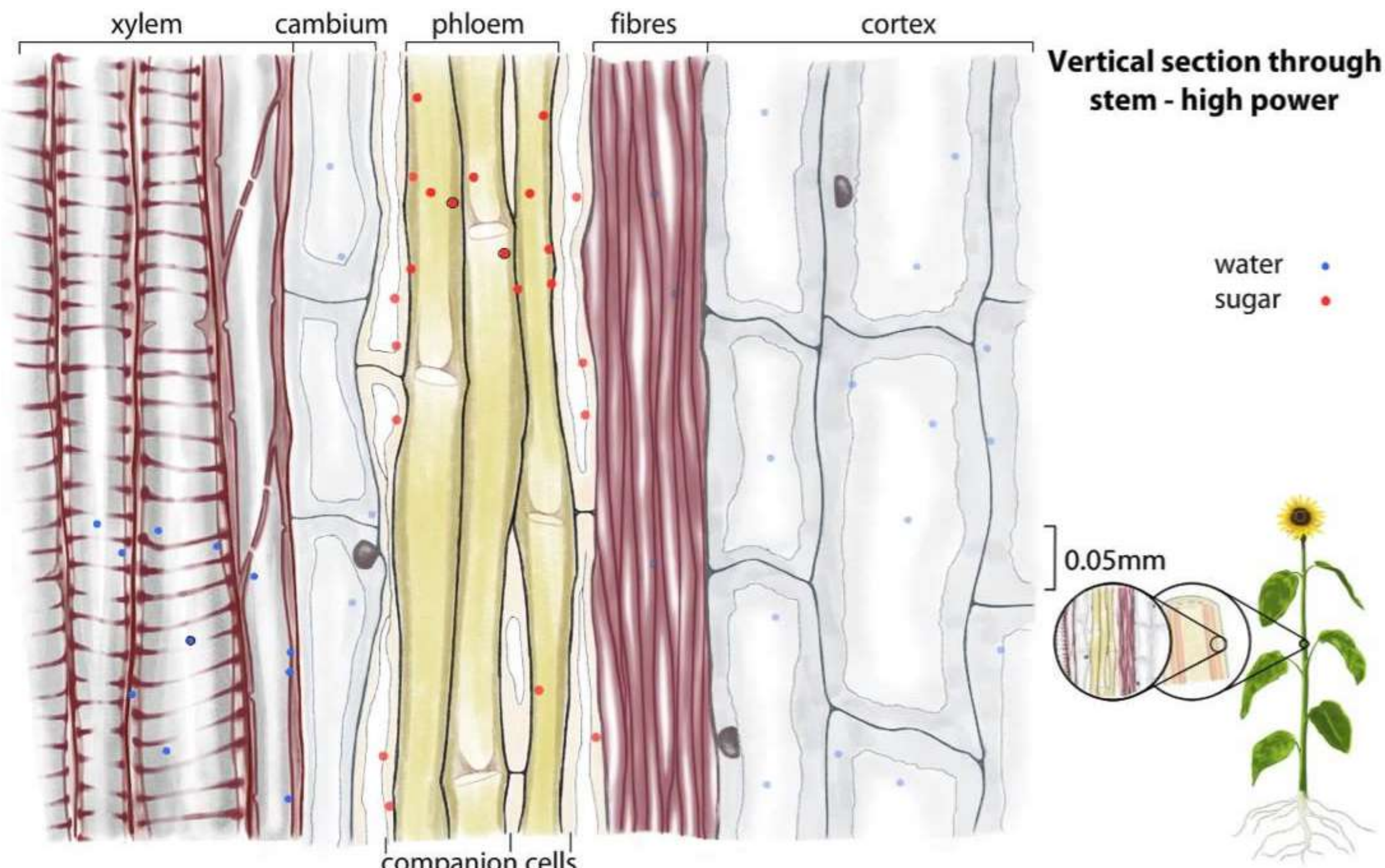
- Since angiosperms are **cormophytes**, they are the most structurally complex plants on Earth.
- Their sporophytes are physically structured in **leaves** (megaphylls), **roots** and **stems**.
- They have **vascular bundles** (xylem and phloem).





Main traits of angiosperms

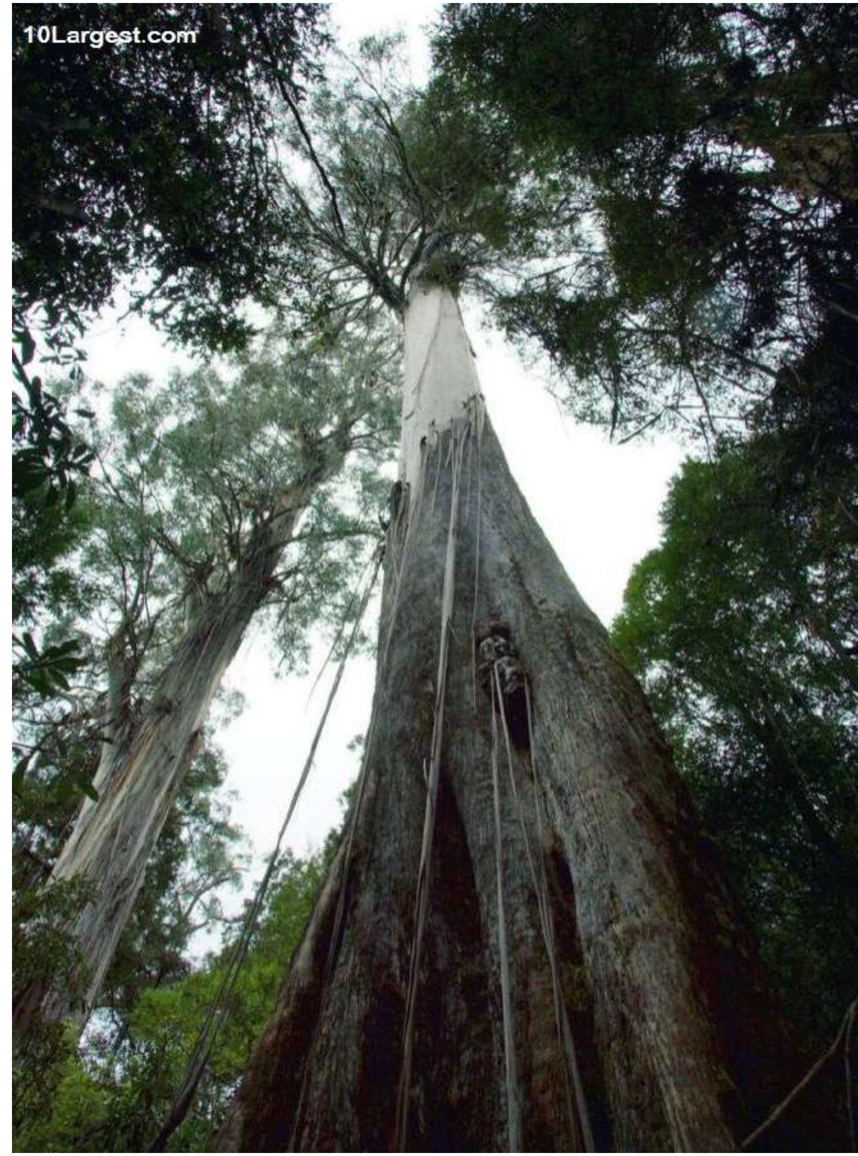
- **Vascular bundles** are generally made up of tracheids and vessel elements (**xylem**), sieve-tube elements and companion cells (**phloem**).



Main traits of angiosperms

- Most species show **secondary growth** (responsible for thickening of stems and roots)
- Their **size** is **variable**: grasses, bushes, shrubs, trees and lianas.
-

Wolffia include the tiniest angiosperms of all (barely 1 mm): in the image above, they are shown next to *Lemna* plants.

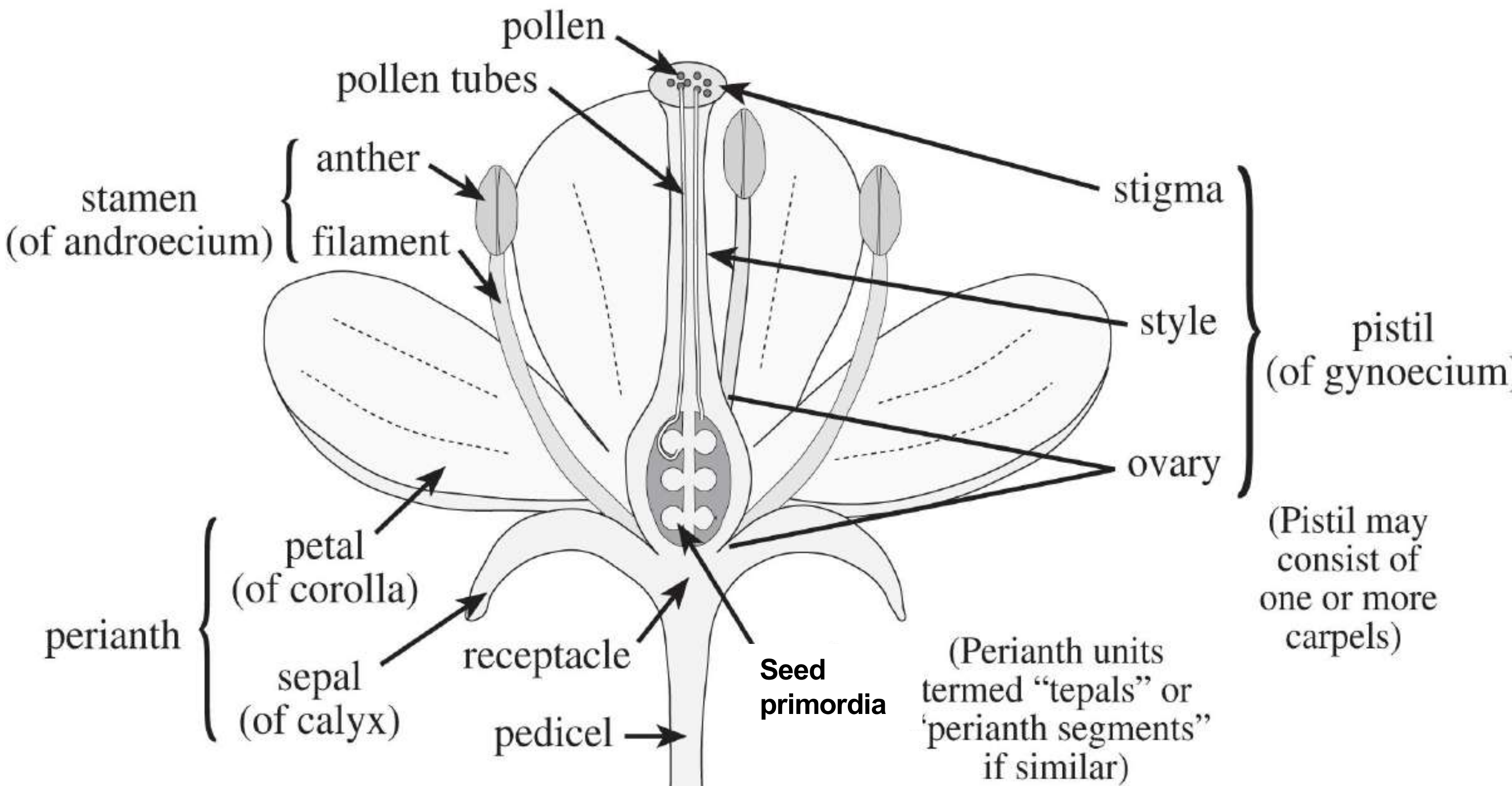


Eucalyptus regnans (the tallest angiosperm on Earth (>100 m), Tasmania.

Main traits of angiosperms: reproduction

- **Angiosperms** are **heterosporic** plants with **flowers** that consists of:

- a more or less widened axis named **peduncle** or pedicel, and the **receptacle**.
- sterile anthophylls (= floral leaves): leaves for protection and visual cues. Together, they form the **perianth**: the **calyx** and the **corolla**.
- fertile anthophylls named sporophylls. There are two types:
  - -microsporophylls, or **stamens**.
  - -megasporophylls, or **carpels** inside which are enclosed **seed primordia**.



Simpson, M: Plant Systematics, 2nd Edition, 2010. Elsevier Academic Press

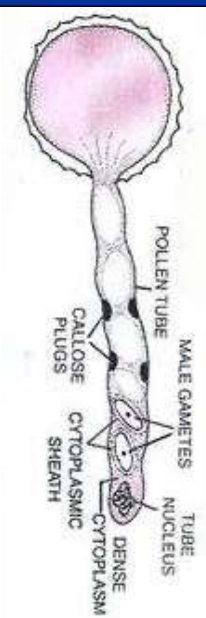
Main traits of angiosperms: reproduction

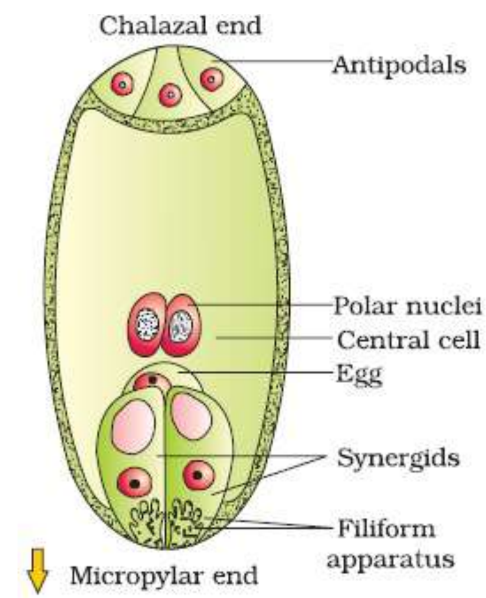
- Most species rely on some kind of pollination vector to accomplish **pollination**. The vector can be any agent that can move pollen from anther to stigma. Most angiosperms are pollinated by **animals**.

K. R. Robertson, plants in Champaign, Illinois.

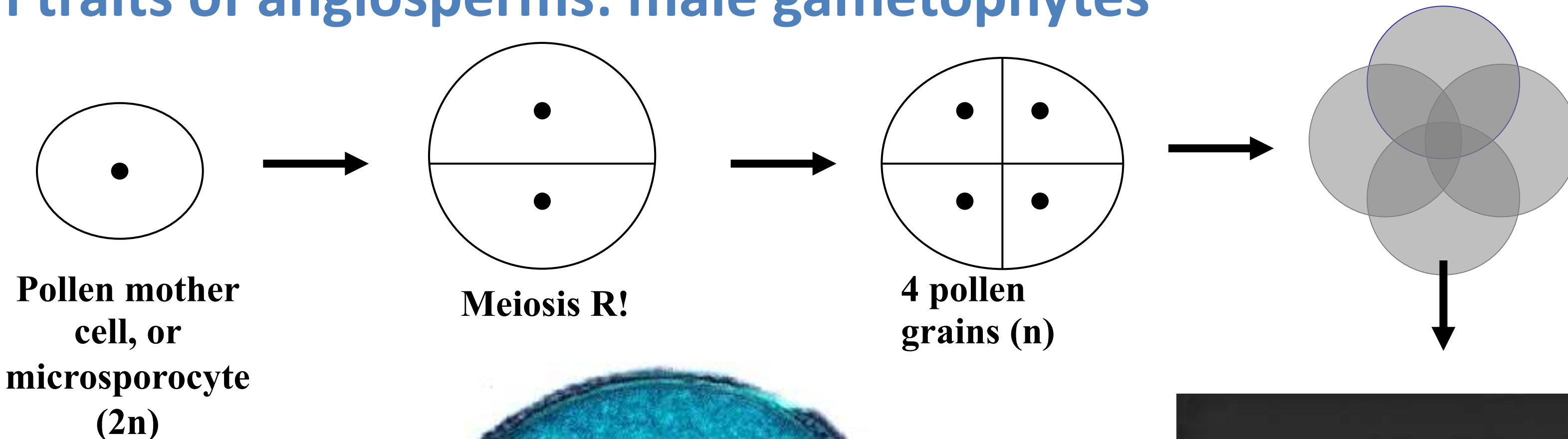
- **Flowers** are generally **bisexual** (hermaphrodites) and markedly **proterandric**.

- Very **small gametophytes** (in terms of the number of forming cells); in addition, gametophytes are **endosporic**:
  - **Male gametophytes** are the germinating pollen grains **made up of only three cells**: the pollen tube cell (vegetative cell) and the two male gametes.
  - **Female gametophytes** are formed inside seed primordia and are named **embryo sacs**. Each embryo sac is made up of only 7 cells (and generally 8 nuclei); no archegonia are formed.

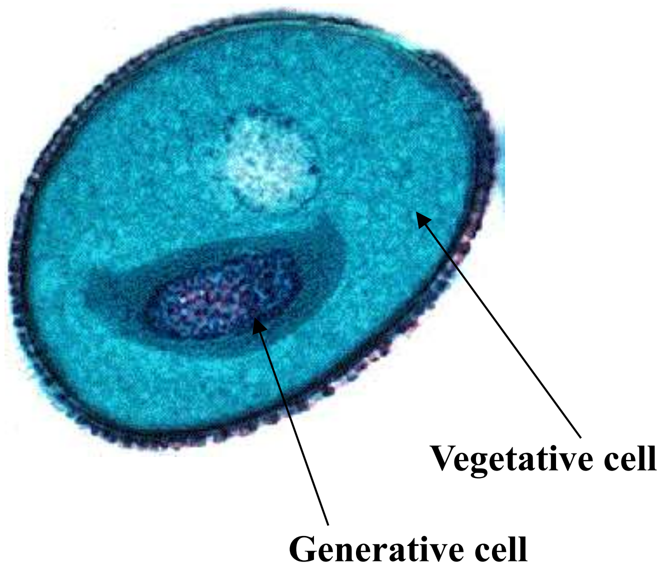


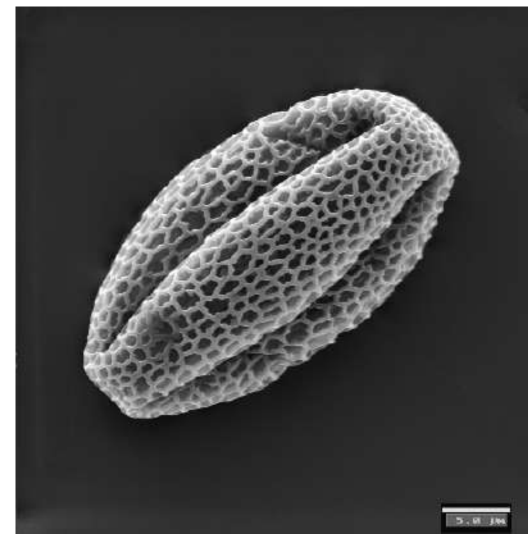


Main traits of angiosperms: male gametophytes



Bicellular pollen of *Lilium* (*Liliaceae*)



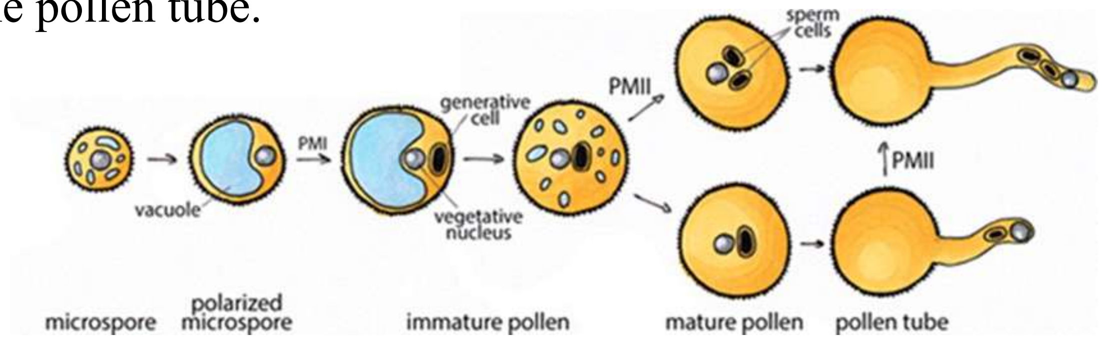


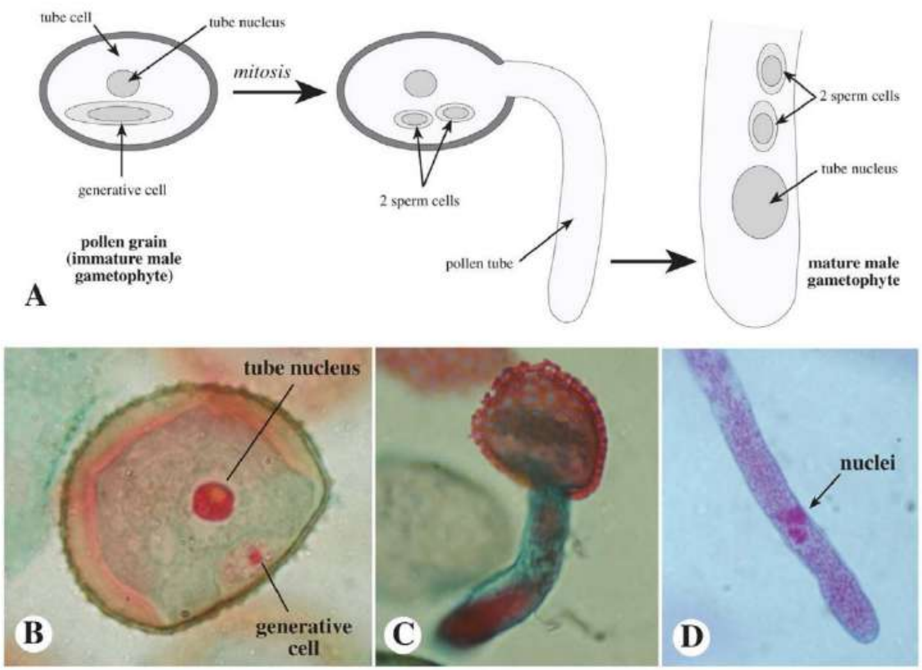
Generative cell —Mitosis→ 2 male gametes

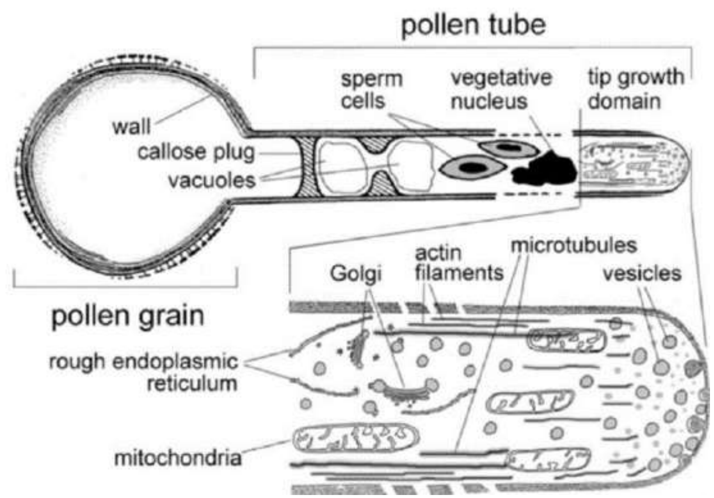
MALE GAMETOPHYTE: Vegetative cell + 2 male gametes

Main traits of angiosperms: male gametophytes

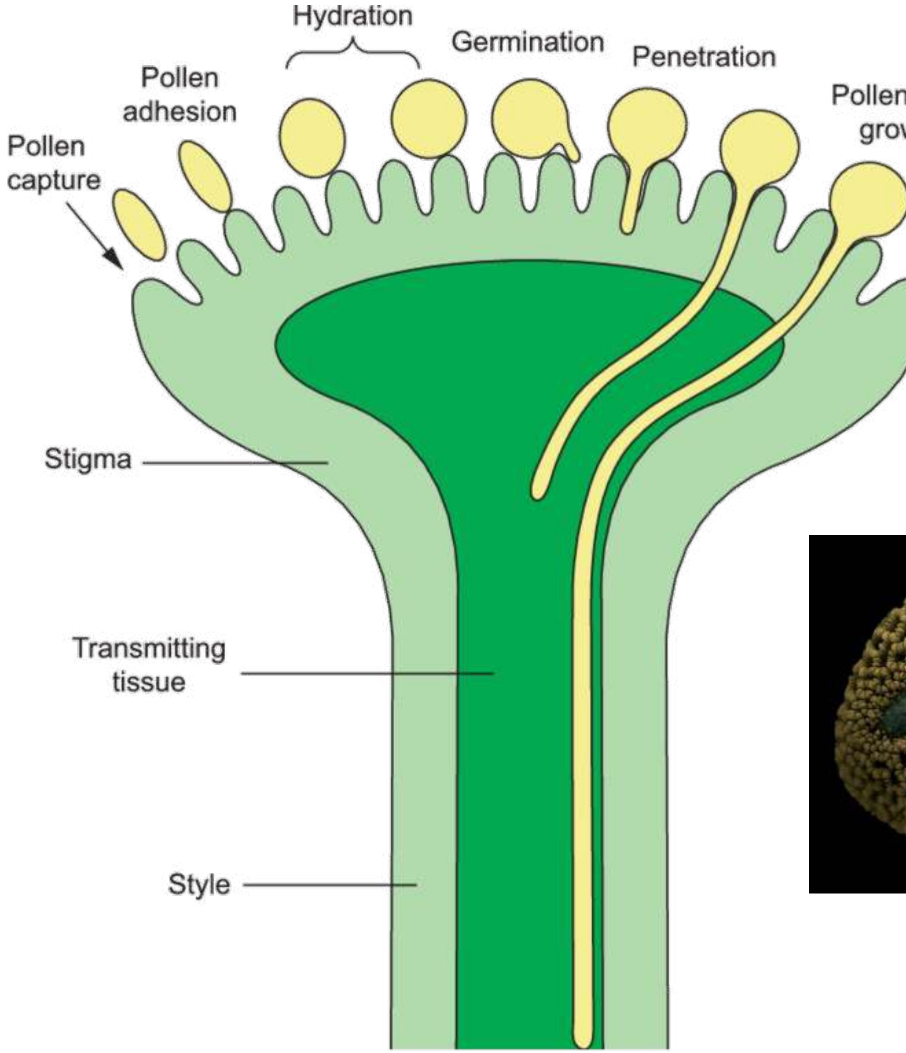
The vegetative cell develops the pollen tube.
The generative cell divides by mitosis and produces two sperm nuclei.
The division can occur during (bicellular pollen grain) or before (tricellular pollen grain) the development of the pollen tube.

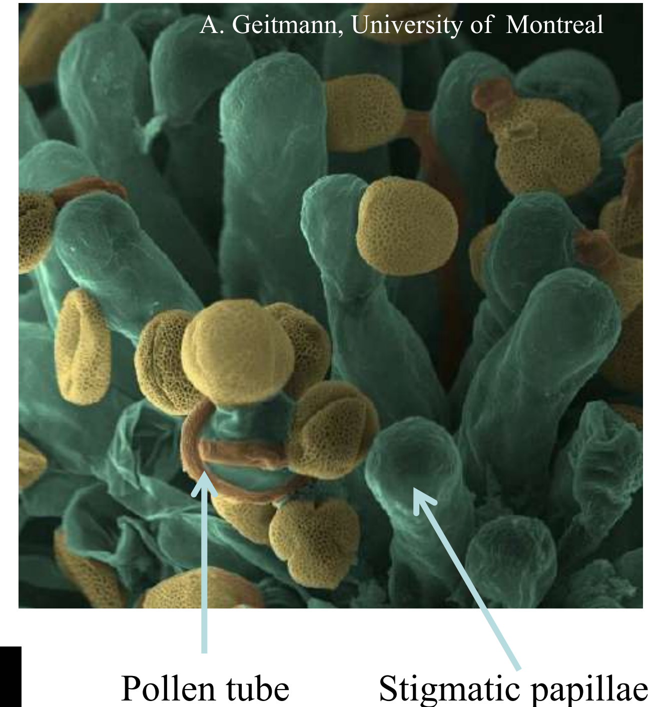


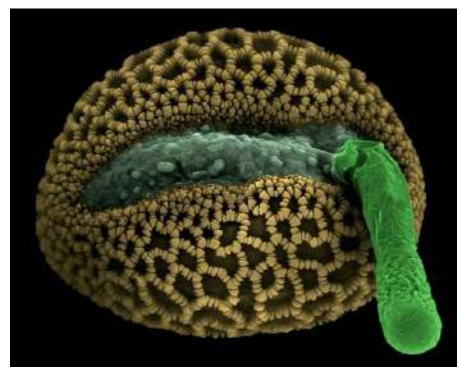


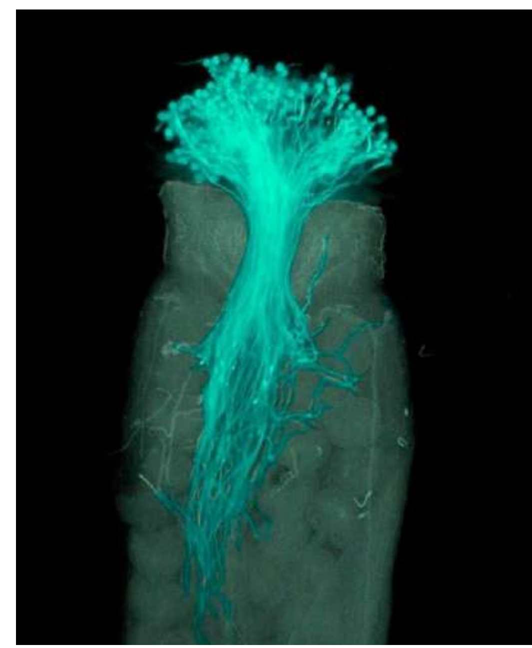


Main traits of angiosperms: pollination





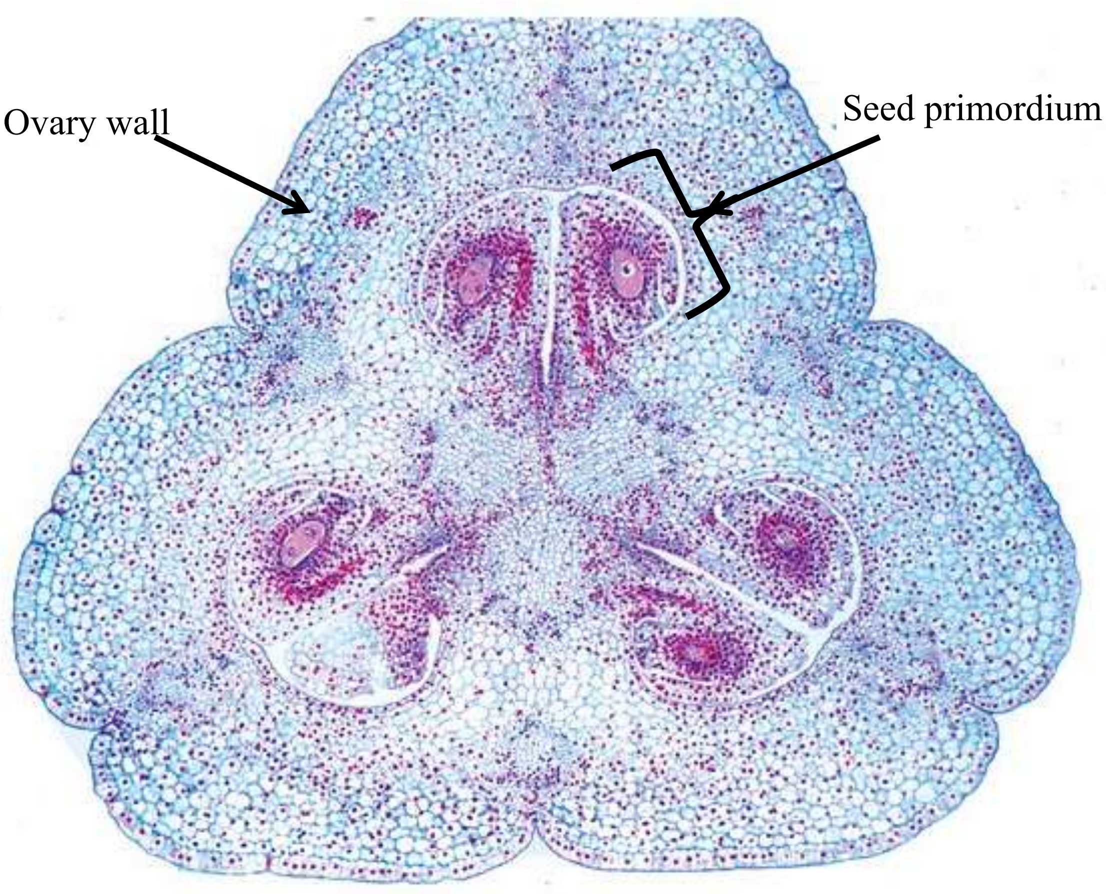




Different stages of interaction between pollen and stigma, and subsequent growth through the transmitting tissue within the style.

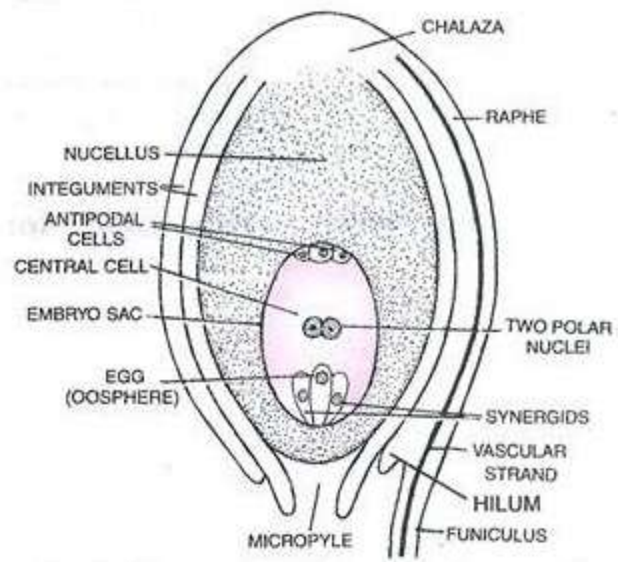
Main traits of angiosperms: female gametophytes

In angiosperms the seed primordia ("ovules") are located in the ovary.



Cross-section *Lilium* ovary

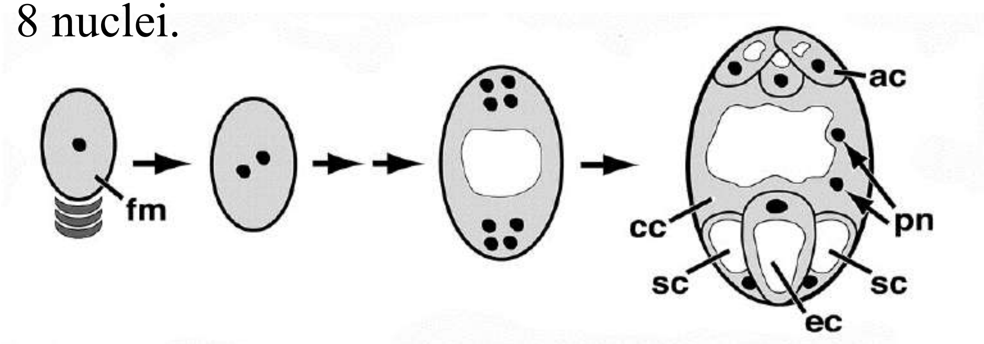
The female gametophyte (**embryo sac**) is protected inside the seed primordium.

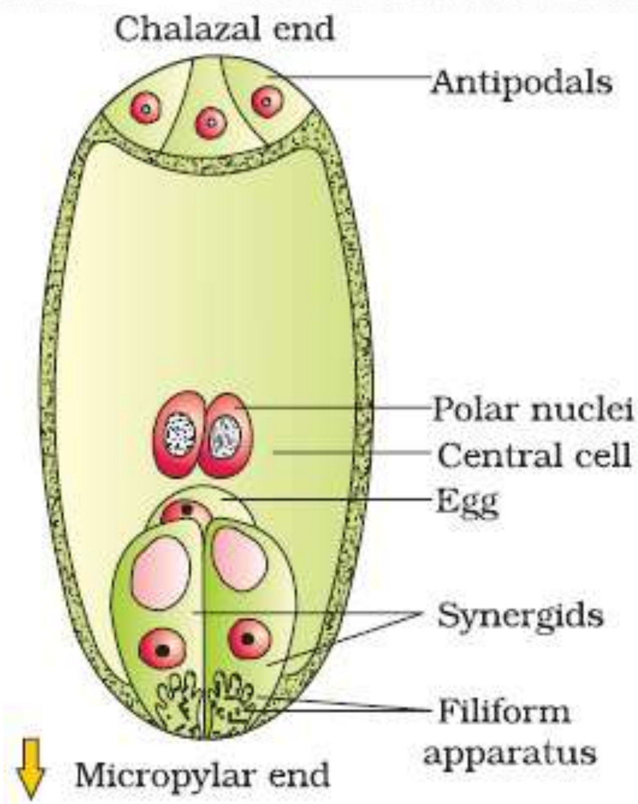


Structure of a typical ovule (anatropous ovule) prior to fertilization.

Main traits of angiosperms: female gametophytes

The embryo sac: standard type (70% angiosperms), *Polygonum*-type, made up of 7 cells and 8 nuclei.





These cells are:

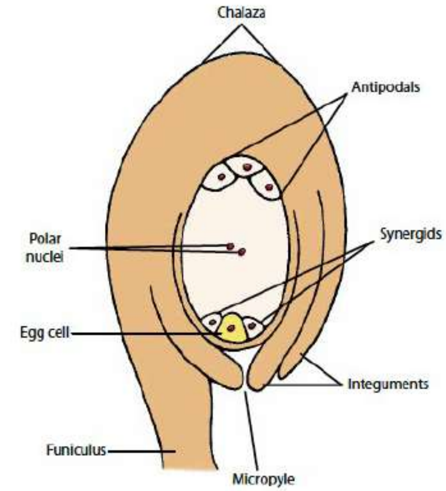
3 ANTIPODALS

2 POLAR NUCLEI (central cell)

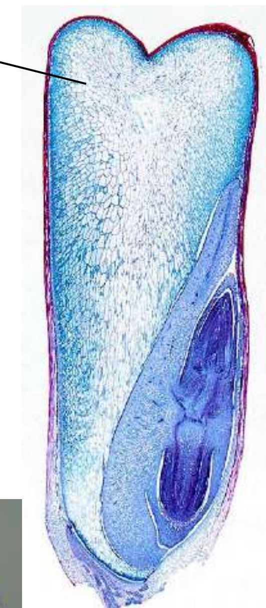
2 SYNERGIDS

1 EGG CELL

Main traits of angiosperms: double fertilisation



- **Double fertilisation**, involving two sperm of the mature male gametophyte, gives rise to the **zygote** (sperm+egg) and the **secondary endosperm** (sperm+2 polar nuclei), which is triploid; the zygote becomes the **embryo**. This endosperm will feed the young, developing sporophyte.



- The transformation of the seed primordia into **seeds** transforms the **ovary wall** into a **fruit**.

Seeds:



- All these characteristics show great variability and are used in the systematics of angiosperms.

Fruits:

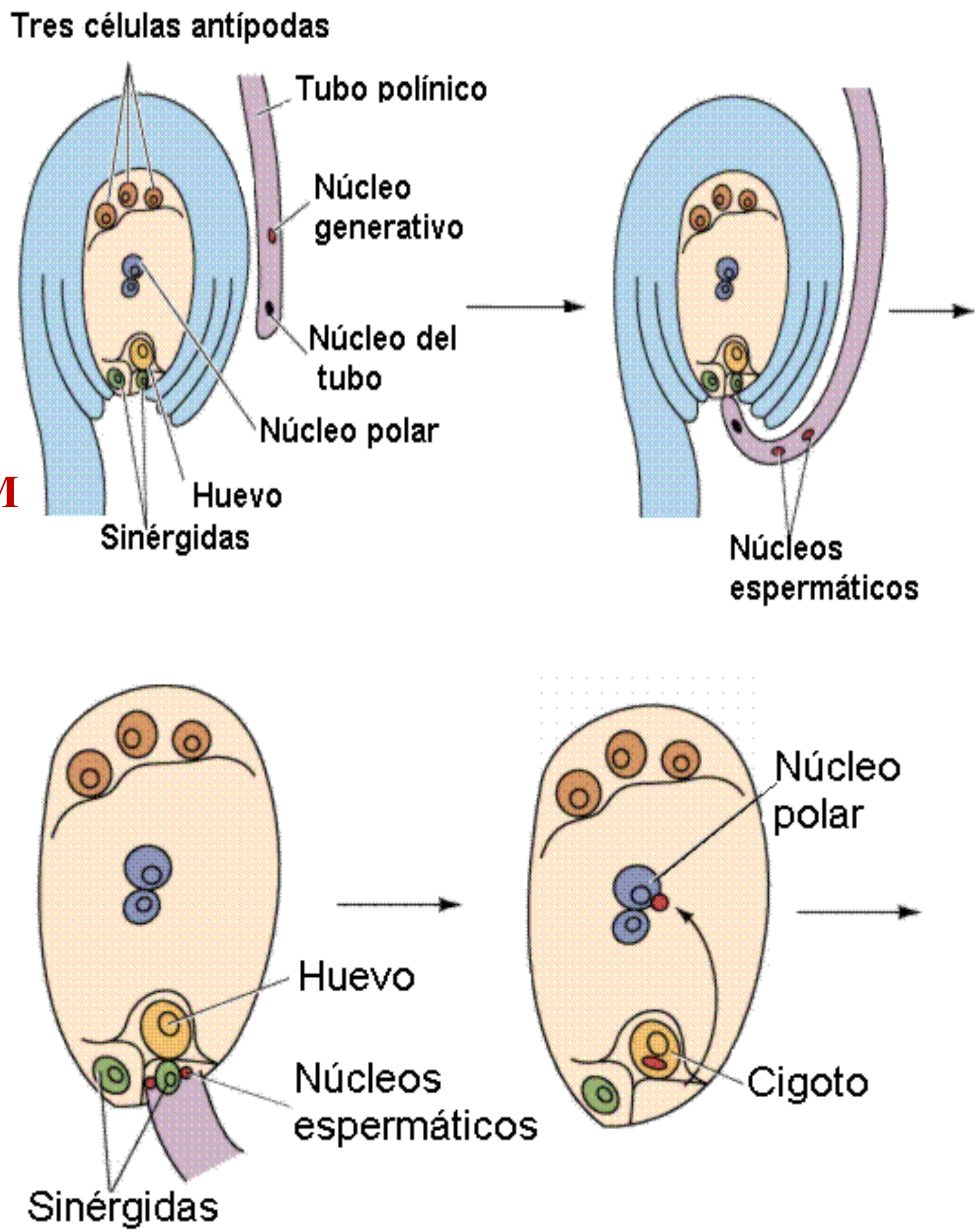




Double fertilisation

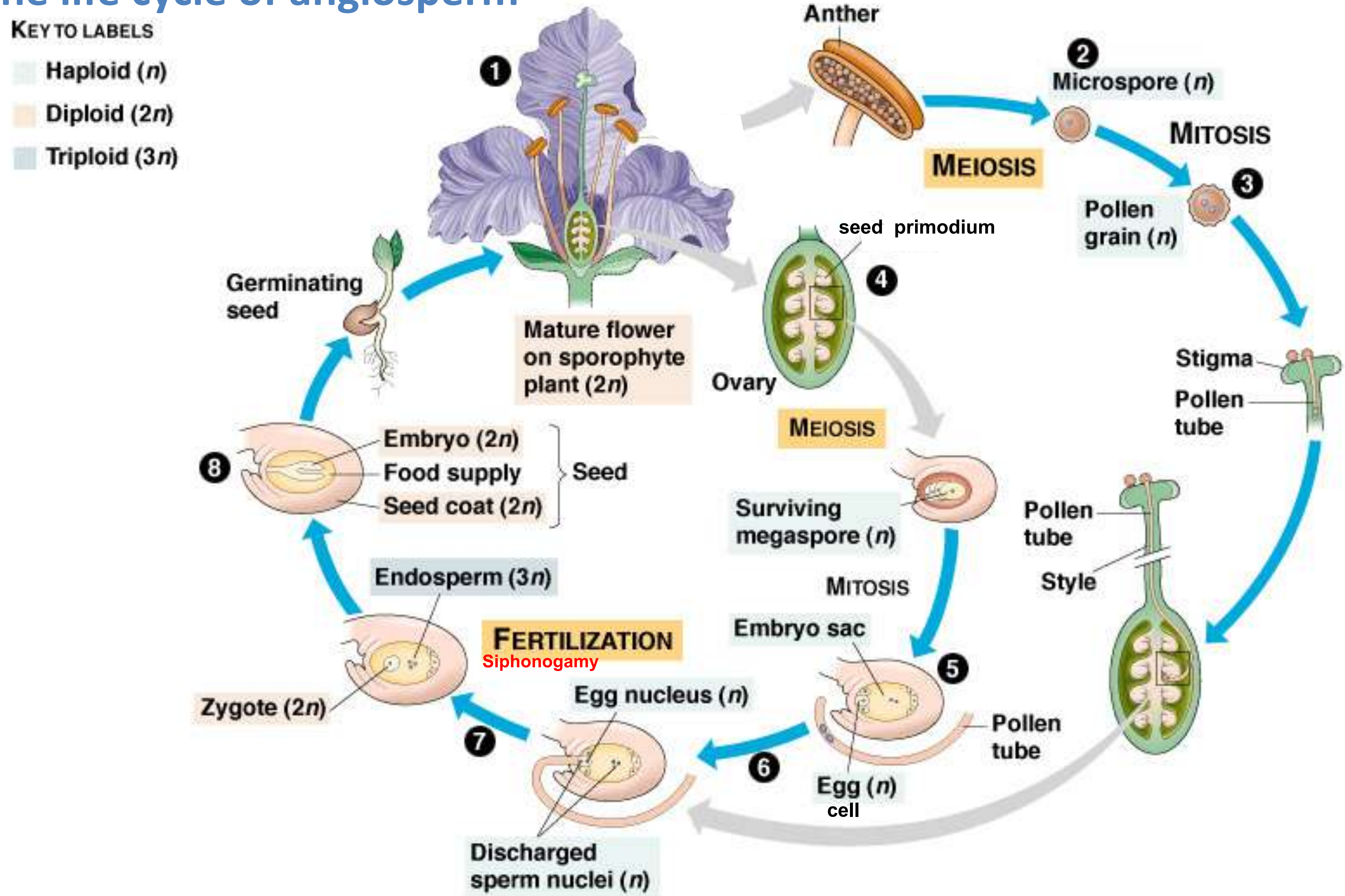
Egg cell + male gamete: zygote 2n
EMBRYO

Two polar nuclei + male gamete:
zygote 3n **SECONDARY ENDOSPERM**



Adapted from Hipertextos de Biología (Raisman & González)

The life cycle of angiosperm

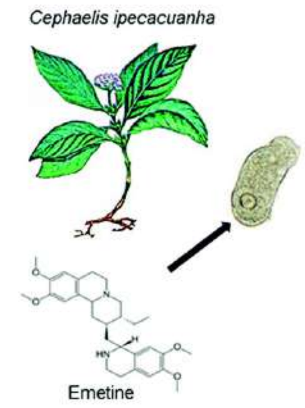


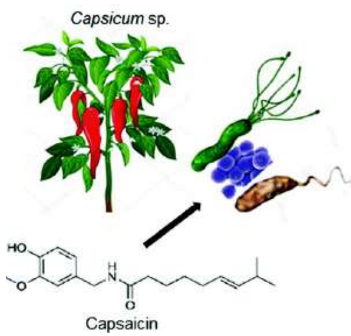
Main traits of angiosperms: phytochemistry

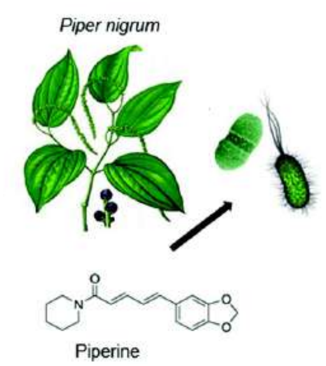
Angiosperms produce a large number of **chemicals**:

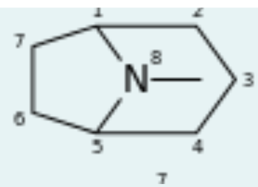
Alkaloids:

- Alkaloids are **small organic molecules** (the largest group of secondary metabolites in plants) containing nitrogen usually in a ring (a base, nitrogenous heterocyclic ring generally derived from amino acids); **roughly 20% of plant species produce alkaloids**.
- Some alkaloids are free bases while others form salts with organic acids such as oxalic and acetic. Some plant alkaloids are present in a glycosidic form such as solanine in *Solanum*.
- They are **physiologically active in animals** (plant defence against herbivores and pathogens) even at low concentrations.
- **Pharmaceutically significant**: 25 to 75% of traditional and modern uses of alkaloids are in drugs, which indicates their great therapeutic potential. **Many are used in medicine**: e.g. atropine, cocaine, colchicine, quinine, morphine, strychnine.





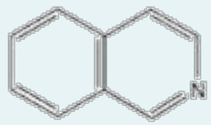
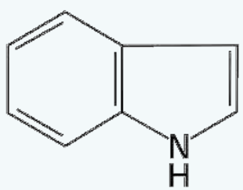


CLASS	BASE STRUCTURE	ALKALOID	TAXON
TROPANE		COCAINE HYOSCYAMINE ATROPINE	*Eritroxylon coca* (*Eritroxylaceae*) *Atropa belladona, Hyoscyamus niger, Mandragora officinalis* (*Solanaceae*)
PYRIDINE		RICININE NICOTINE ARECOLINE CONIINE LOBELINE	*Riccinus communis* (*Euphorbiaceae*) *Nicotiana tabacum* (*Solanaceae*) *Areca catechu* (*Palmaceae*) *Conium maculatum* (*Apiaceae*) *Lobelia* sp. (*Lobeliaceae*)

Eritroxylon coca

Atropa belladona

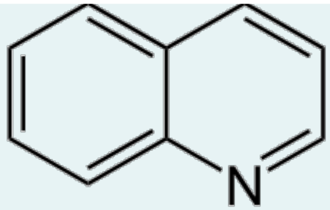
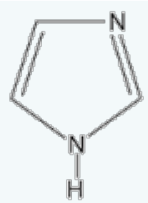
Nicotiana tabacum

CLASS	BASE STRUCTURE	ALKALOID	TAXON
ISOQUINOLINE	 isoquinoleína	MORPHINE, PAPAVERINE HYDRASTINE, BERBERIDINE EMETINE	*Papaver somniferum* (*Papaveraceae*) *Berberidaceae, Ranunculaceae* *Cephaelis hipecacuana*
INDOLE		STRYCHNINE RESERPINE VINBLASTINE VINCRISTINE	*Strychnos* sp. pl. *(Loganiaceae) Rauwolfia* sp. pl. (*Apocynaceae*) *Catharanthus roseus* (*Apocynaceae*)

Papaver somniferum

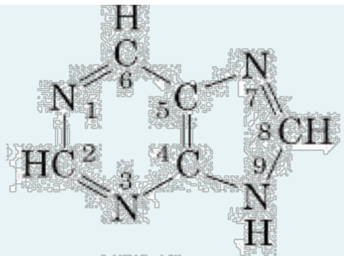

Strychnos nux-vomica


Catharanthus roseus

CLASS	BASE STRUCTURE	ALKALOID	TAXON
QUINOLINE		Quinine Cusparine	*Cinchona* (*Rubiaceae*) *Cusparia* (*Rutaceae*)
IMIDAZOLE	 imidazol	Pilocarpine	*Pilocarpus* (*Rutaceae*)

Cinchona officinalis

Pilocarpus jaborandi

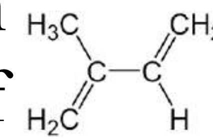
CLASS	**BASE STRUCTURE**	**ALKALOID**	**TAXON**
PURINE	 PURINA	CAFFEINE THEOBROMINE	*Coffea arabica* *Camelia sinensis* *Ilex paraguayensis* *Theobroma cacao*

Coffea arabica

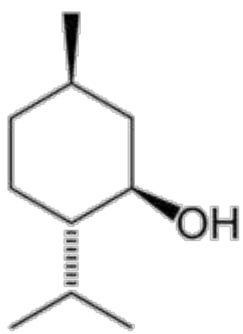
Camelia sinensis

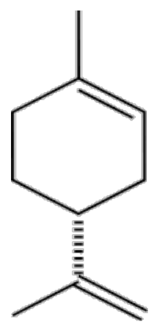
Theobroma cacao

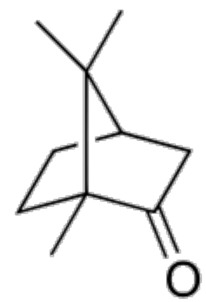
- Terpenoids: these compounds, which are derived from isoprene, can be of different types. Components of what we call essential oils (essences), they are responsible for the odours and flavours of plants:

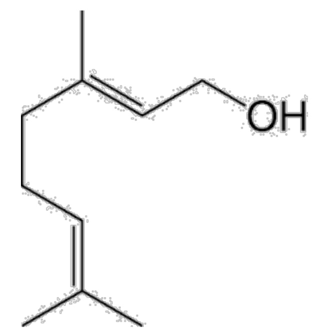


menthol limonene camphor geraniol









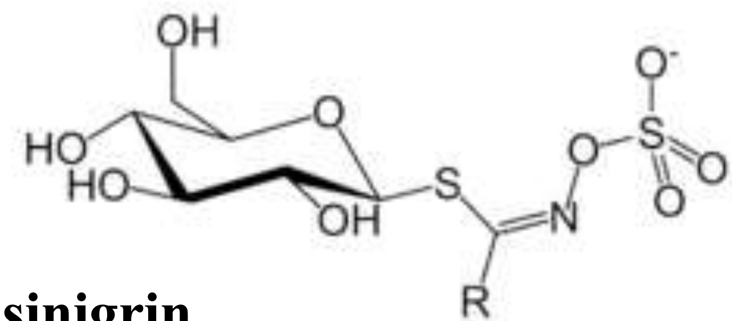
Mentha piperita

citrics

Cinammomun camphora

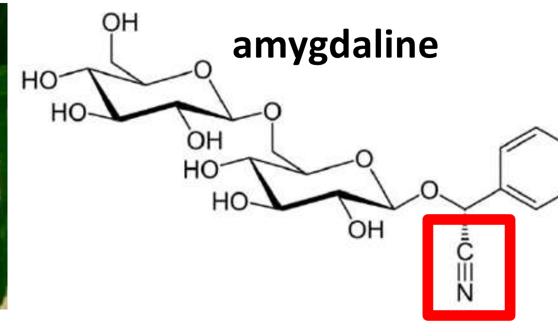
Pelargonium graveolens

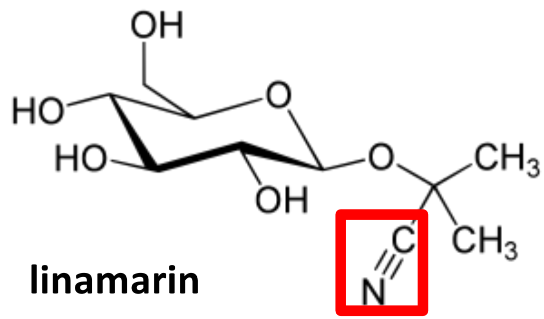
- **Glycosides**: sugars associated with non-sugar molecules. Examples: mustard oil, glycoside from many cruciferous vegetables.



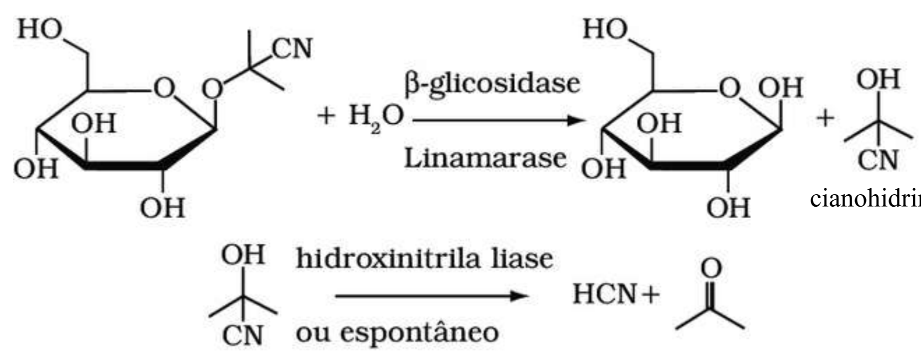
sinigrin

Cyanogenic glycosides: compounds that release cyanide when metabolised and are toxic to animals.

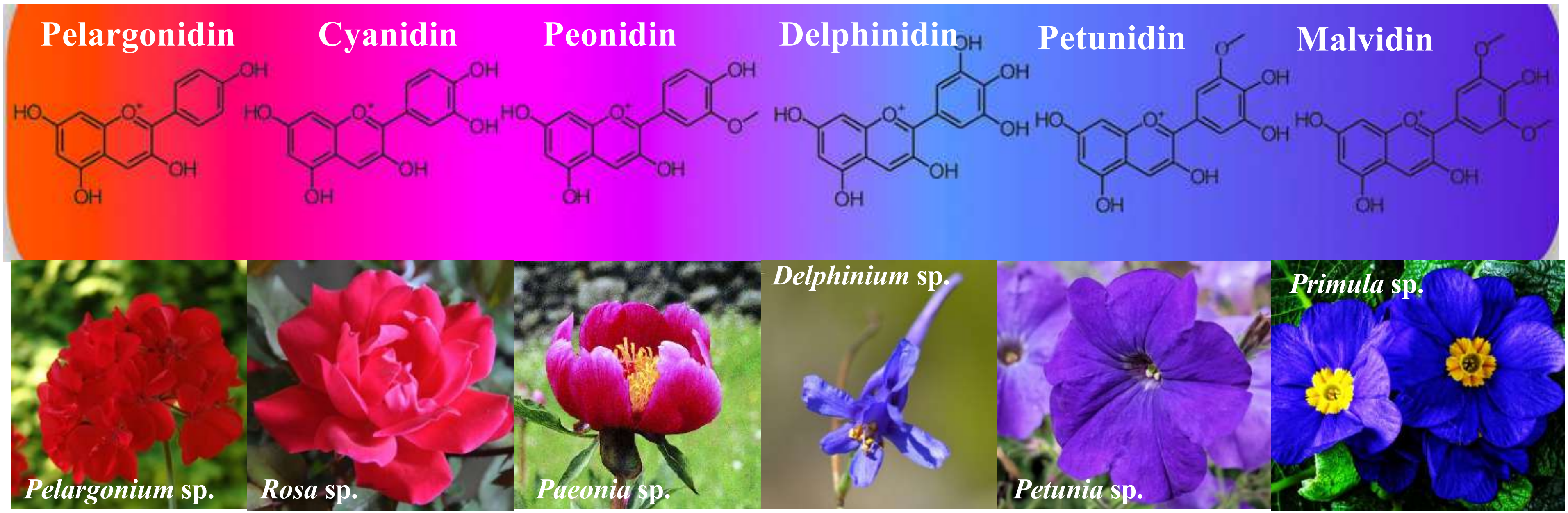




Manihot esculenta

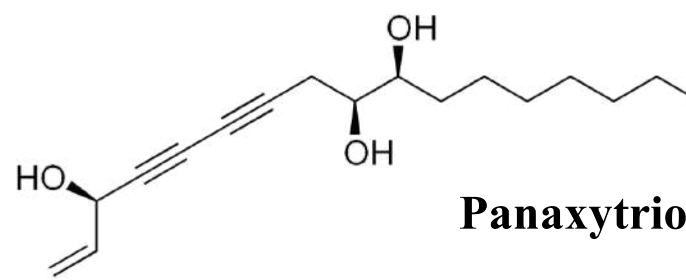


- **Flavonoids**: phenolic compounds made up of three rings derived from cinnamic acid. Over 4,000 of them exist in plants. Many are responsible for the colours of flowers: **anthocyanins**, **cyanidin**.



- **Polyacetylenes**: non-nitrogenous secondary metabolites formed by the union of acetate units.

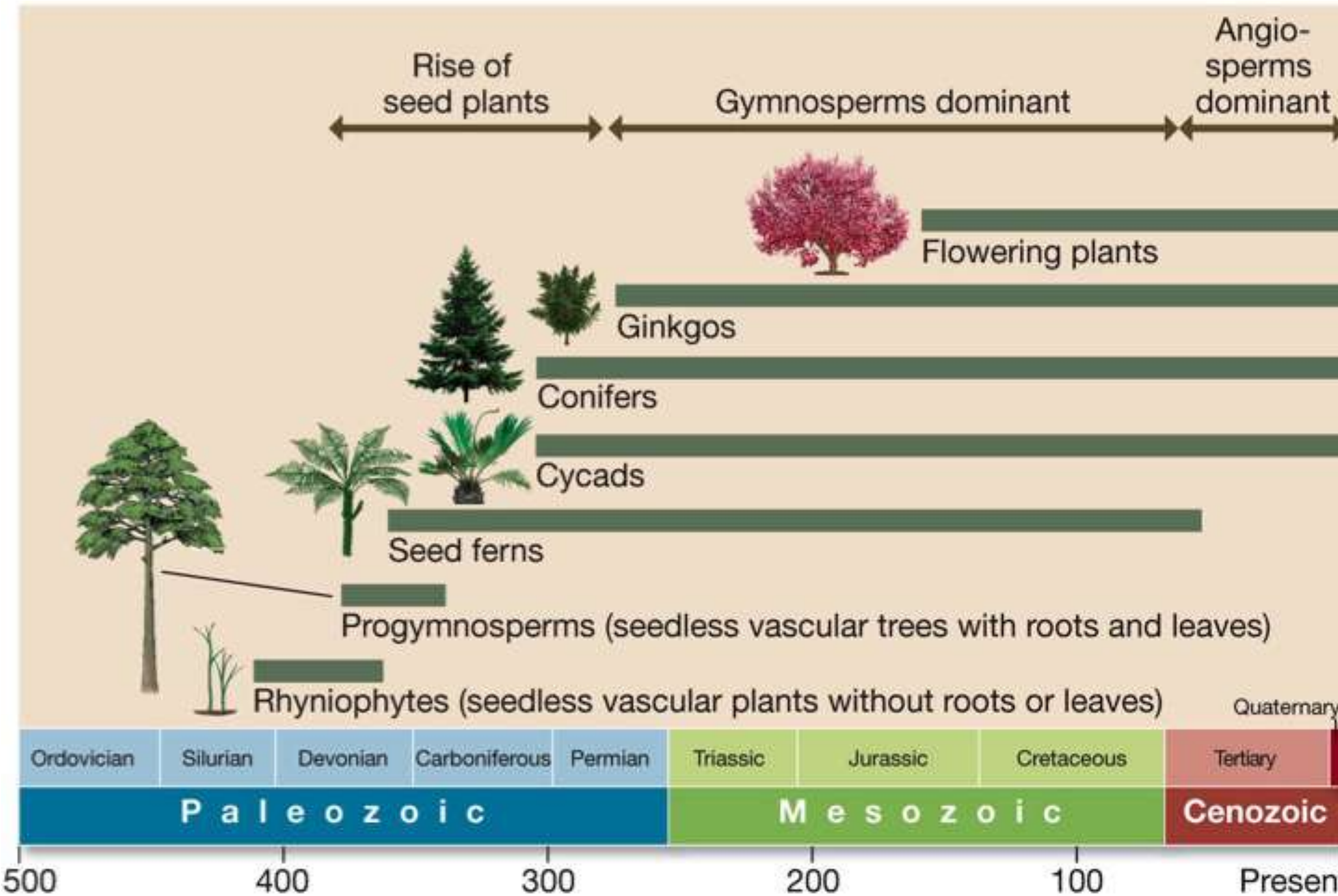
Panax ginseng



Panaxytriol

Angiosperm diversity and phylogeny

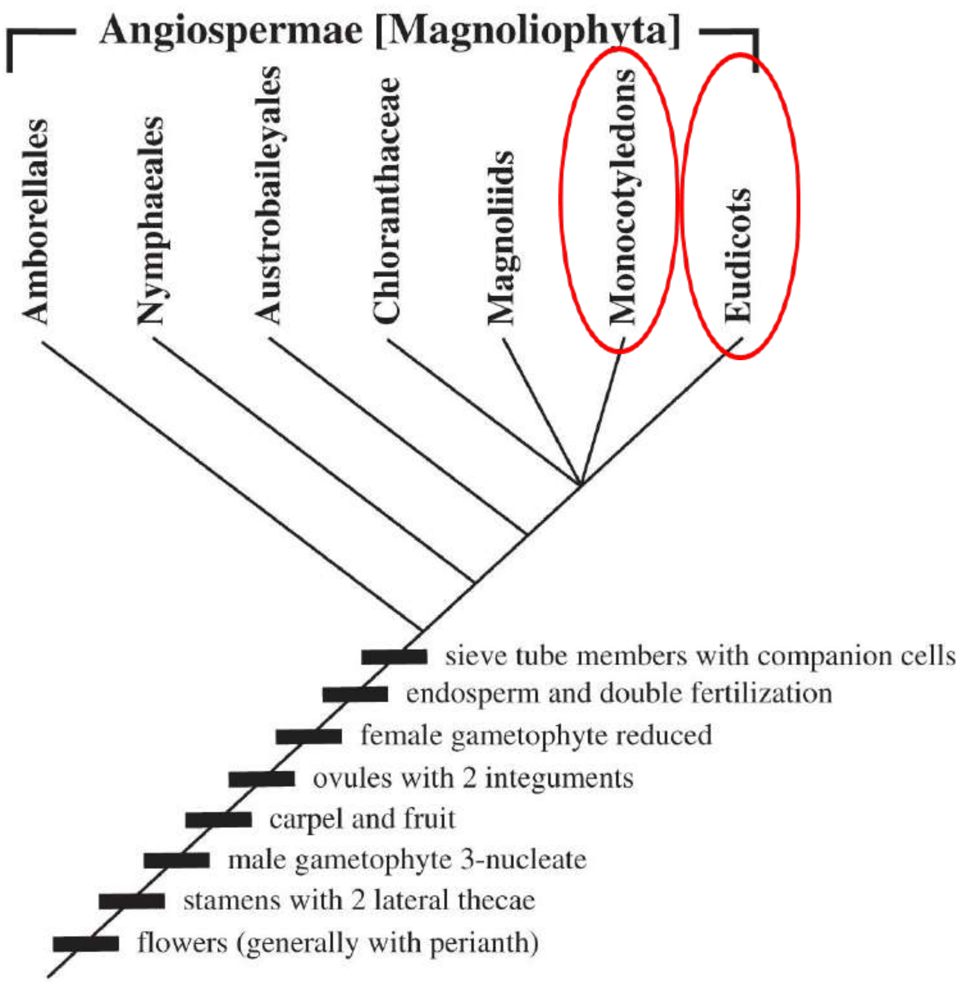
Angiosperms, with **protected seed primordia**, have dominated terrestrial flora for roughly 60-70 million years. They probably originated in the Jurassic.



LIFE 9e, **Figure 29.1**

Angiosperm diversity and phylogeny

- Cladogram of the angiosperms (**Phylum *Magnoliophyta***) showing the main **apomorphies** (= exclusive traits) and **taxonomic groups**.



Topics

Introduction

Flowers, inflorescences, androecium and gynoecium

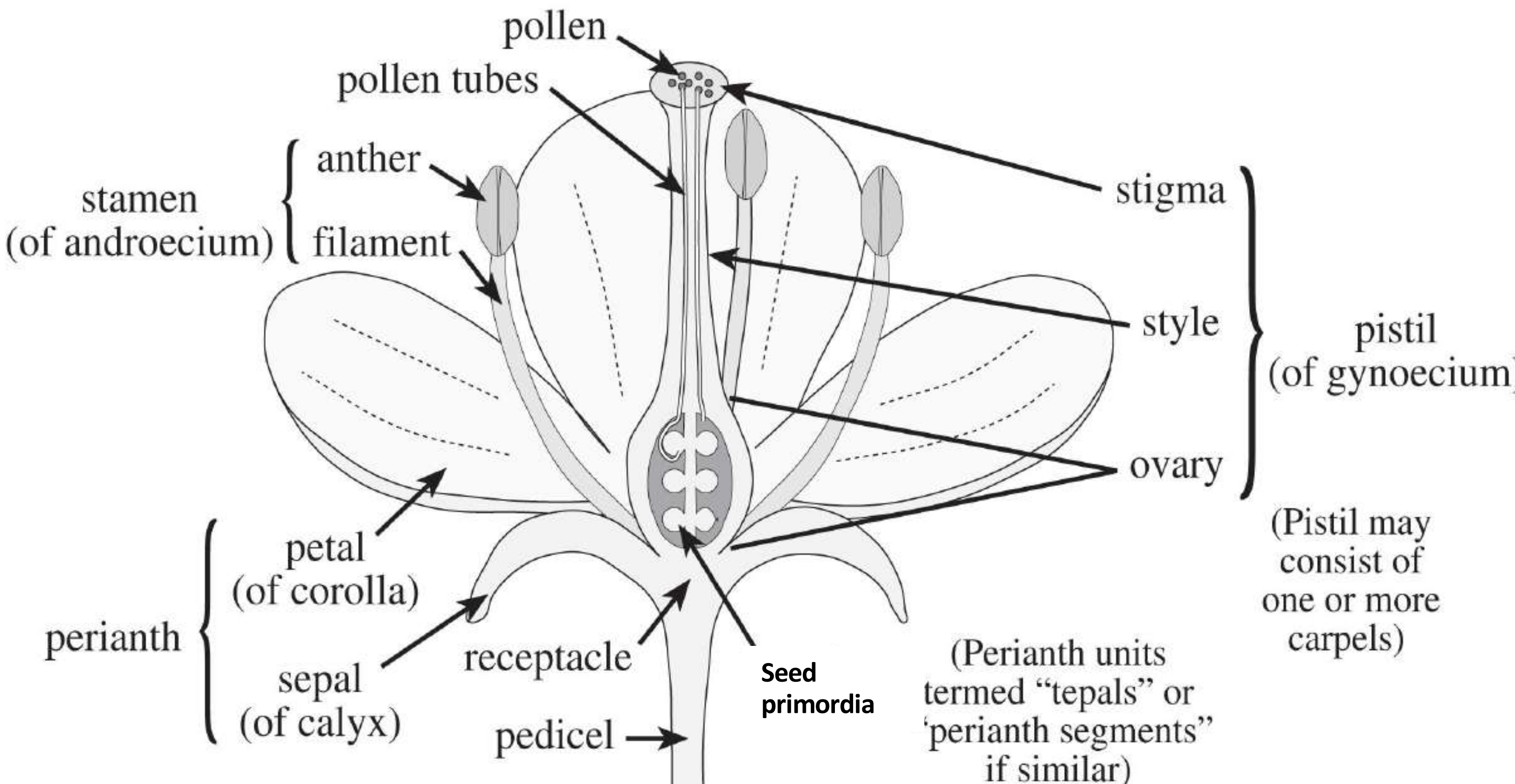
Pollination and fertilisation

Seeds and fruits

The flower of angiosperms

Angiosperms are **heterosporic** plants with **flowers** that consists of:

- a more or less widened axis named **peduncle** or pedicel, and the **receptacle**.
- sterile anthophylls (= floral leaves): leaves for protection and visual cues. Together, they form the **perianth**: the **calyx** and the **corolla**.
- fertile anthophylls named sporophylls. There are two types:
  - -microsporophylls, or **stamens**.
  - -megasporophylls, or **carpels** inside which are enclosed **seed primordia**.



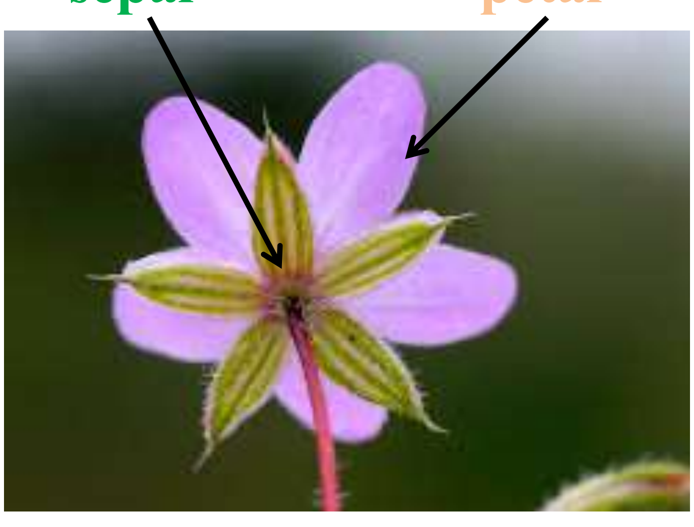
Simpson, M: Plant Systematics, 2nd Edition, 2010. Elsevier Academic Press

The perianth

The **perianth** may be:

- homochlamydeous: when the sterile parts of a flower are similar (not distinguishable), they are called **tepals**. The set of tepals is named the **perigonium**.
- heterochlamydeous: when the sterile parts of a flower are distinct and clearly organised in two whorls:
  - the external whorl is made up of pieces called **sepals** (which are usually green); the set of sepals is named the **calyx**.

  - the internal whorl is made up of pieces called **petals** (which vary in size and are generally coloured); the set of petals is named the **corolla**.



The perianth

A **monochlamydous** flower is one that lacks one of the two perianth whorls.

Brachychiton populneum

Ceratonia siliqua

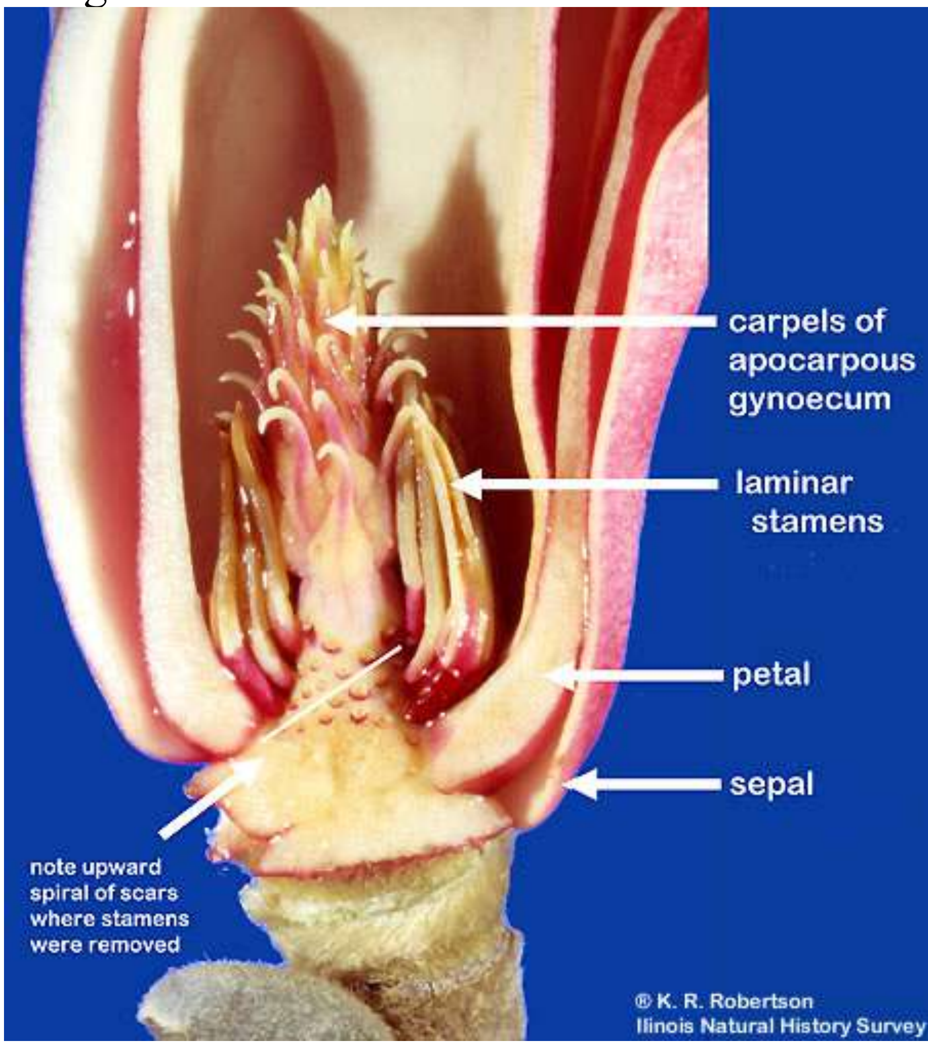
Sometimes the perianth is absent: these flowers are called **achlamydeous**.

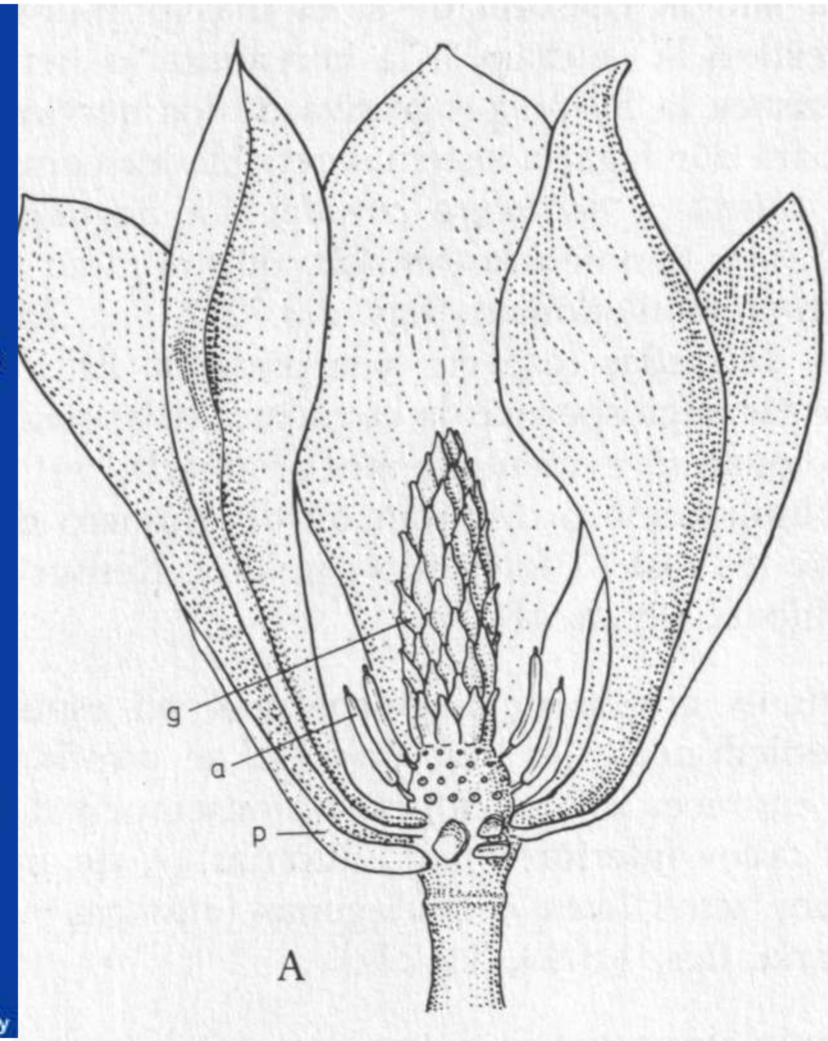
Piper nigrum

Populus nigra

Arrangement of floral elements

Flowers are **acyclic** when the floral leaves (sepals, petals, stamens and carpels) are arranged around the axis to describe a helix.





Arrangement of floral elements

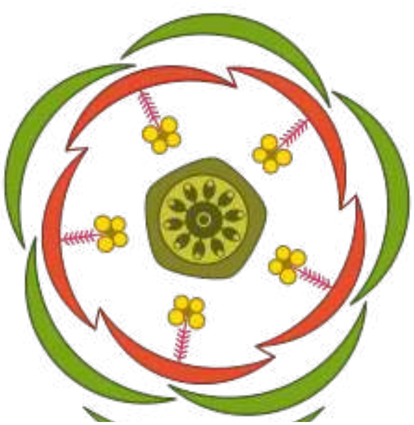
Flowers are **cyclic** when the floral leaves are arranged in whorls:

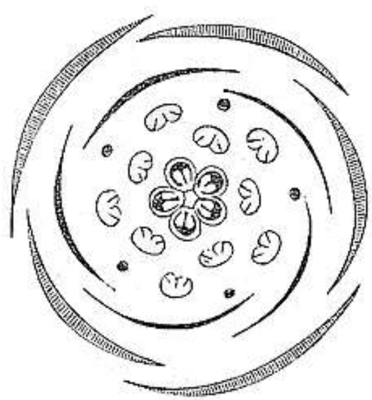
- **tetracyclic** (four whorls: two for the perianth, one for the stamens and one for the carpels).
- **pentacyclic** (two whorls for the perianth, two for the stamens and one for the carpels).

Anagallis arvensis

Geranium sp.

Asphodelus fistulosus

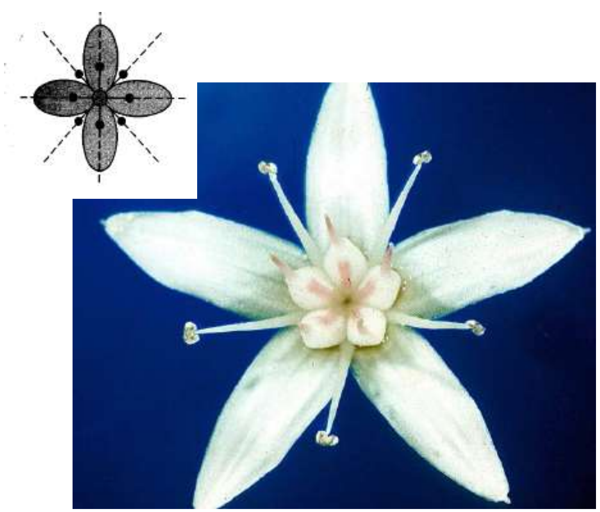




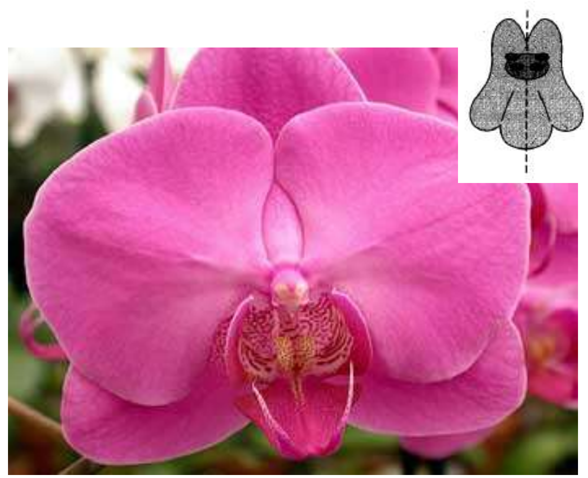
Floral symmetry

Depending on the arrangement of the floral pieces or leaves, flowers can be:

- **asymmetrical**, when no plane divides the flower into equal halves.
- monosymmetrical or **zygomorphic,** when flowers have only one plane of symmetry (e.g. *Fabaceae* and *Labiatae*).
- **dissymmetrical**, when flowers have two planes of symmetry (e.g. *Cruciferae*).
- polysymmetrical or **actinomorphic**, when flowers have many planes of symmetry (e.g. *Cistaceae*, *Rosaceae*).



Actinomorphic



Zygomorphic

Asymmetrical

Flower variability

The perianth pieces may be:

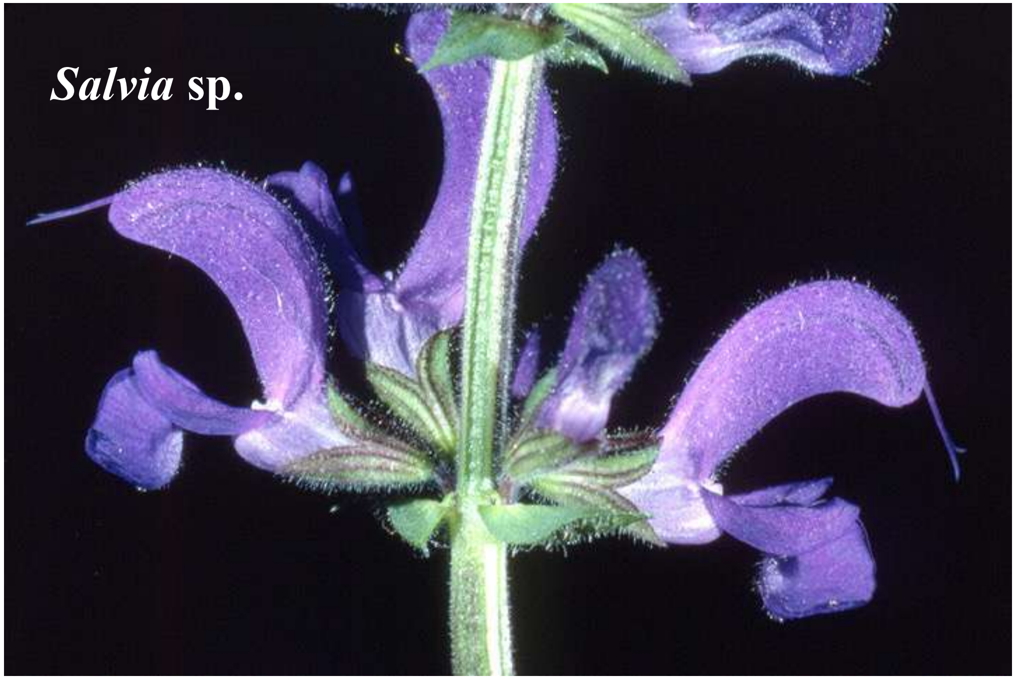
- free: chori- o dialy-
- fused: gamo- o sin-

Choripetalous (or dialypetalous) flower

Gamopetalous (or synpetalous) flower

Flower variability

Some types of **gamopetalous corollas**



Bilabiate corolla

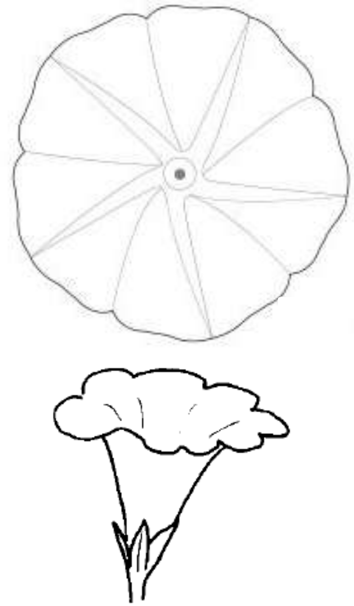
Flower variability

Some types of **gamopetalous corollas**

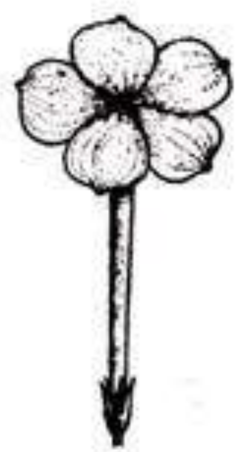
Campanulate

Campanula sp.

Infundibuliform



Convolvulus arvensis

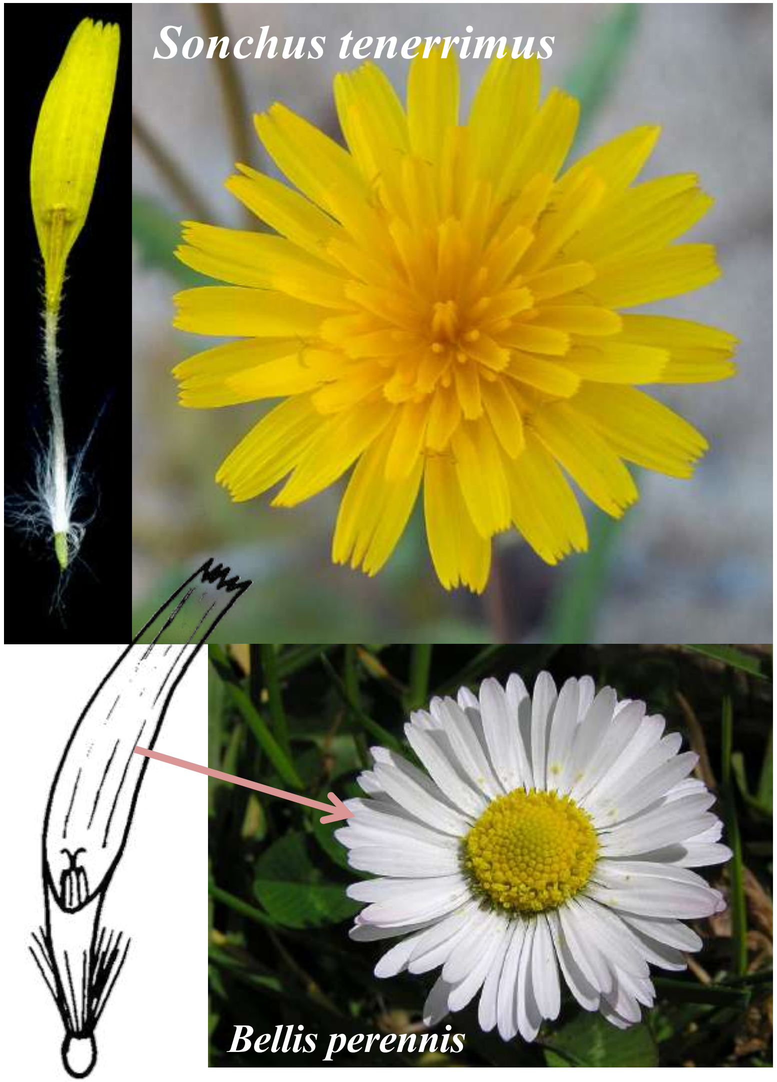


Hypocrateriform

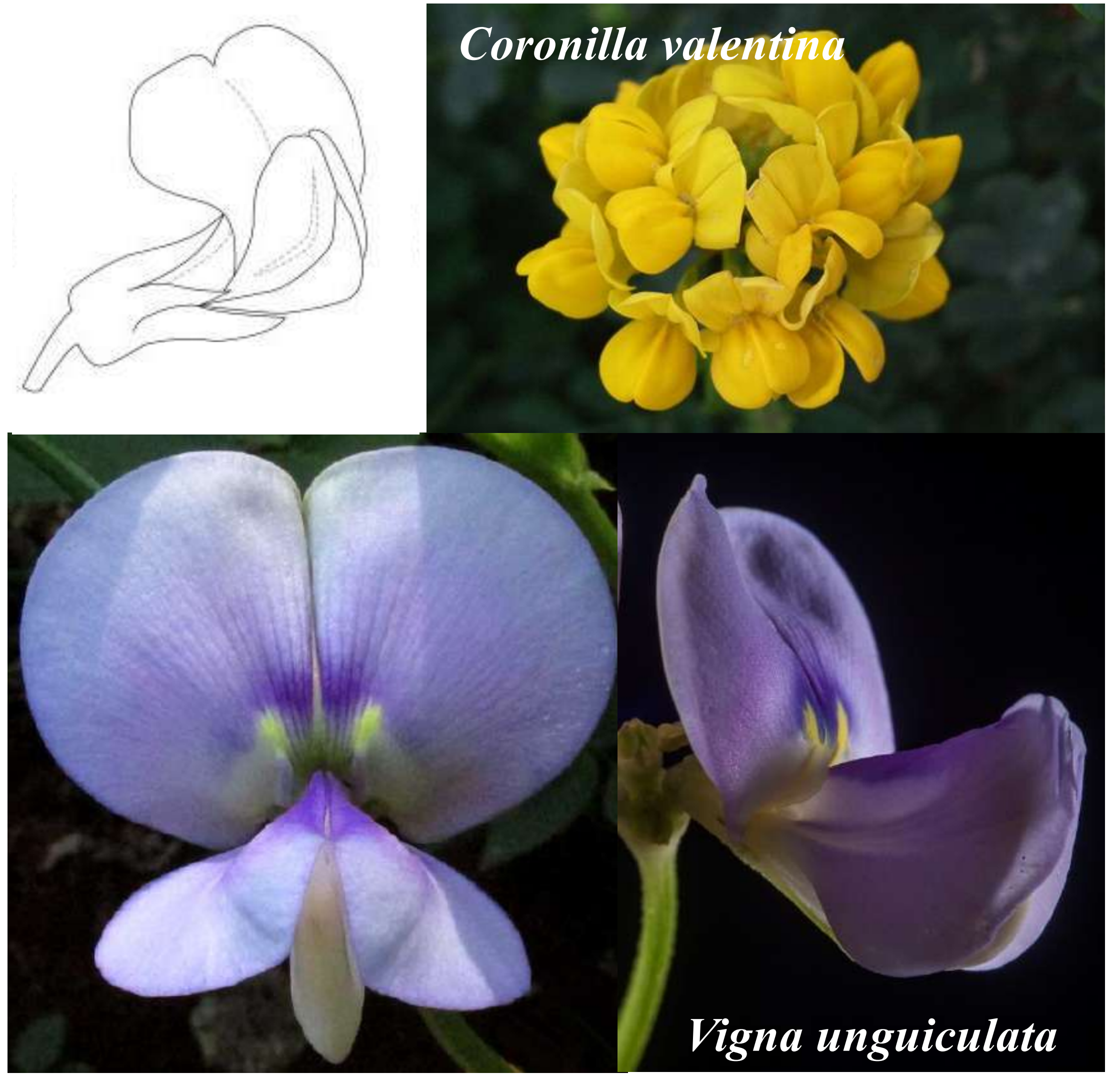
Flower variability

Some types of **gamopetalous corollas**

Ligulate



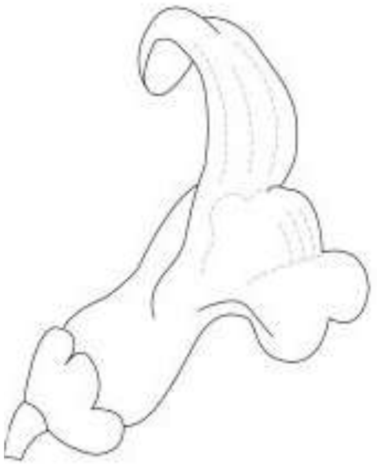
Papilionaceous

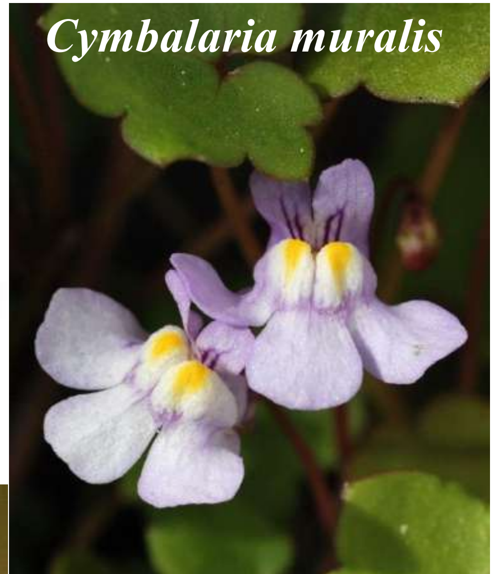


Flower variability

Some types of **gamopetalous corollas**

Personate



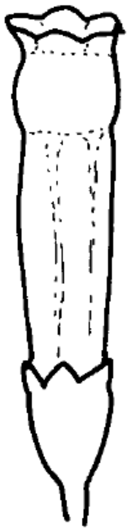


Wheel-shaped

Flower variability

Some types of **gamopetalous corollas**

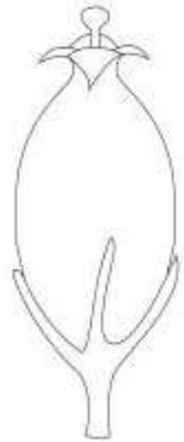
Tubular



Iochroma cyanea

Nicotiana glauca

Urceolate



Arbutus unedo

Arctostaphylos uva-ursi

Erica tetralix

Inflorescences

In most angiosperms, more than one flower is produced in the same individual plant at the same time (it is less common to find a plant with just one flower per stem: see the poppy, *Papaver* sp., on the right).

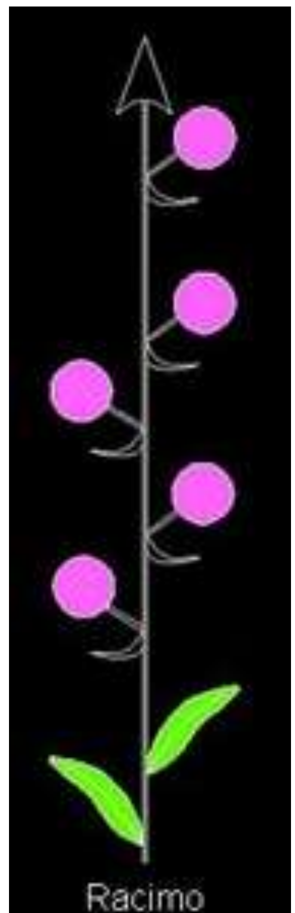
An **inflorescence** is a group or cluster of flowers arranged on a stem that is composed of a main branch or a complicated arrangement of branches.

Simple inflorescences (with first-order branches only)

Racemose (open): the main axis continues to grow indefinitely (monopodic growth) to produce lateral flowers. The basic type is the **raceme**.

Raceme: the flowers have pedicels (peduncles) inserted around the axis.

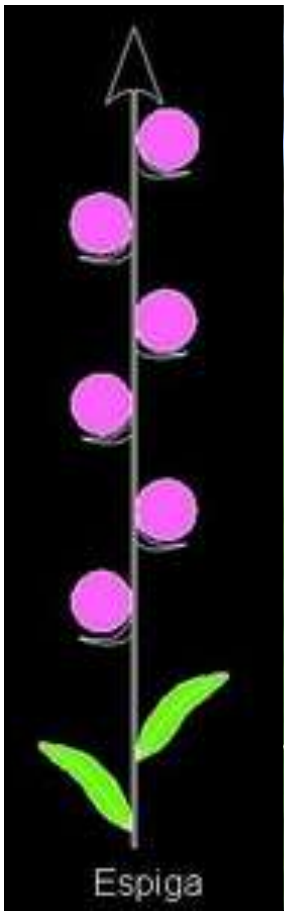
Example: *Diplotaxis erucoides*.



Simple inflorescences (with first-order branches)

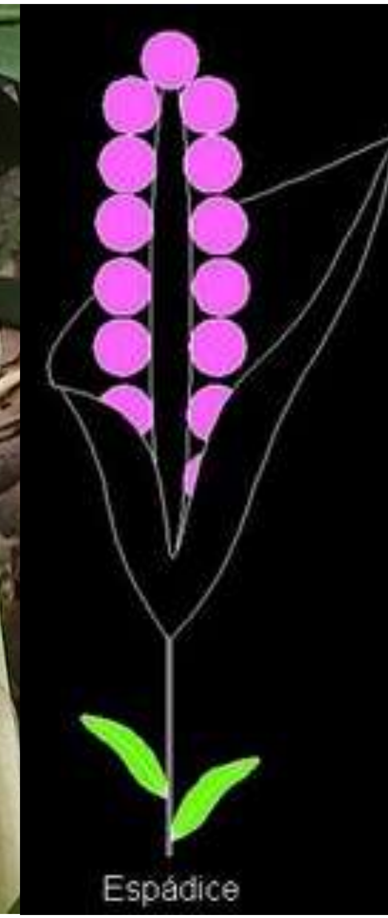
A **spike** is a raceme except that the flowers are attached directly to the axis rather than through a pedicel.

A **spadix** is a spike with a thickened axis.



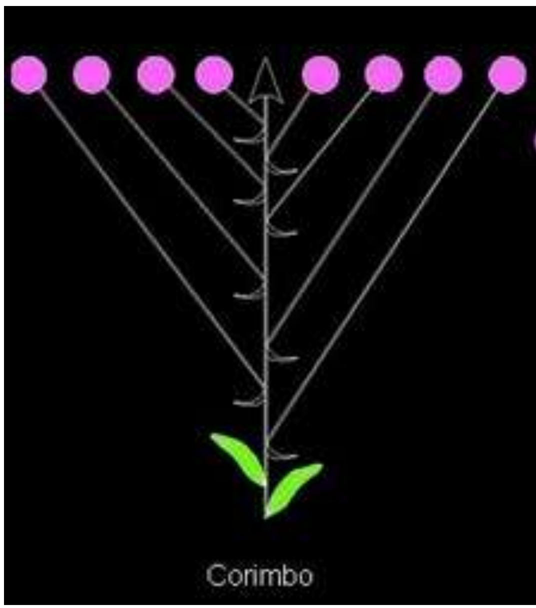

Dipsacus fullonum (*Dipsacaceae*)


Monstera deliciosa (*Araceae*)

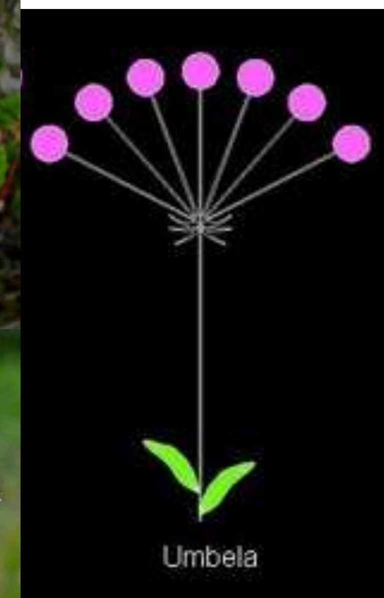


Simple inflorescences (with first-order branches only)

Corymb: the flowers are pedunculate, are inserted at different points on the axis, and reach a similar height.

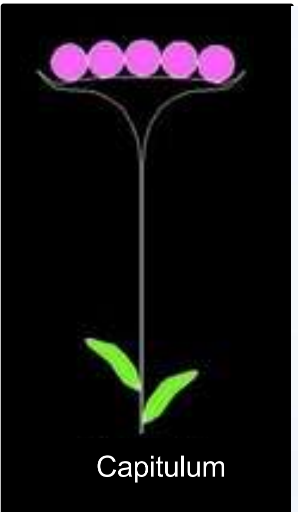


Umbel: the flowers emerge from the same point on the axis and reach a similar height.



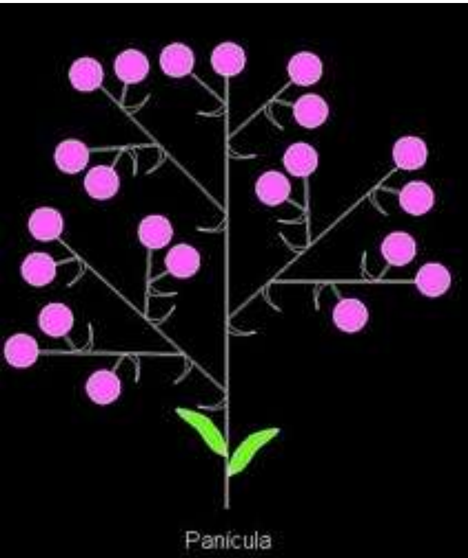
Simple inflorescences (with first-order branches only)

A **capitulum** consists of closely packed flowers that have no peduncles and arise from a flattened axis (the **receptacle**) all at the same level. The capitulum is surrounded by an **involucre** of **bracts** that afford it the appearance of a single flower. Capitula are typical of *Compositae*.

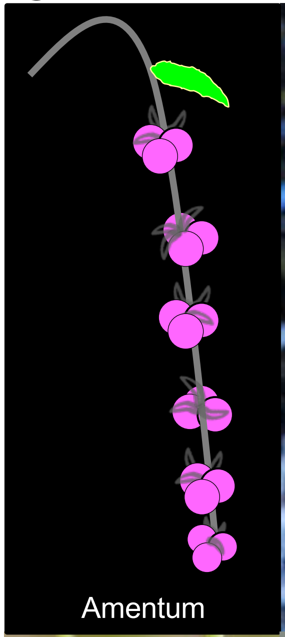


Composite inflorescences (made up of combinations of the previous inflorescences)

A **panicle** is a raceme of racemes (e.g. many graminoid plants).

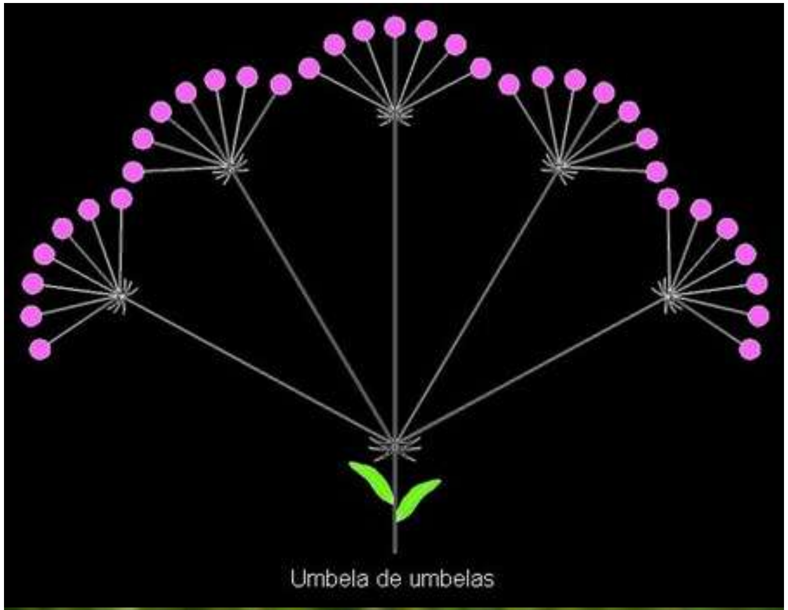


An **amentum** is a pendulous inflorescence, a spike of cymes. The flowers are unisexual: *Quercus*, *Populus*.



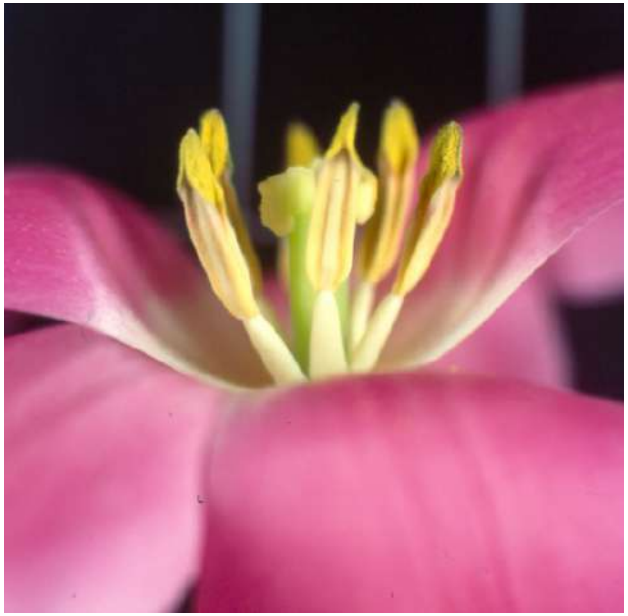
Composite inflorescences (comprising combinations of the previous inflorescences)

Umbel of umbels



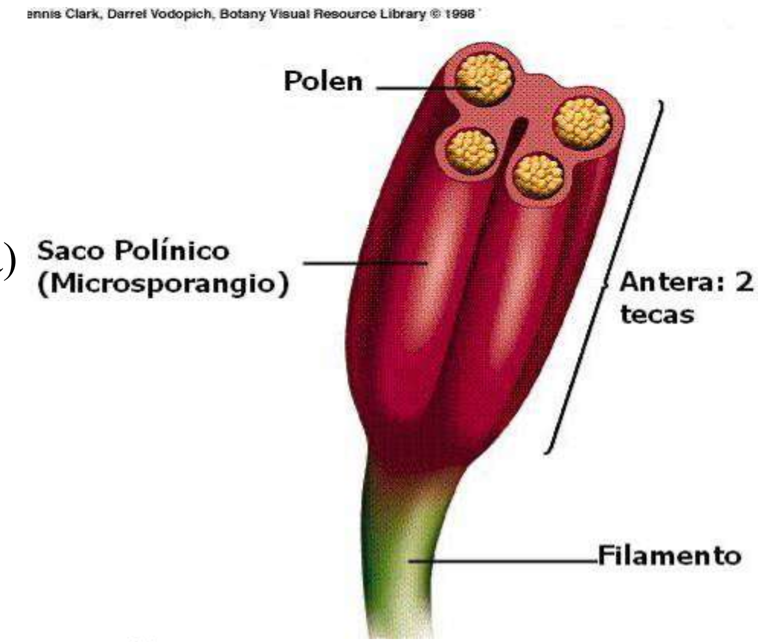
The androecium

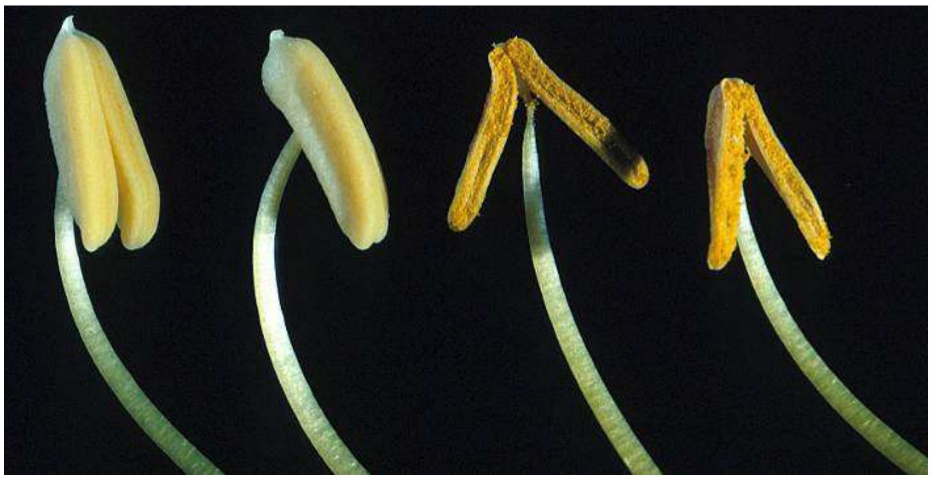
- The androecium is the **set of stamens** of a flower.
- Each stamen is considered a **microsporophyll**.
- Each stamen holds several **microsporangia** (= **pollen sacs**).
- **Microspores** (= **pollen grains**) are produced inside the microsporangia.

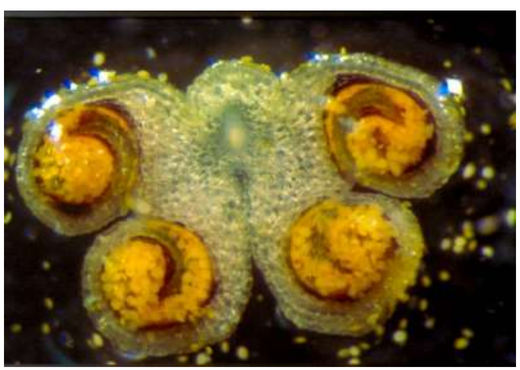


The stamen

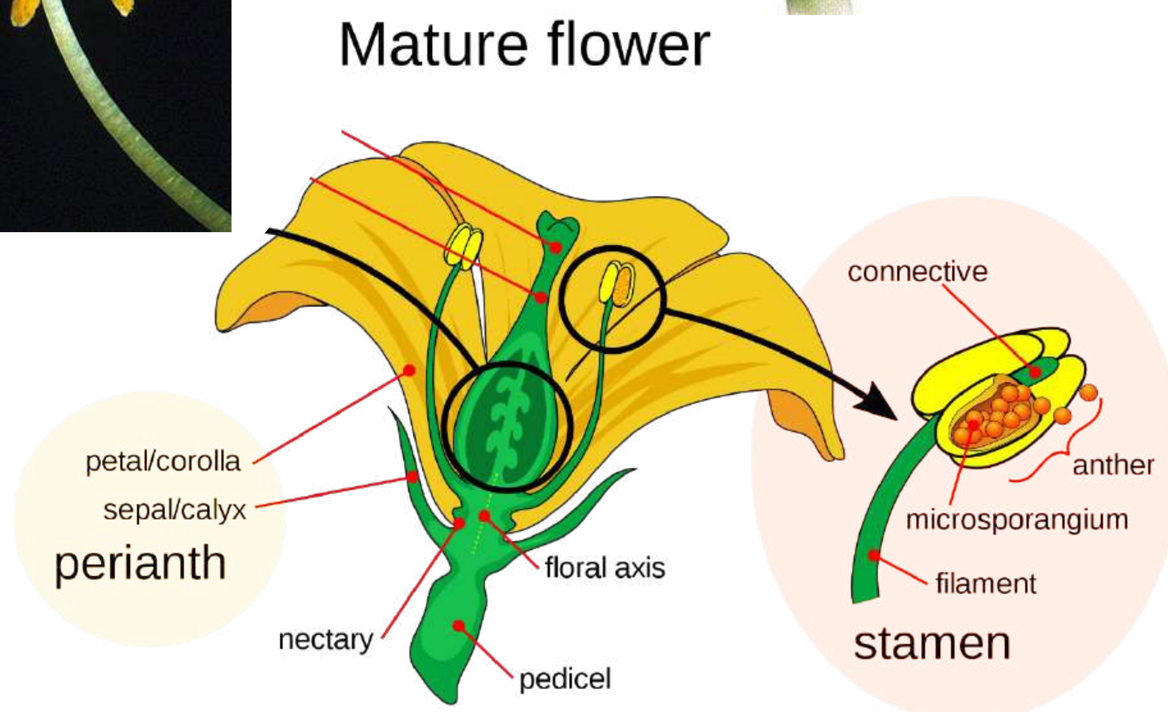
- **filament**
- **anther** (two thecae, and four **pollen sacs** or microsporangia)
- connective







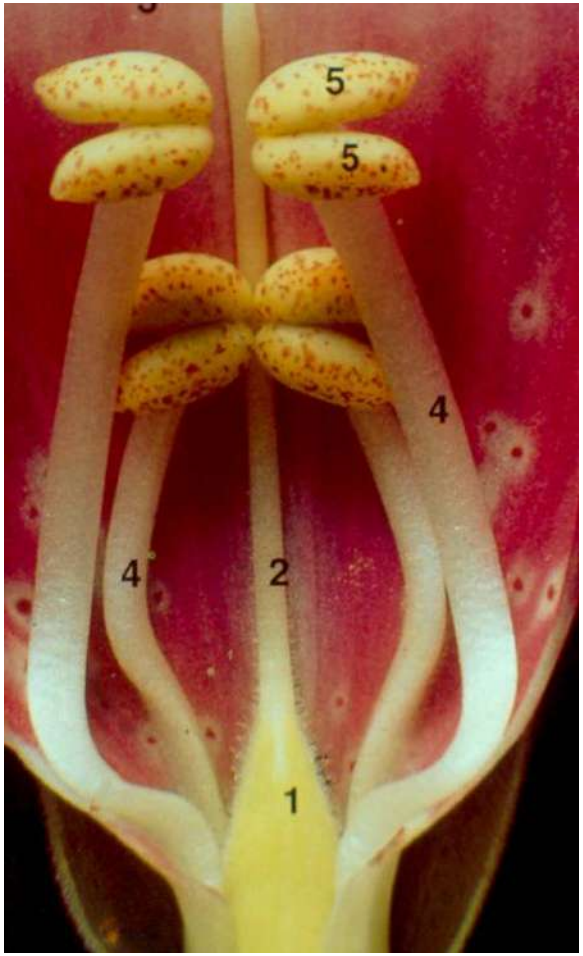
Cross-section of an anther



Androecium variability

The number, shape and colour of the stamens are variable.

- Heterostemonous (**heterostomy**): the stamens of a single flower are different.




Diplotaxis erucoides


Antirrhinum (snapdragon)

Examples of differences in the length of stamen filaments.

Androecium variability

Different number of pieces

Isostemonous (**isostemony**): having the same number of stamens as pieces in each perianth component (calyx, corolla).


Anagallis (*Primulaceae*)


Solanum (*Solanaceae*)

Anisostemonous (**anisostemony**): having a different number of stamens to pieces in each perianth component (calyx, corolla).


Teucrium (*Lamiaceae*)


Diplotaxis (*Brassicaceae*)


Papaver (*Papaveraceae*)

Androecium variability

Different number of whorls

Haplostemonous: only one whorl of stamens. The number of stamens is the same as the number of petals and sepals.

Diplostemonous: two whorls of stamens. The number of stamens is twice the number of petals and sepals.

Polystemonous: more than two whorls of stamens.

Androecium variability

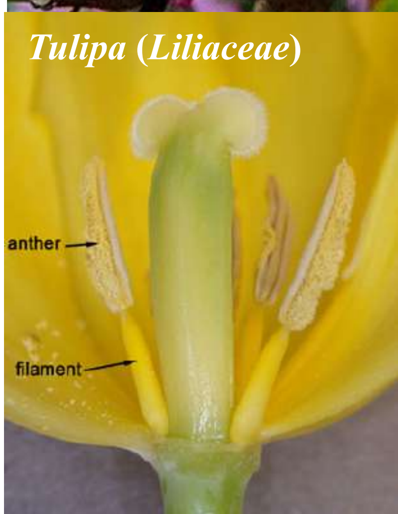
Different length

Homodynamous: all stamens have a similar length.

Heterodynamous: the stamens have different lengths.

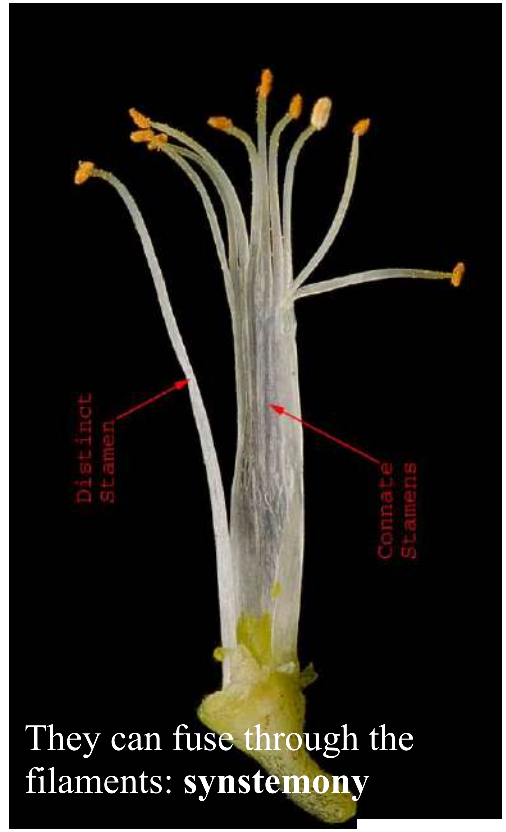
Androecium variability

dialystemonous: free stamens

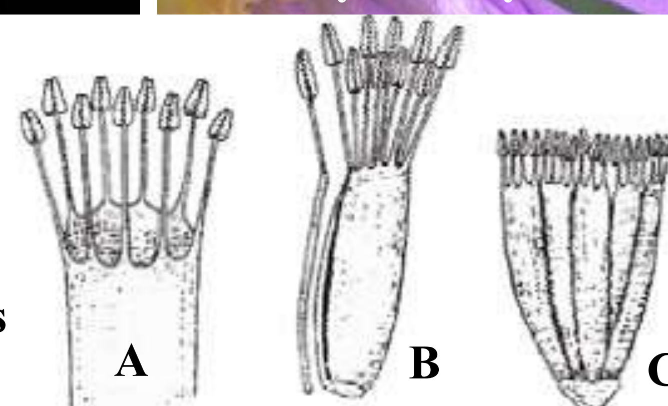


Degree of fusion among stamens

gamostemonous: the stamens are fused to each other.



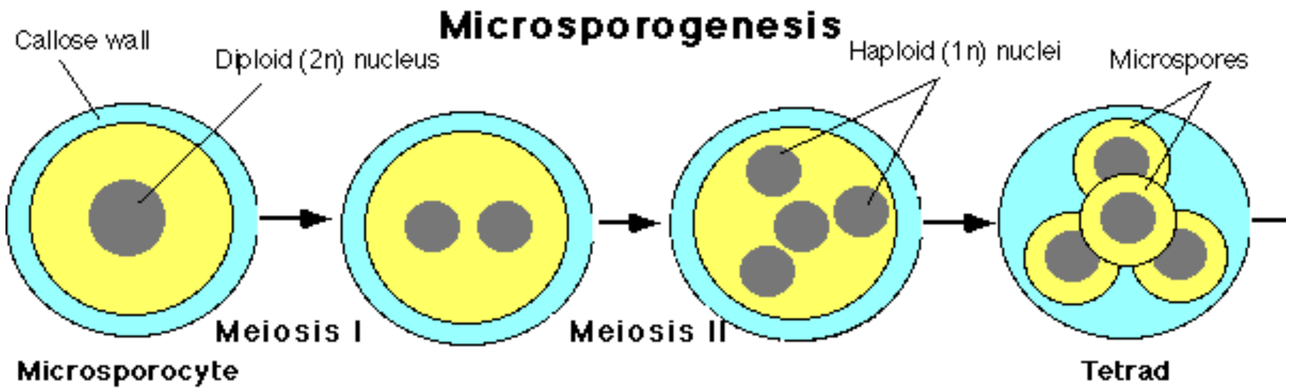
A. 1 group: **monadelphous**
B. 2 groups: **diadelphous**
C. >2 groups: **polyadelphous**

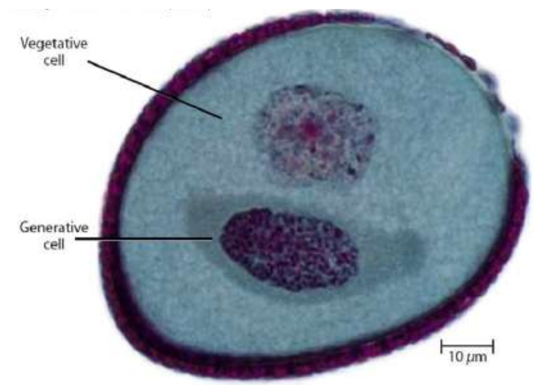


Microsporogenesis and microgametogenesis

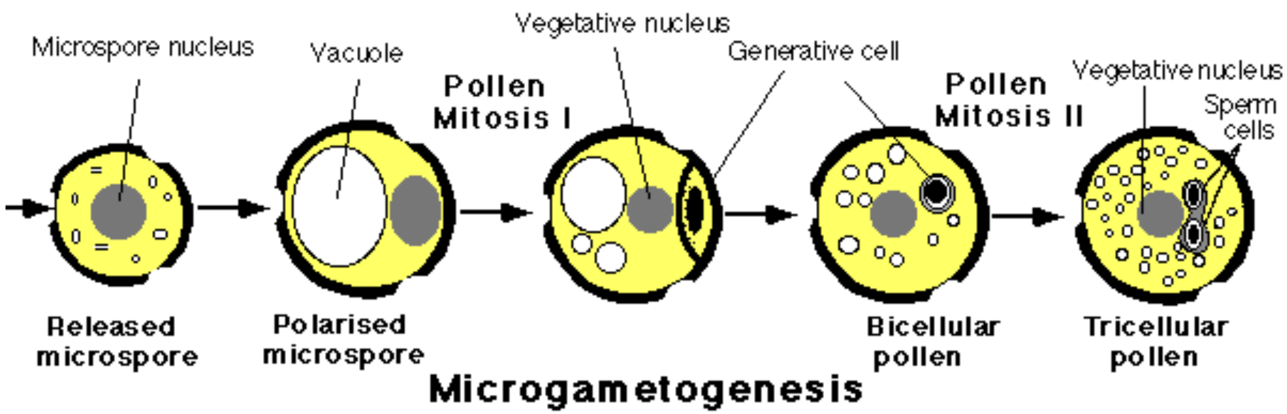
Microsporogenesis: the formation of a microspore (n) from a microsporocyte (2n).

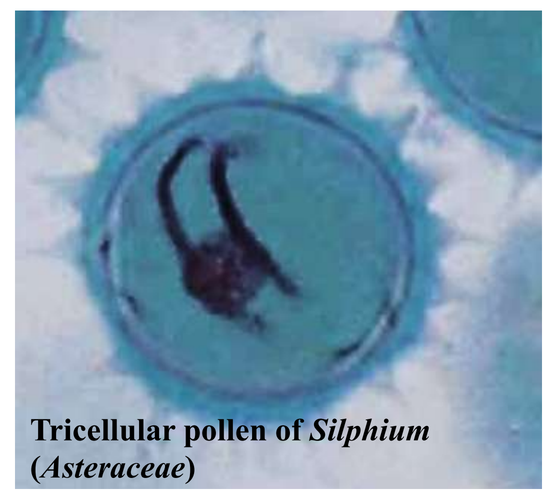
Microgametogenesis: the formation of a microgametophyte (male gametophyte, n) from a microspore (n).





Bicellular pollen of *Lilium* (*Liliaceae*)





Tricellular pollen of *Silphium* (*Asteraceae*)

https://www2.le.ac.uk/departments/genetics/people/twell/lab/pollenis/development

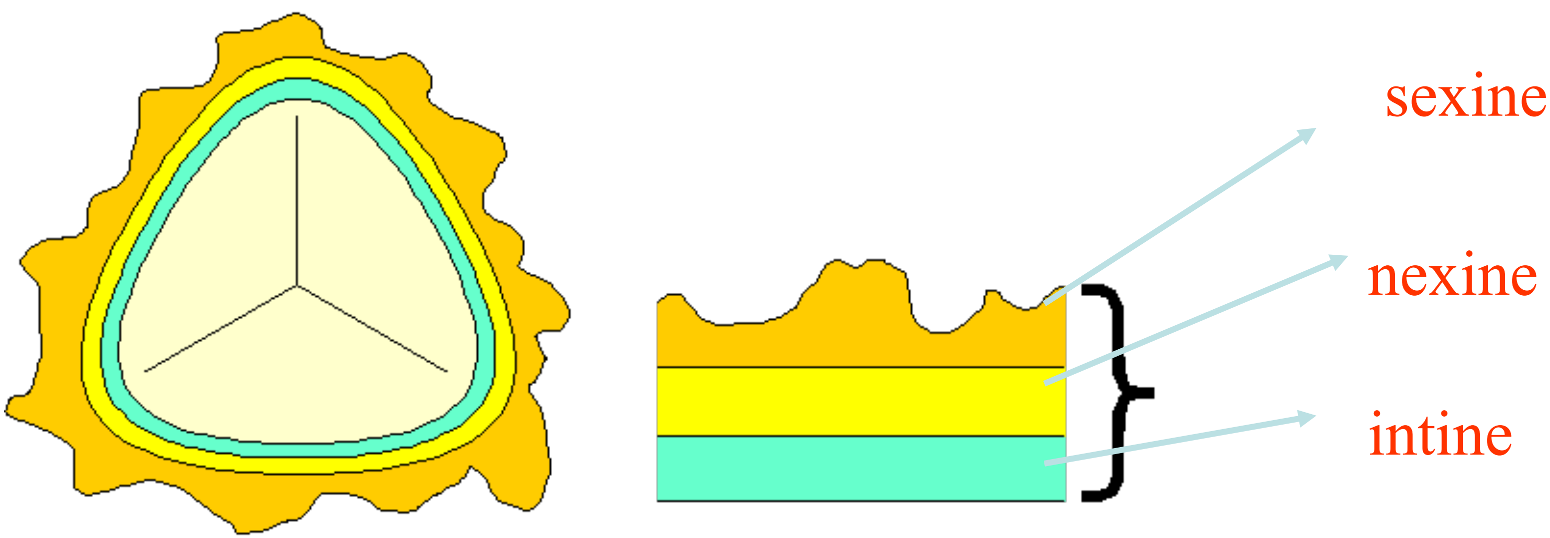
http://www.biologydiscussion.com/palynology/morphological-characteristics-of-pollen-grains/64545

Main traits of a pollen grain

The covering of a pollen grain is made up of three layers:

- the intine is made up of pectins and cellulose
- the exine mainly comprises sporopollenin
    - the nexine is the inner layer
    - the sexine is the outer layer

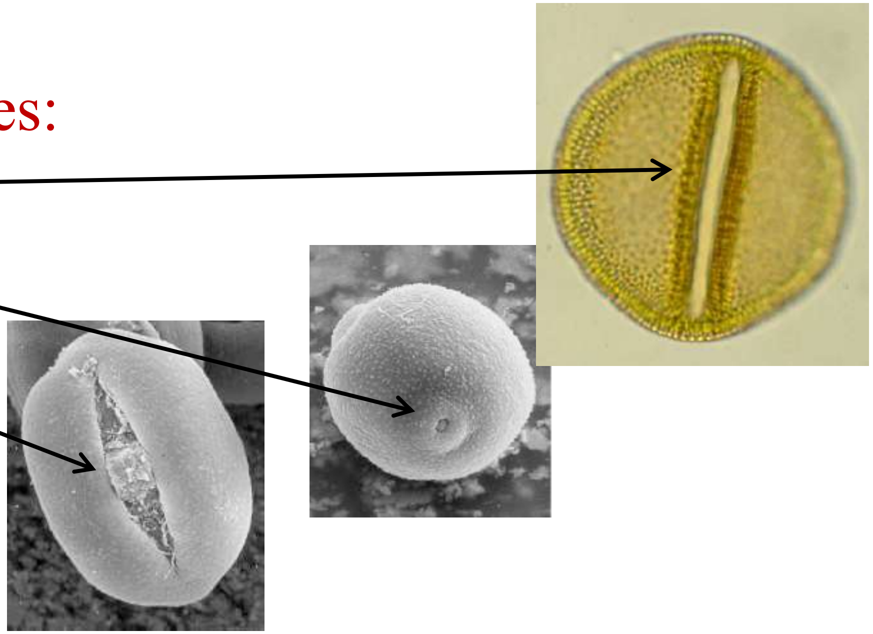
Sporopollenin:
- Fatty acids
- Phenolic compounds
- Carotenoids



Main traits of a pollen grain

- Size: 2.5 and 200 µm.
- Morphology: spherical, ellipsoidal, subtetrahedric, pyriform, etc.
- Ornamentation
- Apertures: pores, colpus, colpus+pore, other more complex apertures.

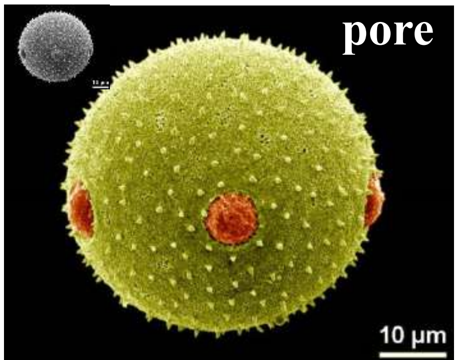
Aperture types:
colpus
pore
colpus+pore

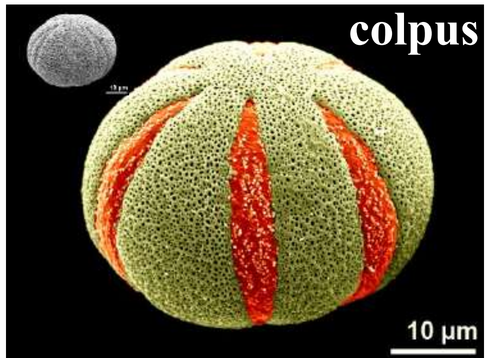


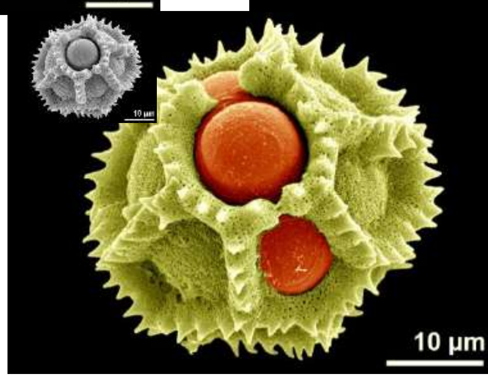
The position and number of apertures are important traits for classifying (and recognising) pollen grains.

Main traits of a pollen grain

The position and number of apertures are important characters for classifying (and recognising) pollen grains.



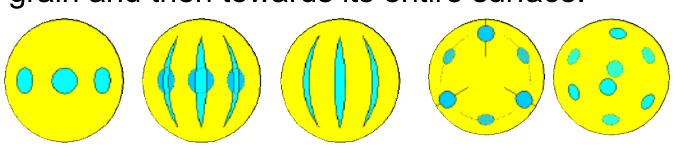


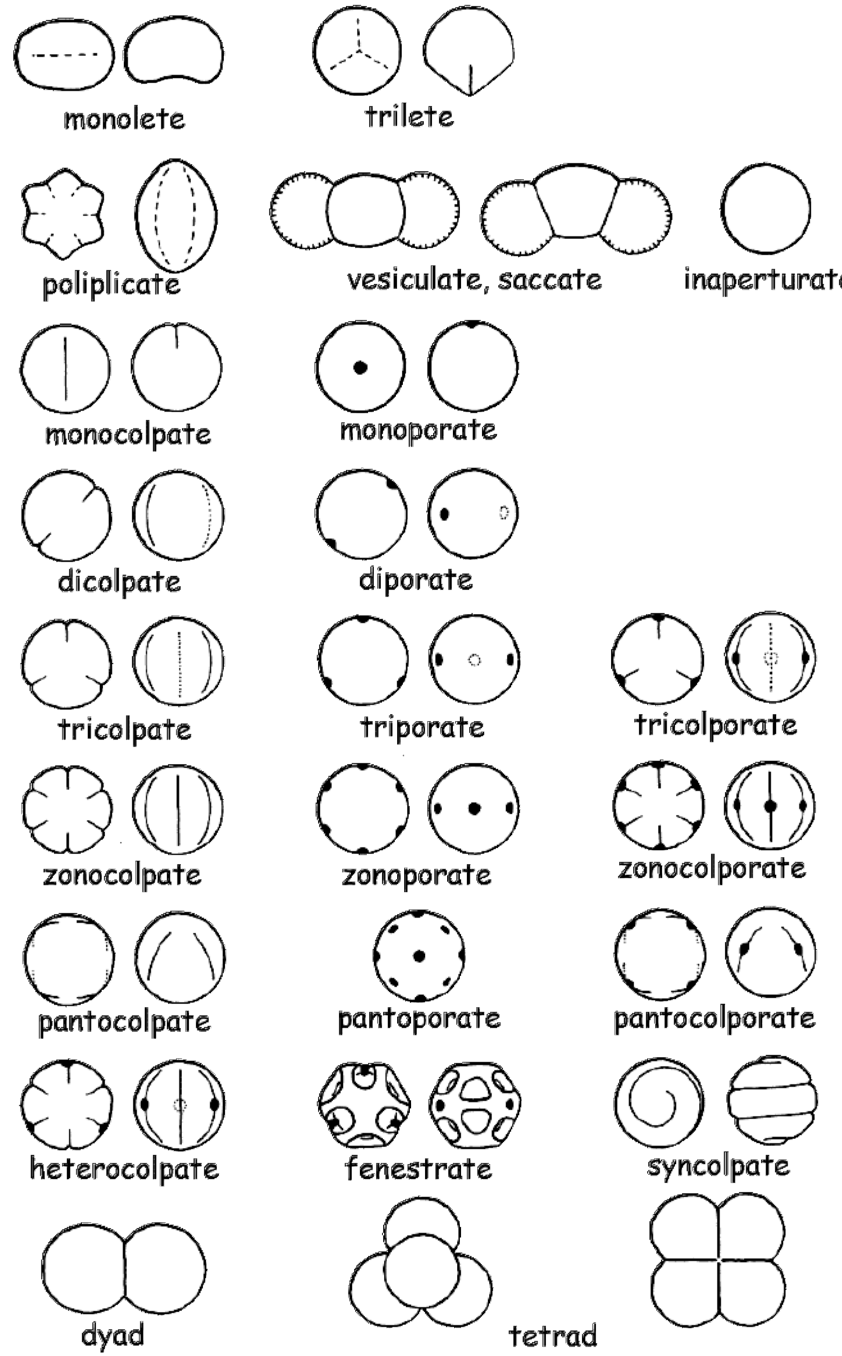


Colpus + pore

In the pollen of angiosperms, there is a tendency:

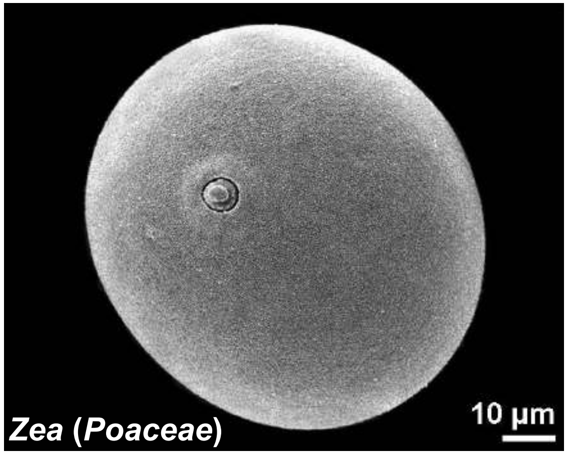
- to increase the number of apertures
- to place them first towards the equatorial area of the pollen grain and then towards its entire surface.

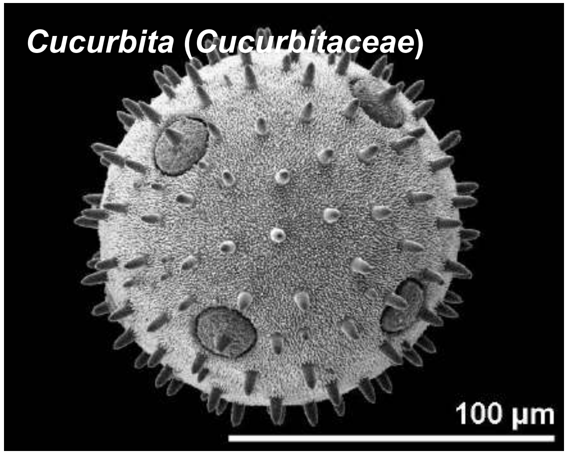


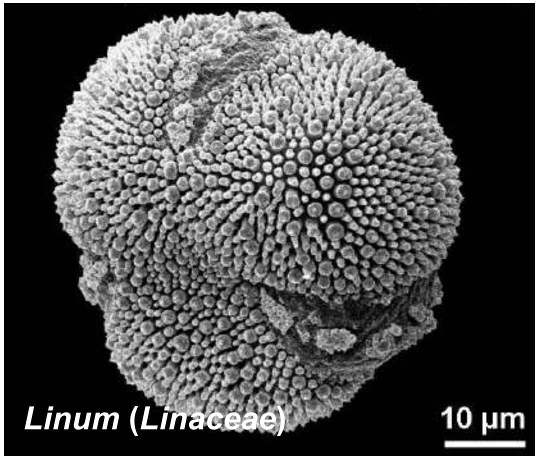


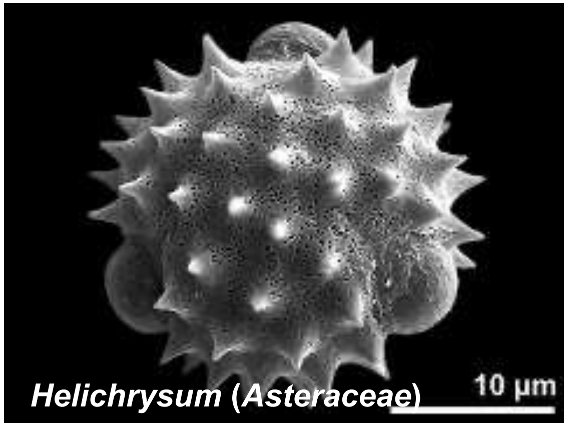
Main traits of a pollen grain

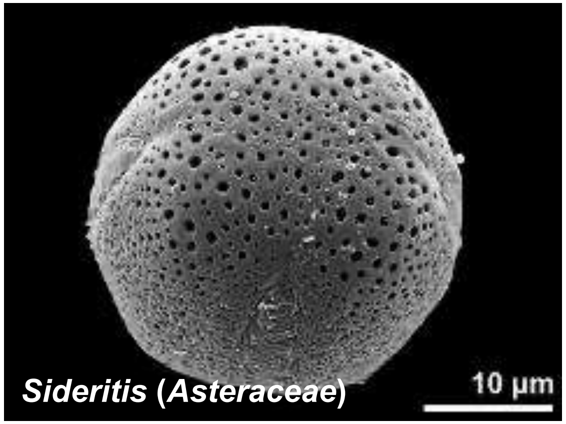
Ornamentation: the surface of the pollen grain is often ornamented with various types of sculptural elements, such as warts, crosiers, thorns, and granules, etc.

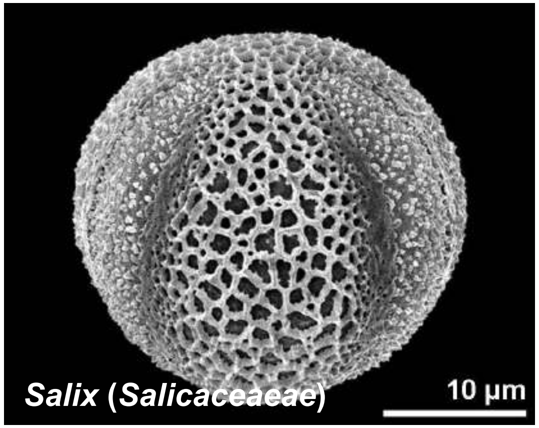


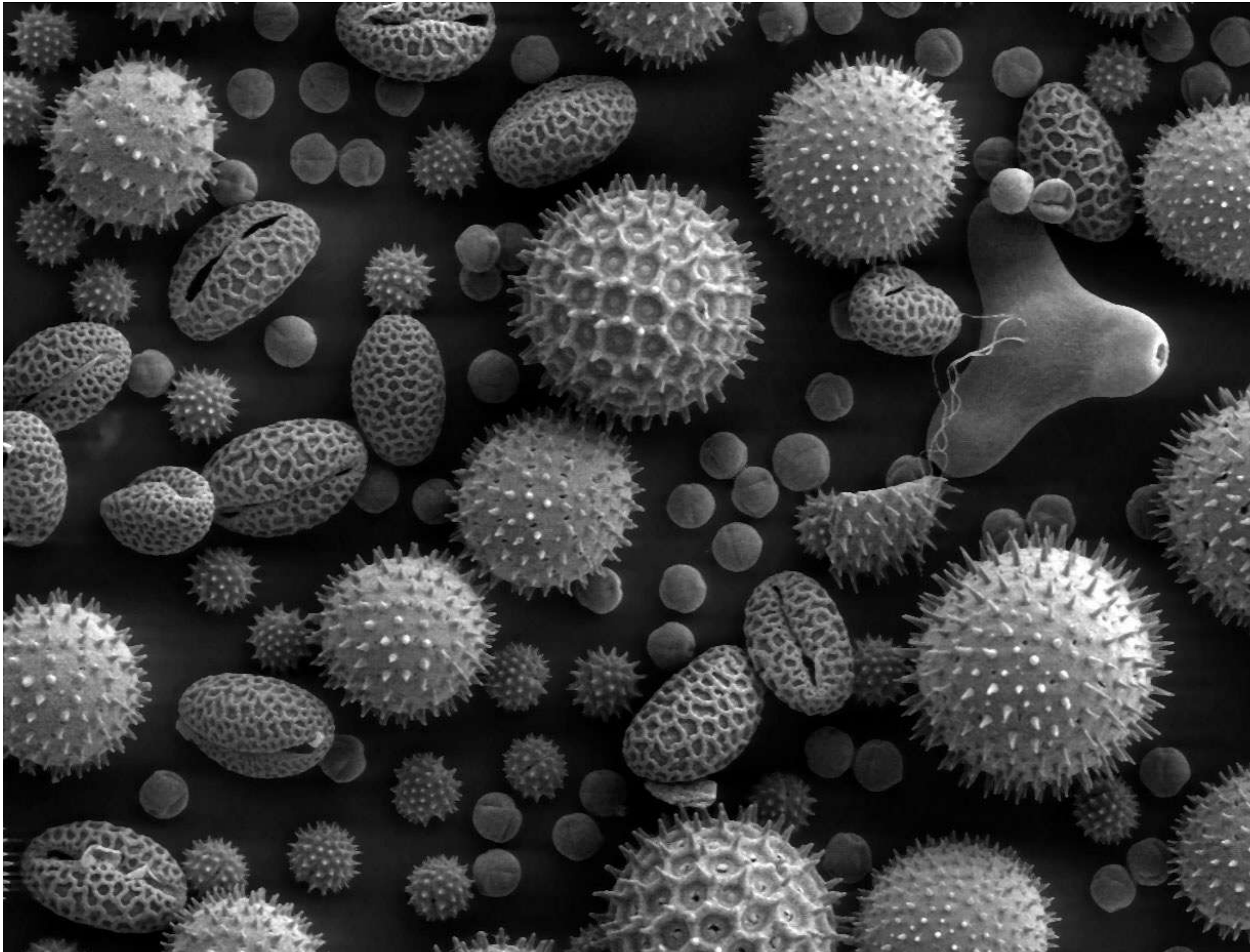












- **Dartmouth College Electron Microscope Facility**

Palynological studies

Studies on pollen = Palynology

Applications:

- plant systematics (i.e. to classify species)
- public health due to the high allergenic power of some plant pollens
- characterisation of honey
- study of flora in earlier times via study of fossil pollen
- stratigraphy

aerobiology

Cupressus

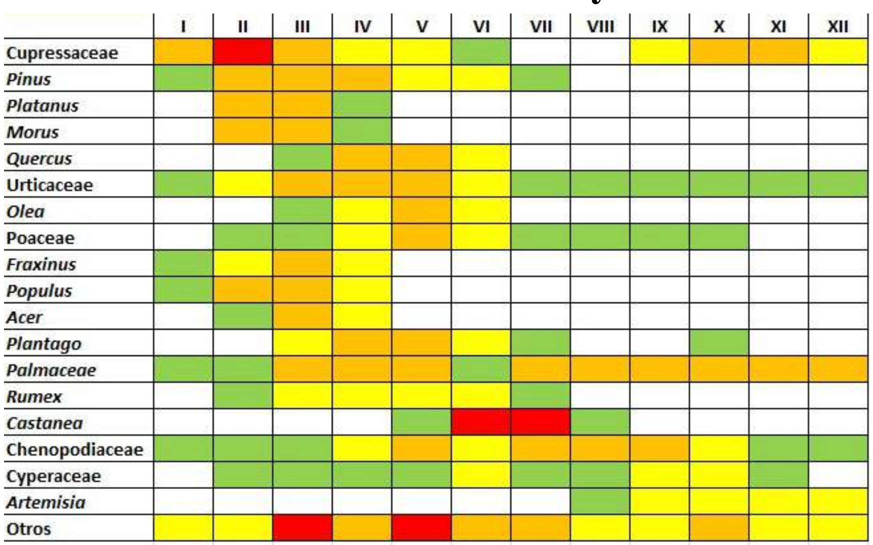
Victoria

Ranunculus

Silene

Diplotaxis

Pollen calendar of the city of Valencia



Asociación Valenciana de Alergología e Inmunología Clínica

http://polenes.avaic.org/

Orange tree

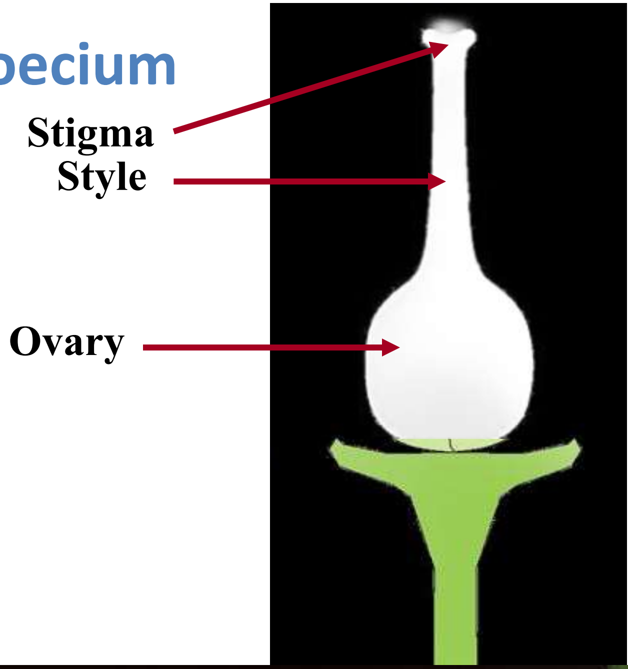
Rosemary

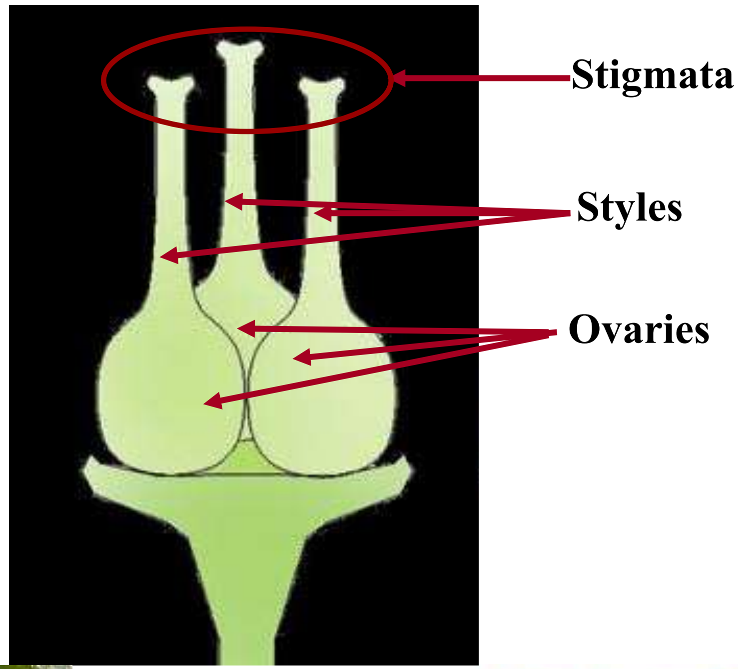
Monofloral or unifloral honeys contain > 45% pollen from the same floral species.

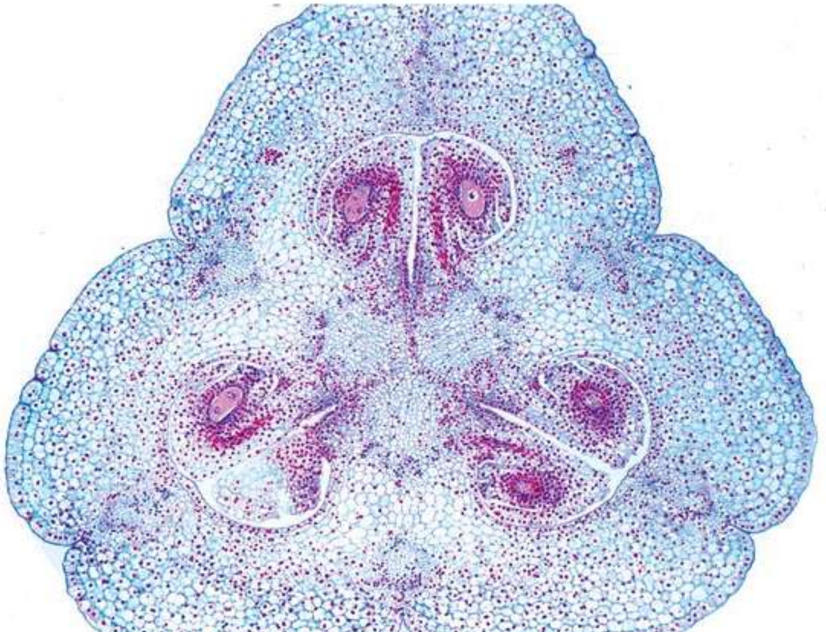
The gynoecium

= a set of carpels (or pistils)

The gynoecium







Cross-section of an ovary

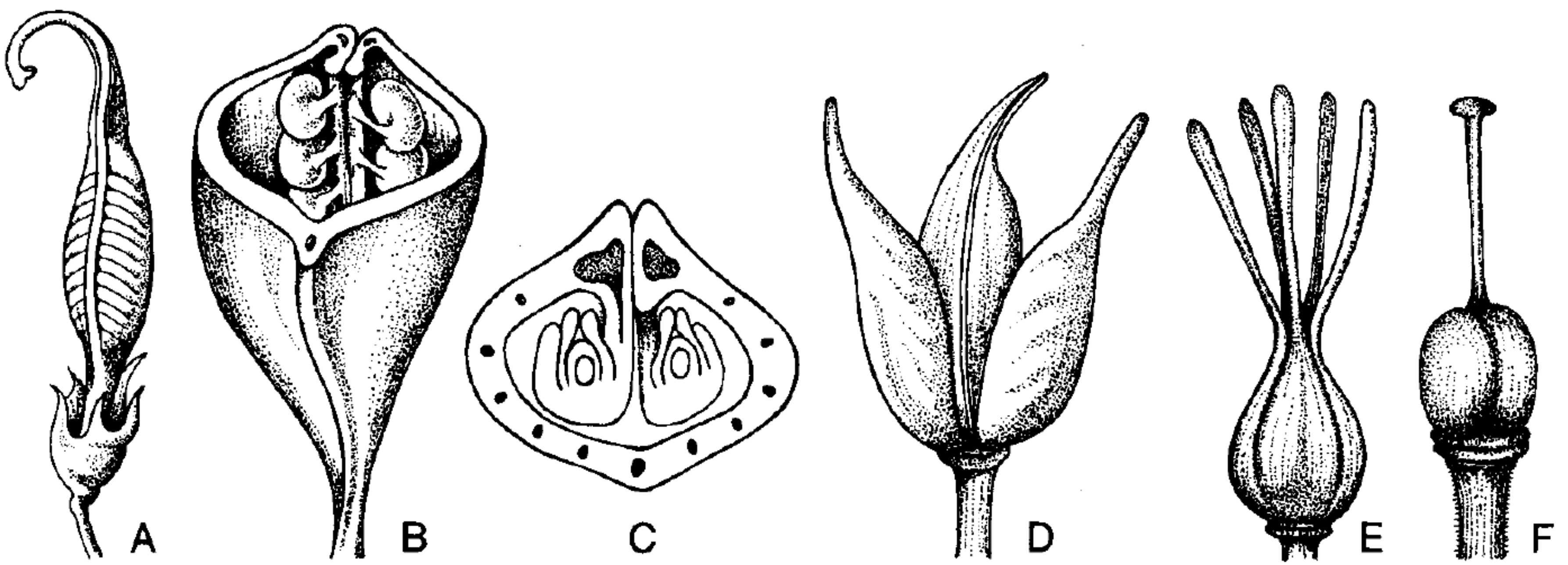
The gynoecium

The gynoecium may be uni- or multicarpellar. With the latter, carpels may be:

- **free** = apocarpous or dialycarpous gynoecium
- **fused** = gamocarpous or syncarpous gynoecium

The degree of carpel fusion is variable:

- The carpels may be fused while maintaining the separation between them (multilocular ovary) or otherwise (unilocular ovary).

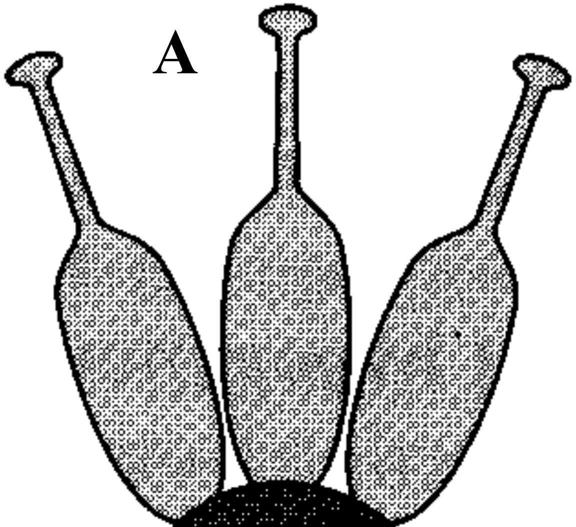


- A, B, C: unicarpellar gynoecium; D: apocarpous multilocular gynoecium; E and F: syncarpous multicarpellar gynoecium

The gynoecium

Multicarpellar apocarpous

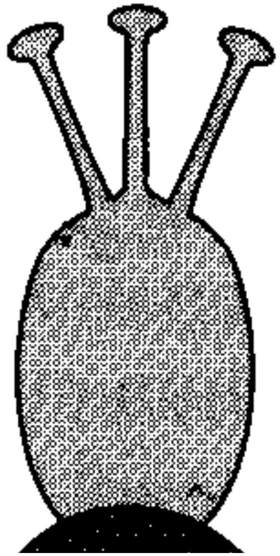
A

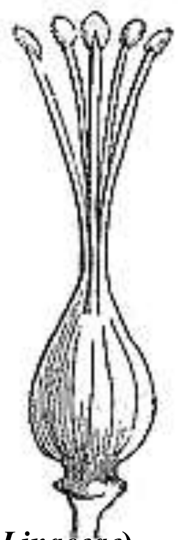


Thalictrum (*Ranunculaceae*)

Multicarpellar syncarpous

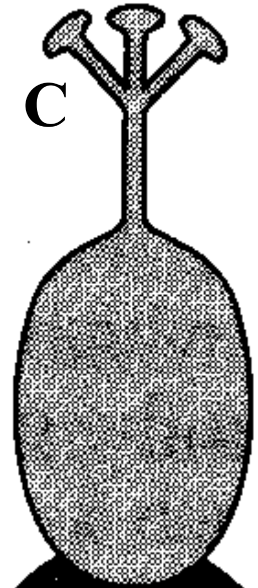
B





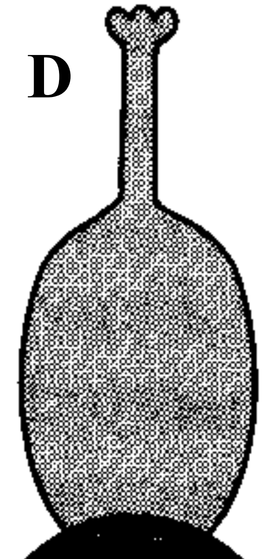
Linum (*Linaceae*)

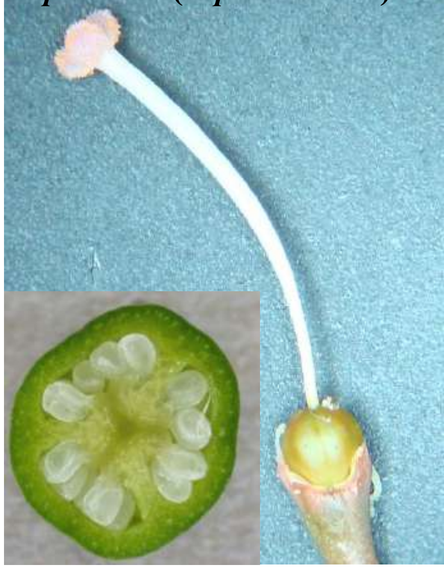
C



Hibiscus (*Malvaceae*)

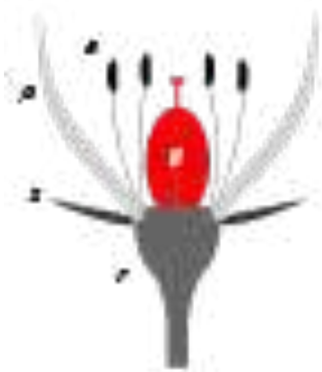
D



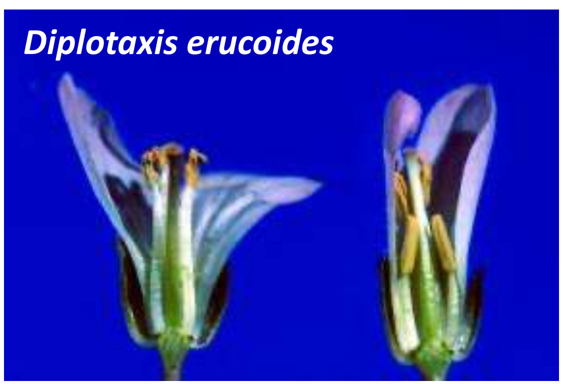


Asphodelus (*Asphodelaceae*)

Location of the gynoecium in relation to other flower components

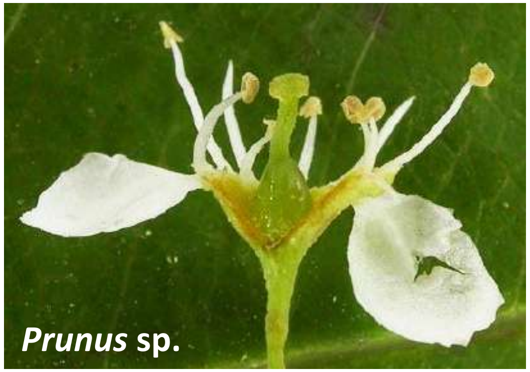


Superior ovary. Hypogynous flower. The ovary is inserted in the floral receptacle **above** the other floral components.



Diplotaxis erucoides

Mid- or central ovary. Perigynous flower. The receptacle is prolonged to form a cup. The ovary is at the same level as the other floral components.



Prunus sp.

Inferior ovary. Epigynous flower. The ovary is inserted in the receptacle below the other floral components.

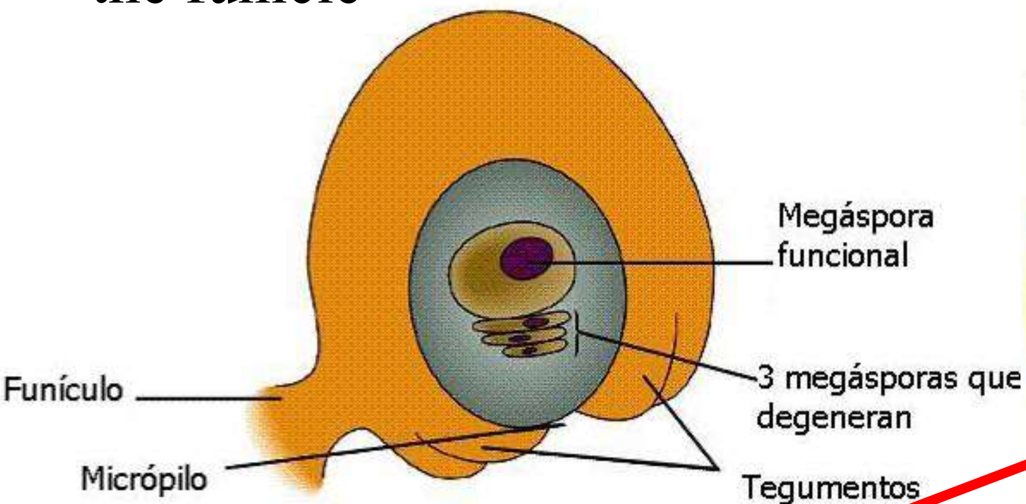
Pyrus sp.

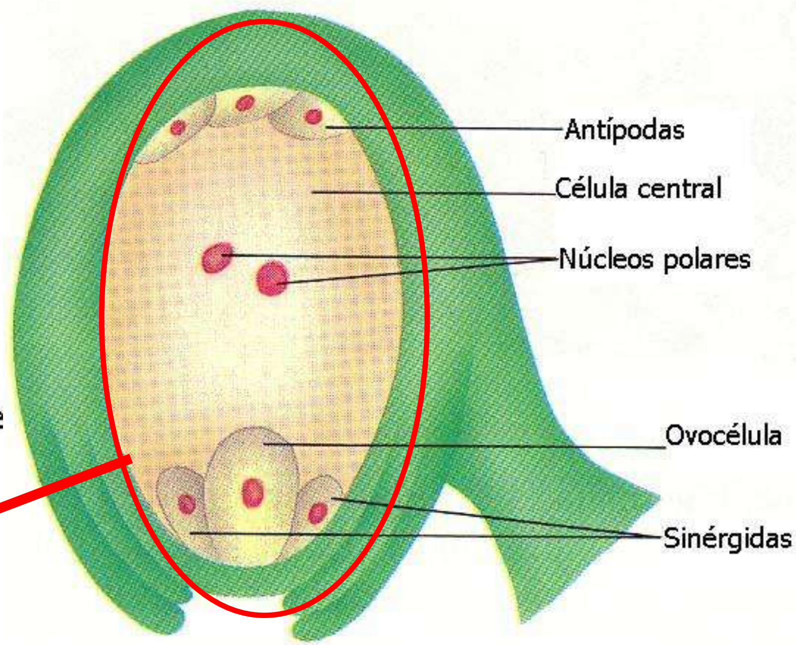
The relative position of the ovary is important for **determining the type of fruit** to be produced. Flowers with a superior ovary produce **simple fruits**, while flowers with mid- and inferior ovaries produce **compound (complex) fruits**.

The seed primordium (sometimes called "ovule")

The seed primordium is made up of:

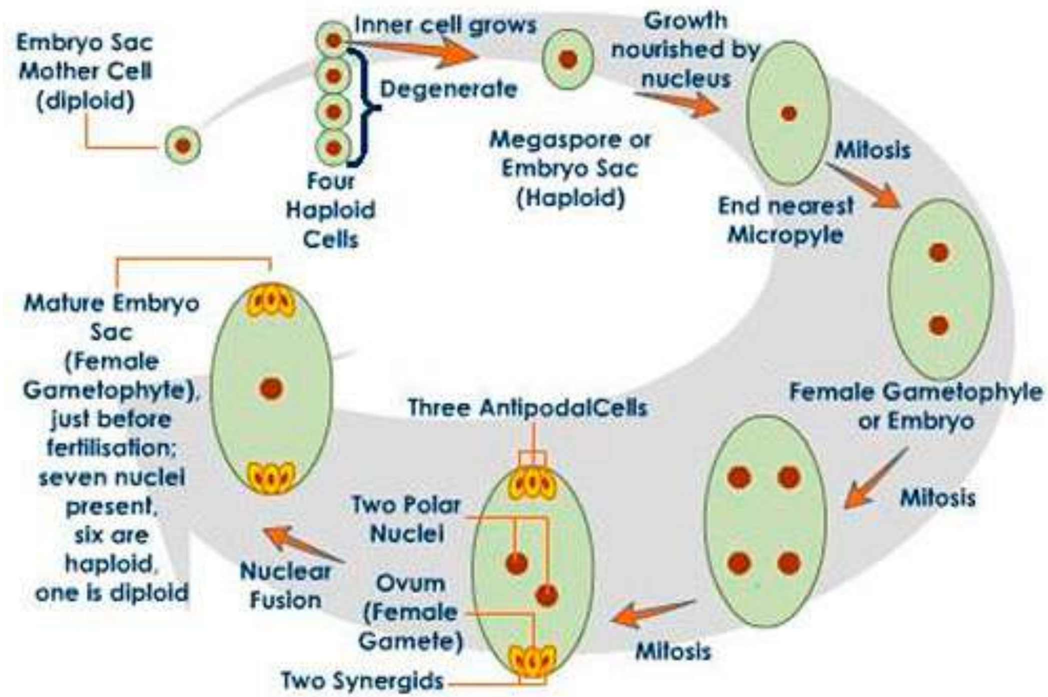
- the nucellus (considered the megasporangium)
- teguments
- the micropyle
- the funicle

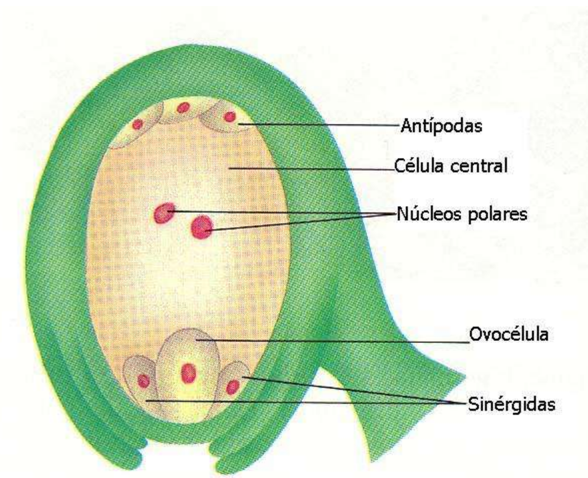




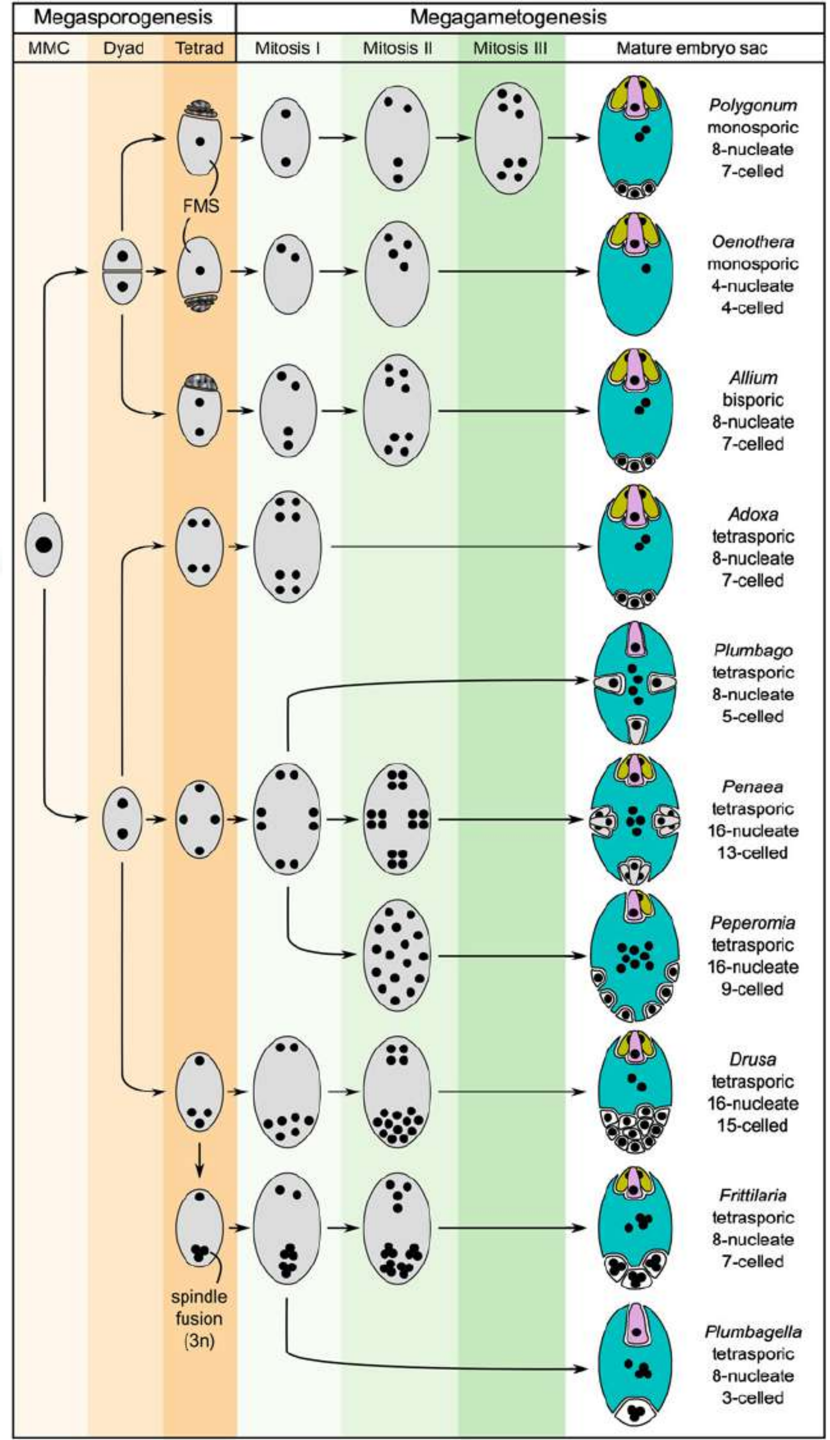
The embryo sac is the female gametophyte of angiosperms.

Megagametogenesis





The embryo sac is the female gametophyte of angiosperms



Topics

Introduction

Flowers, inflorescences, androecium and gynoecium

Pollination and fertilisation

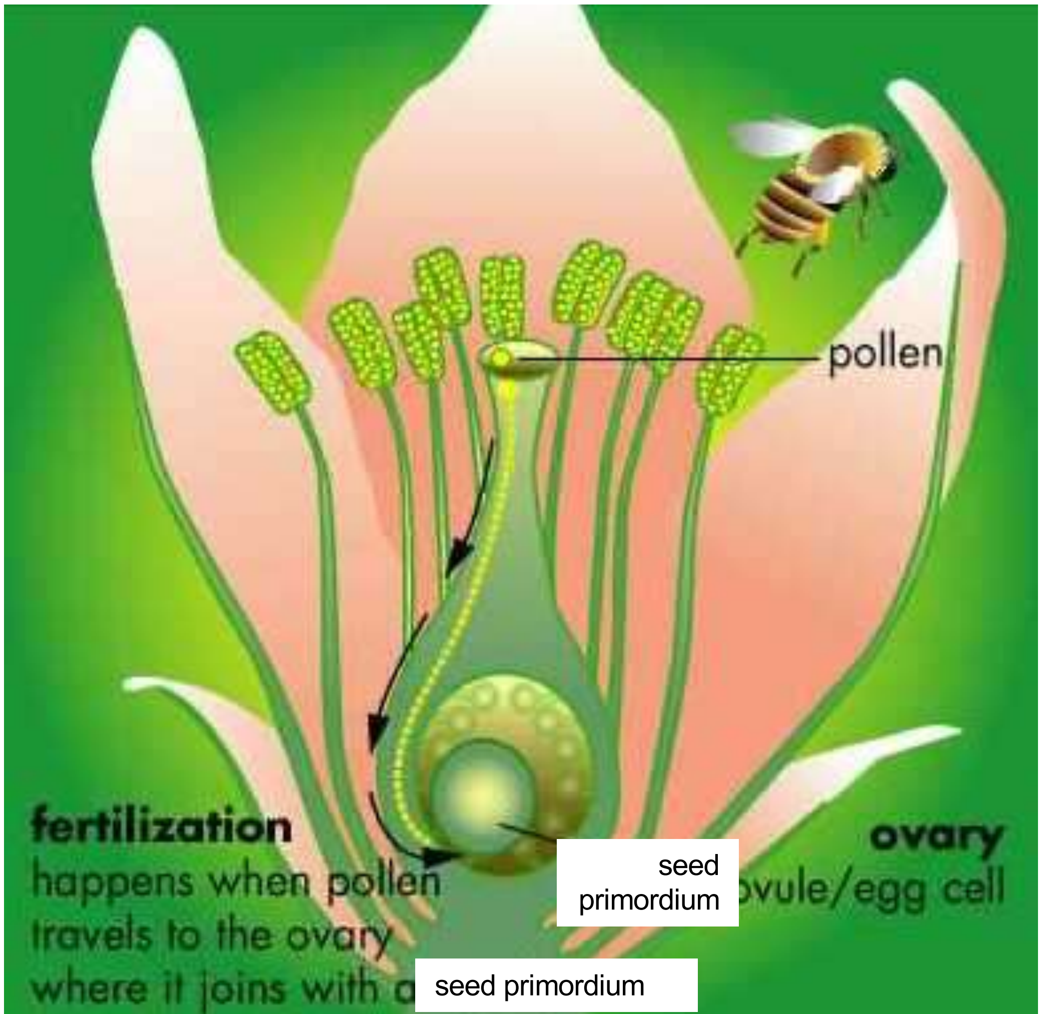
Seeds and fruits

Pollination

Pollination is the transport of pollen from the anther, where it is produced, to the stigma of a flower of the same species.

Fertilisation

Fertilisation starts with the entry of the pollen tube into a seed primordium, thus transporting the male gametes there. Then, the male gametes are released and they fuse with the egg cell and polar nuclei.



Each fertilised seed primordium gives rise to a seed.

Types of pollination

Depending on the destination of the pollen :

Pollen source	Pollination type	Fertilisation	Genetic consequences
The same flower	Self-pollination (autopollination)	Autogamy	Consanguinity
The same plant but a different flower	Allogamy	Geitonogamy	Consanguinity
A different plant	Cross-pollination allogamy	Xenogamy/Allogamy	Increase in genetic diversity

Depending on the pollination vector:

Wind: anemophilous pollination
Water: hydrophilic pollination
Animals: zoophilic pollination

Wind pollination

Flower traits:

-small

-not very evident

-no nectar, no scent

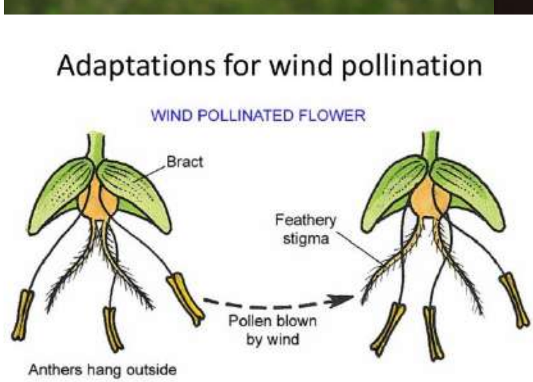
-exposed stamens

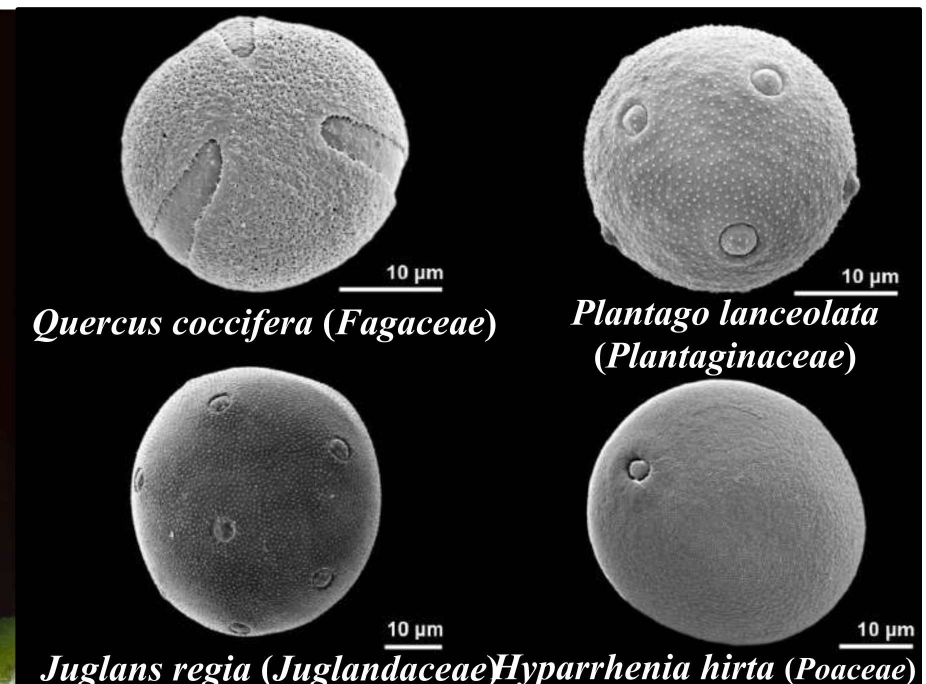
-protruding styles

-in deciduous plants, flowering before leaf budding

Pollen traits:

- small
- light
- not very ornamented
- no pollen cement
- massive pollen production: **costly for the plant**.





Wind pollination

Exposed anthers and feathery stigmas, which increase the surface area for pollen capture.

Mercurialis tomentosa

Quercus ilex **subsp.** *rotundifolia*

Juglans nigra

Plantago media

Salix

Zea mays

Wind pollination

Large and deciduous plants: flowering before the formation of new leaves

Quercus petraea

Quercus ilex* subsp. *rotundifolia

Ulmus minor

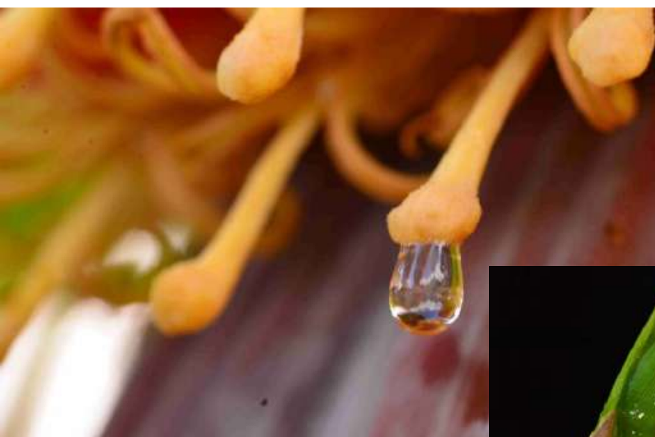
Animal pollination

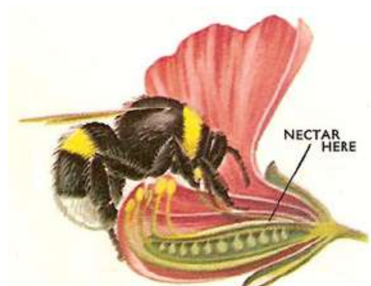
Flower traits:

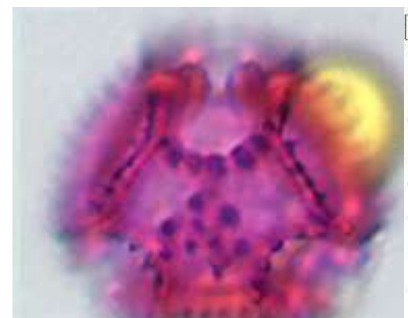
- Special mechanisms and structures are developed to attract animals.
- Animals look for lures and rewards that induce them to visit flowers.
- There are different types of flowers depending on the group of pollinators.
- Safe mechanism → The flower produces small amounts of pollen → **The plant can save energy.**

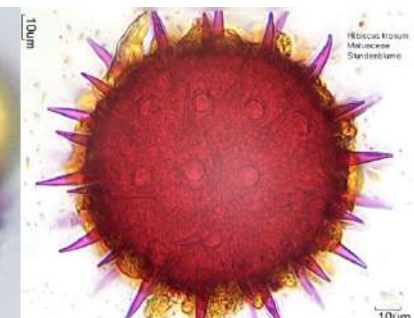
Pollen traits:

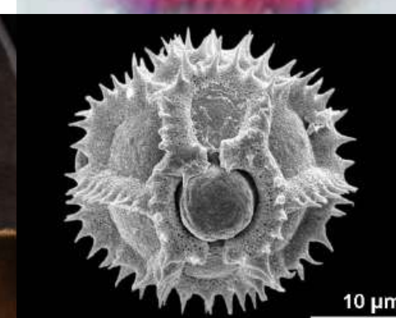
- Pollen has substances that make it sticky and facilitate adherence to pollinators: **pollen cement**.
- There are different sizes (they can be large).
- The surface is ornamented.



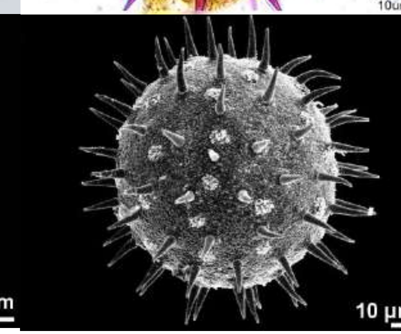








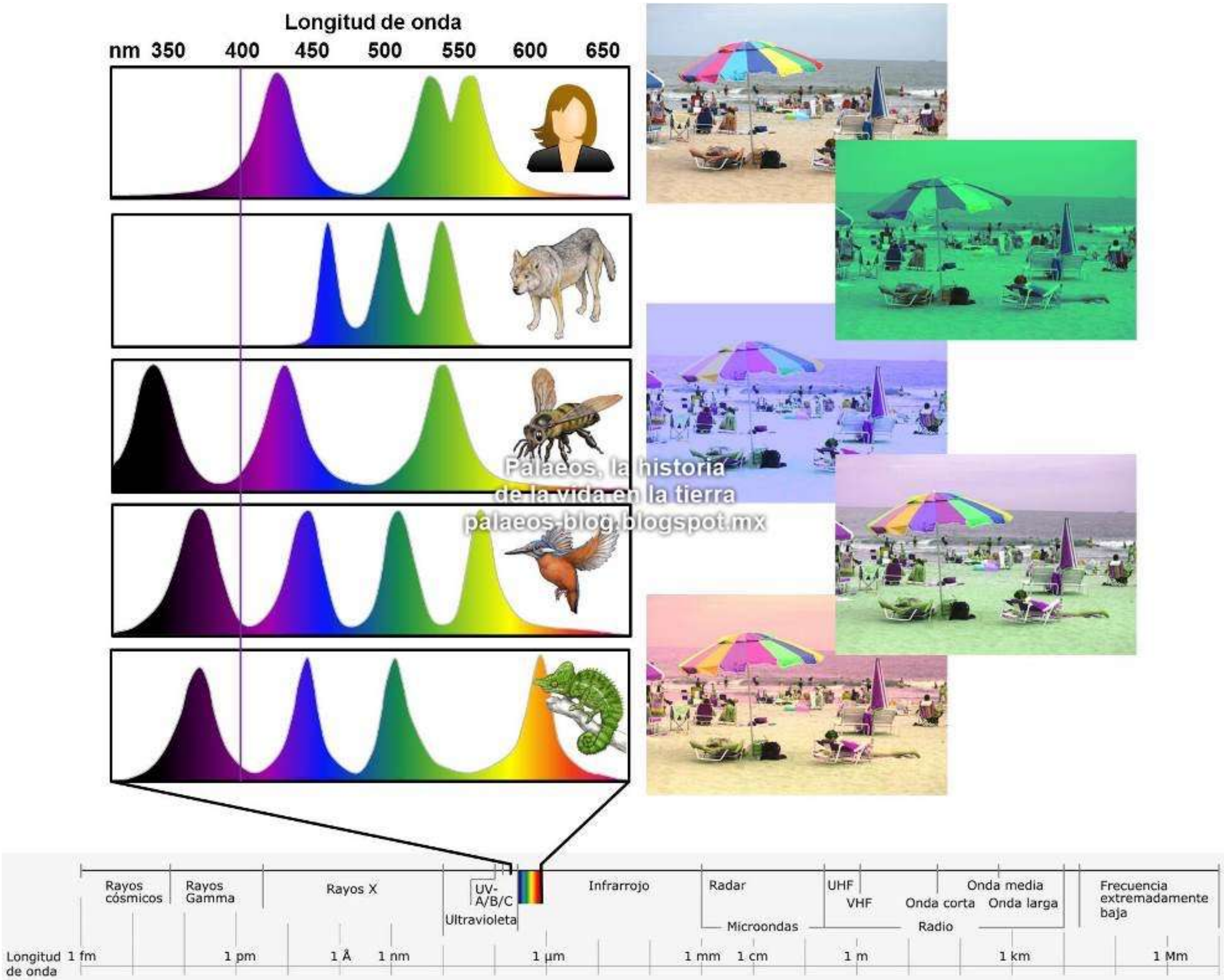
Sonchus



Hibiscus

Animal pollination

Visual claims: note that the vision spectrum of many pollinators does not match that of humans.

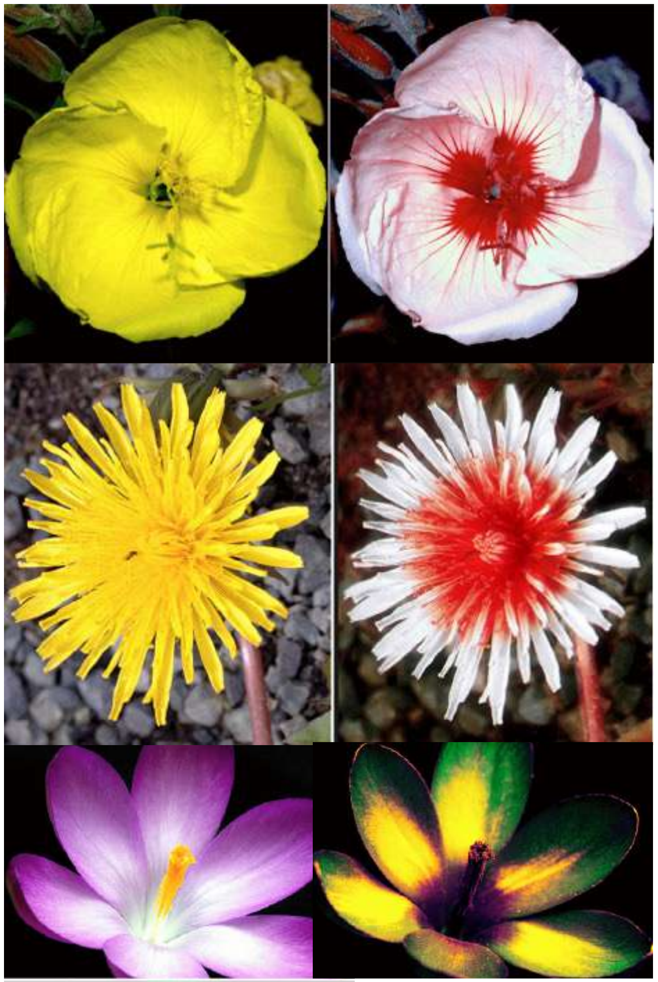


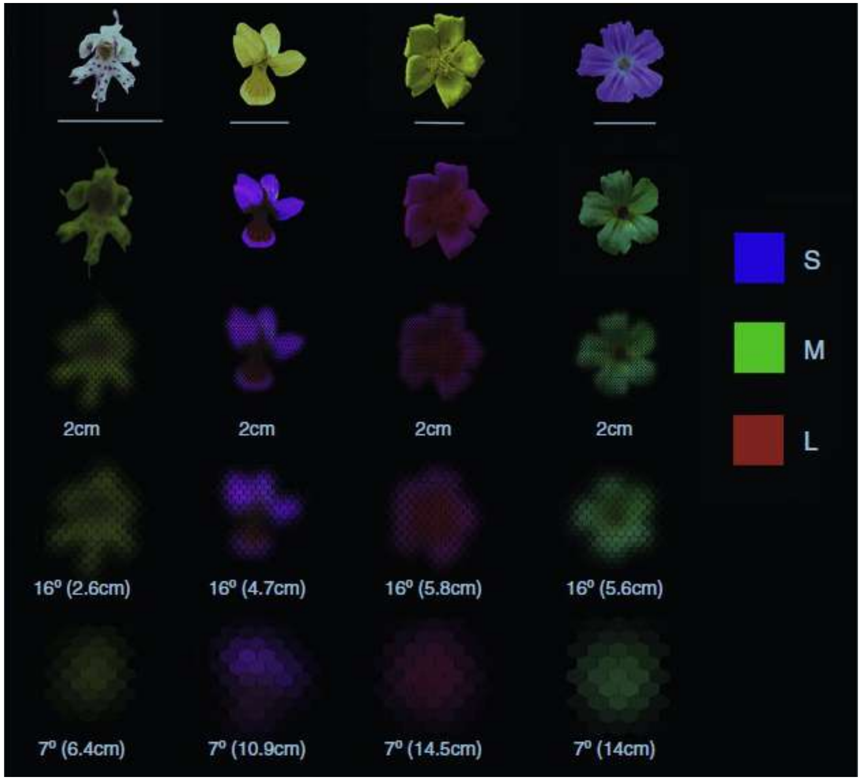
Animal pollination: how bees see flowers

Bees mainly capture three wavelengths, at roughly 350, 440 and 520 nm.

The chromatic pattern of the flowers changes under their visual spectrum; areas that attract the insect to the area of interest are often highlighted.

Humans **Bees**





Hempel de Ibarra *et al.* (2015). *Current Opinion in Insect Science* 12: 64-70.

Animal pollination

Olfactory claims: aromas or scents are sometimes pleasant and sometimes foul but are attractive to pollinators.

These claims are especially important for nocturnal pollinators.

Amorphophallus titanum

Rafflesia

Stapelia

Diplotaxis

Rosa

Animal pollination

Rewards: The plant offers something in exchange for the pollinator's services.

Nectar: sugary substances that animals use as food, mainly as a source of energy.

Pollen: a complete food containing sugars, proteins and lipids and rich in vitamins.

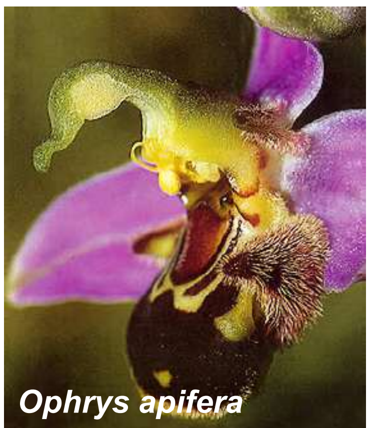
André Karwath aka Aka - Own work
This image shows a close-up of the head of a marmalade fly (*Episyrphus balteatus*) sitting on a flower of a Grey-haired Rockrose (*Cistus creticus*). The fly's head has a diameter of 0.1 inches (2.5 mm). This image is a 100% crop, not a downscaled version of a larger photograph.

“Apis mellifera flying” by Muhammad Mahdi Karim (www.micro2macro.net) Facebook Youtube - Own work. Licensed under GFDL 1.2 via Commons - https://commons.wikimedia.org/wiki/File:Apis_mellifera_flying.jpg#/media/File:Apis_mellifera_flying.jpg

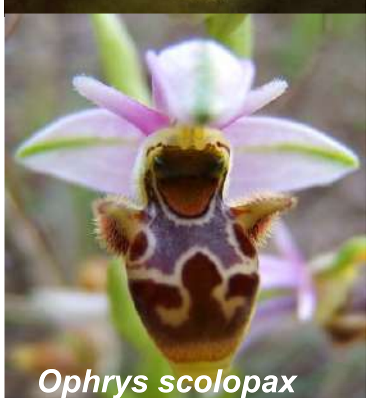
Animal pollination

Deceptive flowers: these plants offer no reward to the pollinator for its services, which can sometimes be detrimental to the pollinator.

In some orchids (*Ophrys*), the flowers mimic the female sex of an insect species. The pollinia remain attached to the male's body when it attempts to copulate.



Ophrys apifera



Ophrys scolopax

Stapelia gigantea (*Asclepiadaceae*)

Animal pollination

Birds = Ornithophyly

Reptiles= Saurophyly

Bats = Chiropterophyly

Insects = Enthomophyly




ANIMAL-PLANT COEVOLUTION





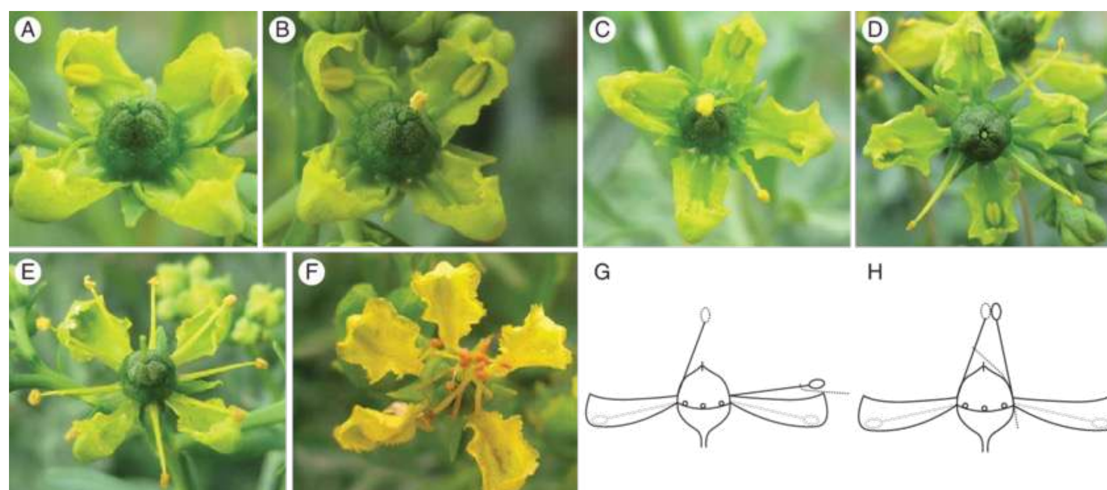
Mechanisms that favour self-pollination (consanguinity)

Cleistogamy: the corolla does not open → obligate autopollination → autogamy.

Common in cereals.

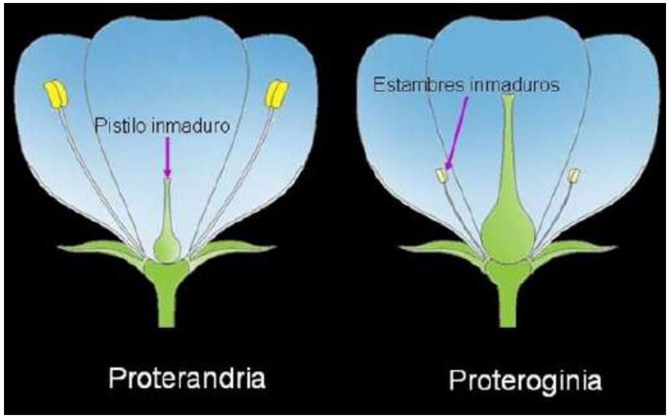
Cleistogamous flowers of *Viola sororia* and ripe fruit showing the seeds. (https://chestnutherbs.com/even-violets-need-a-plan-b/)

Stamens approaching the stigma in *Ruta graveolens* (Ren & Tang, 2012. *Annals of Botany* 110: 1017-1025.)



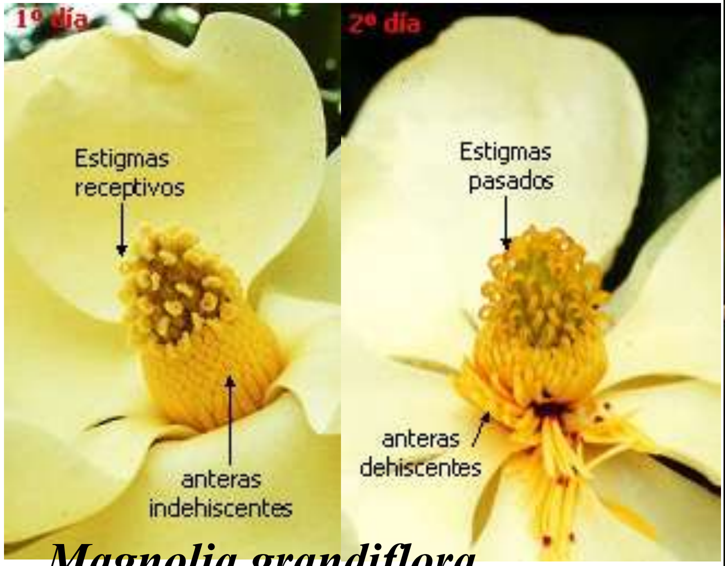
Mechanisms that reduce or prevent self-pollination (consanguinity)

DICHOGAMY = temporary separation of the sexes



Protandry

Proteroginy

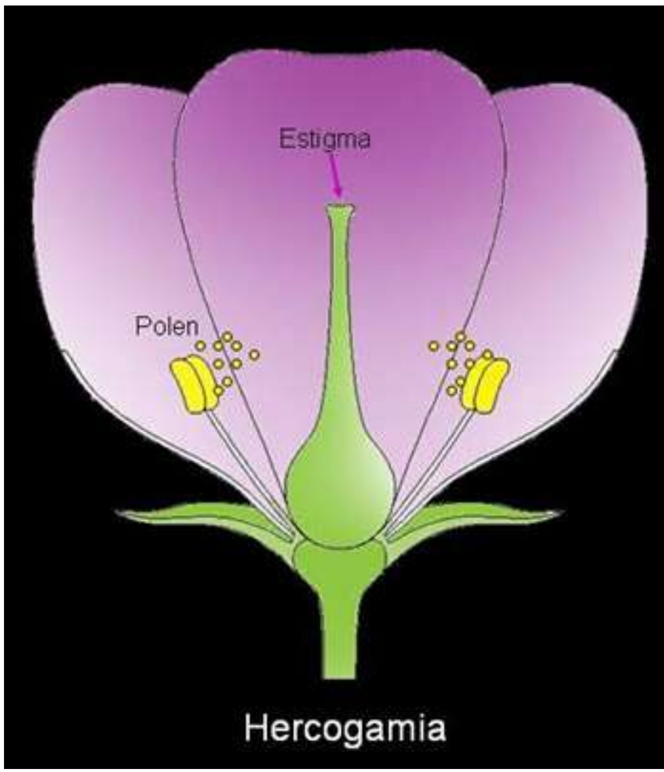


Magnolia grandiflora

Crassula

Mechanisms that reduce or prevent self-pollination (consanguinity)

Herkogamy = this common strategy is employed by hermaphroditic angiosperms to reduce sexual interference between the male (anthers) and female (stigma) functions. Herkogamy differs from other strategies (e.g. dichogamy) by supplying a spatial separation of the anthers and stigma, thus hindering the arrival of its own pollen.



Hibiscus rosa-sinensis

Mechanisms that prevent self-pollination (consanguinity)

DIOECY = unisexual flowers in independent individuals.

- This is an expensive system due to its low efficiency: only half the population can produce seeds.
- It is common in gymnosperms but rare in angiosperms (only 4% of which are dioecious).
- Dioecious angiosperms are divided into several families → Dioecy has occurred repeatedly in the evolution of angiosperms.

***Pistacia lentiscus* (*Anacardiaceae*)**

***Silene latifolia* (*Caryophyllaceae*)**

Topics

- Introduction
- Flowers, inflorescences, androecium and gynoecium
- Pollination and fertilisation
- Seeds and fruits

Fruits

Three processes are initiated after the double fertilisation that characterises angiosperms:

* Zygotes divide to form the embryo (2n) and the endosperm (3n).

* Seed primordia grow and undergo various modifications to become seeds.

* The floral parts are transformed in different ways: some fall, others atrophy (the majority), and others (mainly the ovary) hypertrophy.

Drupes in *Cocos nucifera*

A **fruit** is what the flower becomes during the transformative process (unripe fruit) or at the end of that process (ripe fruit).

Fruit structure

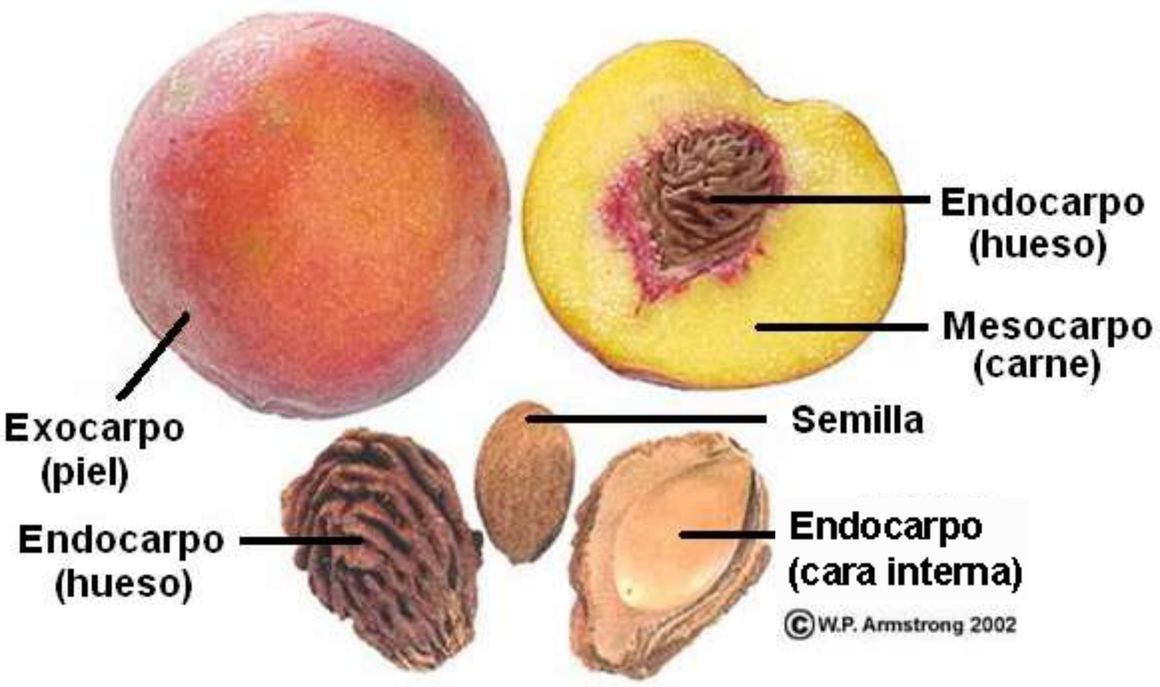
A simple fruit is made up of a **pericarp** (a wall with a carpellar origin) and a seed (or multiple seeds).

- The pericarp can be divided into three layers:

 * the epicarp, or exocarp

 * the mesocarp

 * the endocarp



Fruit types

Simple fruit, fleshy, multicarpellar, non-dehiscent and polyspermous (*Lycopersicum esculentum*)

1. Depending on the consistency of the mesocarp, fruits can be:
   * *Fleshy* (with sarcocarp).
   * *Dry* (without sarcocarp and not very developed mesocarp).

2. Depending on the parts of the flower that participate, they can be:
   * *Simple*: only the gynoecium (carpels).
   * *Complex*: including other parts (receptacle, peduncles, etc.).

Simple fruit, dry, multicarpellar, dehiscent and polyspermous (*Papaver* sp.)

3. Depending on the number of carpels that participate, they can be:
   * monocarpous or monocarpellar (1 carpel).
   * polycarpous or multicarpellar (several carpels).

4. Depending on the number of seeds, they can be: monosperms (one), polyspermous (many), or oligospermous (just a few).

5. Depending on how they open, they can be:
   * *Dehiscent*: they open while still on the plant.
   * *Indehiscent*: they drop or are wholly dispersed.
   * *Fragmentable*: they break down into several monospermous units.

Fruit types

1. Follicle (simple fruit)

Dry fruit, monocarpellar, derived from a succulent ovary, polyspermous, dehiscent (simple dehiscence through the ventral suture). One of the earliest fruits, present in ancient families and genera (e.g. *Ranunculaceae*).

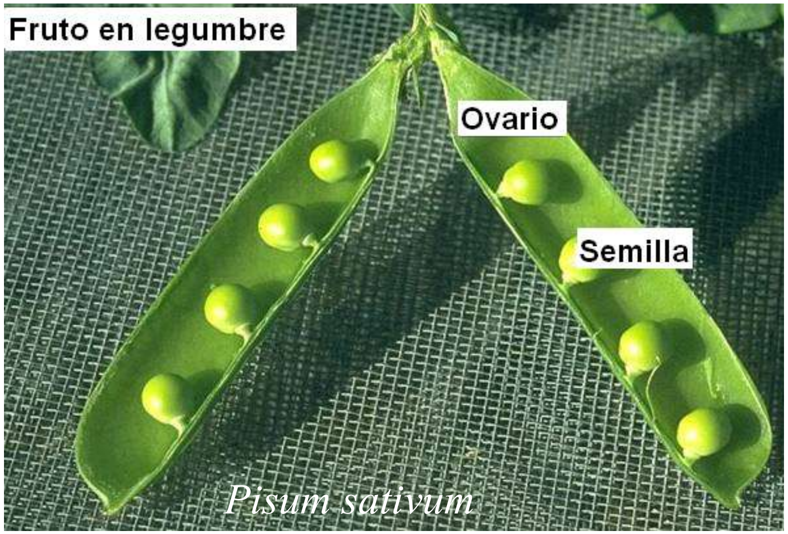
Consolida regalis (*Ranunculaceae*)

Asclepias curassavica (*Asclepiadaceae*)

Fruit types

2. Legume (simple fruit)

Dry fruit, monocarpellar, derived from a succulent ovary, dehiscent, with double dehiscence (dorsal and ventral suture). Present in *Fabaceae*.



Fruit types

2. Legume (simple fruit)

Non-typical legumes may be indehiscent (*Arachis*), fleshy (*Ceratonia*), spiralled (*Medicago*), monospermous (*Trifolium*), or samaroid (*Tipuana*), etc.

Ceratonia siliqua

Arachis hyppogea

Trifolium repens

Medicago orbicularis

Tipuana tipu

Fruit types

3. Loment (simple fruit)

Dry fruit, monocarpellar or bicarpellary, syncarpous (bilomentate), derived from a superior ovary, polyspermous, indehiscent but transversely fragmentable. Present in some *Fabaceae* (*Coronilla*, *Hedysarum*, *Ornithopus*, etc.), *Brassicaceae* (*Raphanus*), etc.

Coronilla sp.

Hedysarum sp.

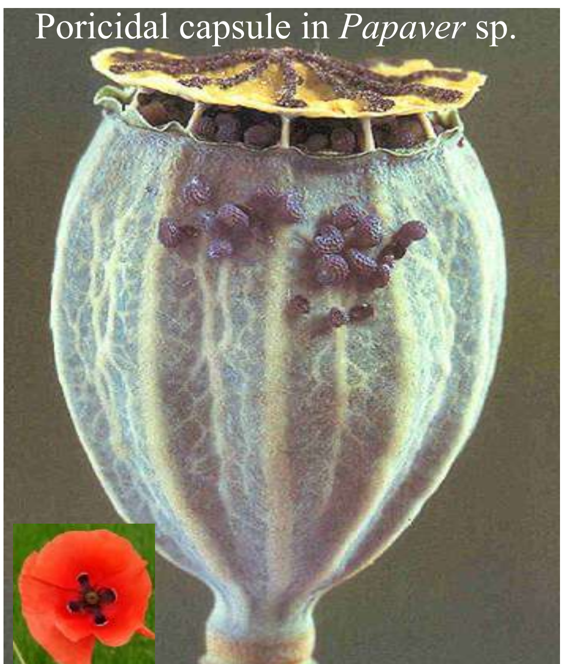
Hippocrepis sp.

Raphanus sativus (*Brassicaceae*)

4. Capsule (simple fruit)

Dry, syncarpous multicarpellar fruit derived from a superior ovary, polyspermous, dehiscent longitudinally or by means of pores. Present in numerous families and genera.

- Longitudinal dehiscence (loculicidal, septicidal, etc.) in *Cistus*, *Gossypium*, etc.
- Poricidal dehiscence (poricidal) in *Papaver*, *Antirrhinum*, etc.
- Dehiscence through teeth in *Silene*, etc.


Poricidal capsule in *Papaver* sp.


Poricidal capsule in *Antirrhinum* sp.

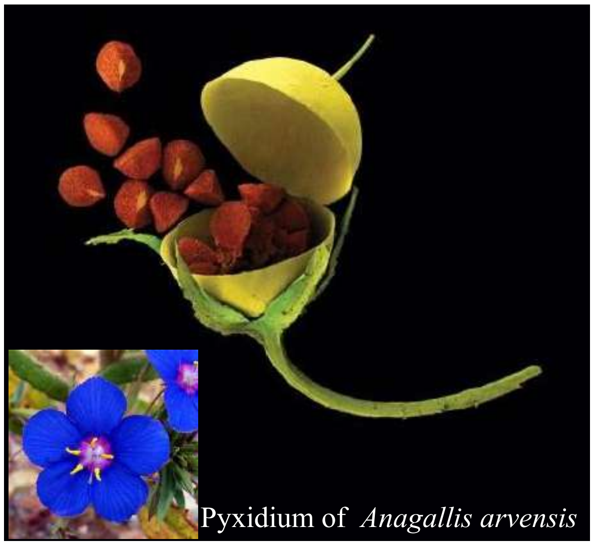
Loculicidal capsule in *Cistus*


Dentate capsule in *Silene*

Fruit types

4. Types of capsules (simple fruits)

Pyxidium: capsule with circumcised dehiscence, transversal (*Anagallis*, *Amaranthus*, *Portulaca*, etc.).

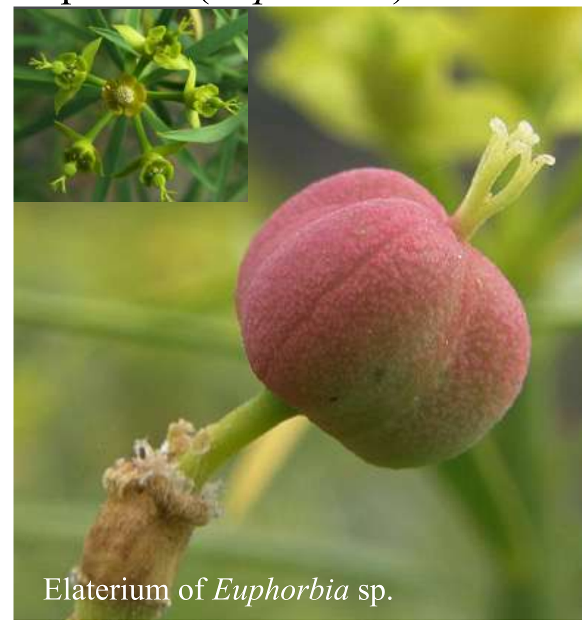


Pyxidium of *Anagallis arvensis*

Carcerulus: if non-dehiscent (*Cakile*, *Tilia*).

Carcerulus of *Cakile maritima*

Elaterium: if dehiscence is explosive (*Euphorbia*).



Elaterium of *Euphorbia* sp.

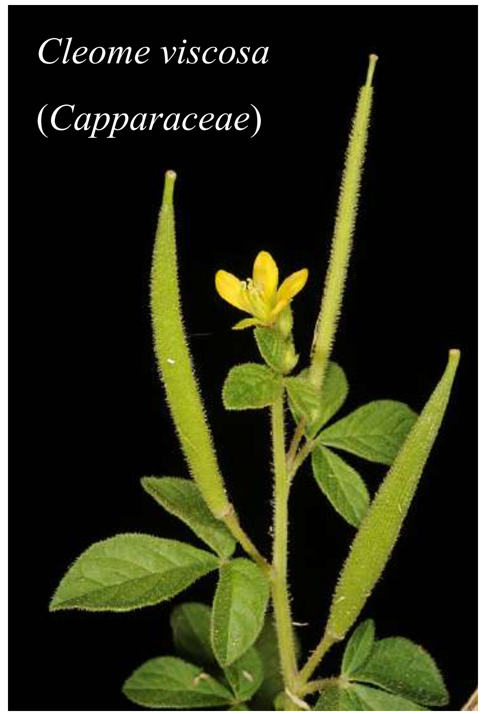
Pyxidia of *Portulaca oleracea*

Carcerula of *Tilia platyphyllos*

Fruit types

5a. Silique (simple fruit)

Dry, syncarpous, bicarpellar fruit derived from a superior ovary, polyspermous, longitudinally dehiscent by means of two leaflets. Seeds arranged in one or two rows per carpel. Present in *Brassicaceae* and some *Papaveraceae* (*Chelidonium, Glaucium*) and *Capparaceae* (*Cleome*).



Cleome viscosa (*Capparaceae*)

Glaucium corniculatum (*Papaveraceae*)

Chelidonium majus

Roripa nasturtium-aquaticum (*Bras* *caceae*)

Fruit types

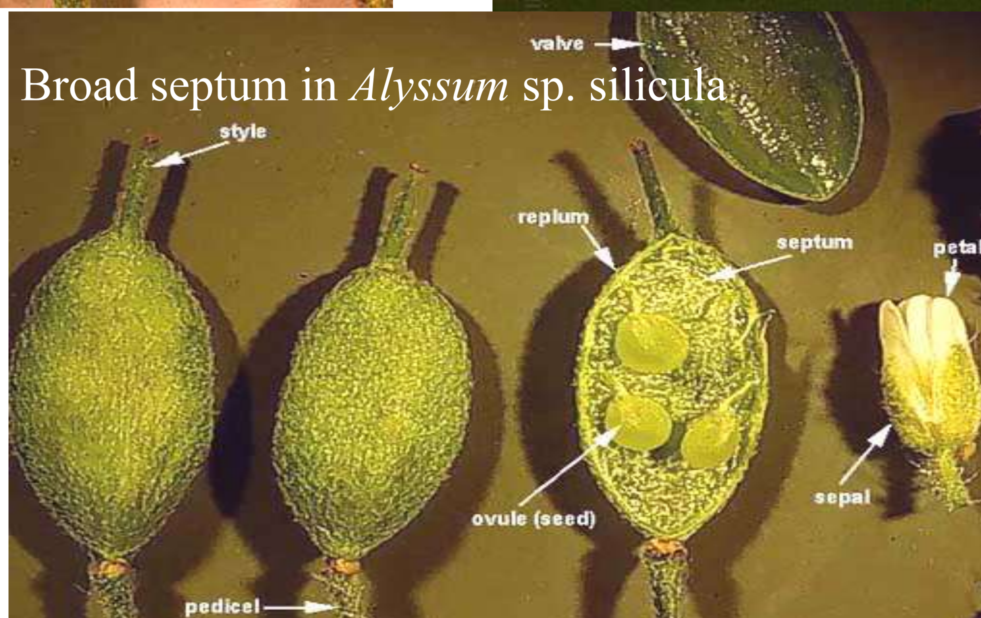
5b. Silicula (simple fruit)

A non-elongated silique with a broad (*Alyssum*, *Lobularia*, etc.) or narrow (*Capsella, Biscutella*, etc.) septum.

Narrow septum

Capsella bursa-pastoris

Broad septum in *Lobularia maritima* silicula



Broad septum in *Alyssum* sp. silicula

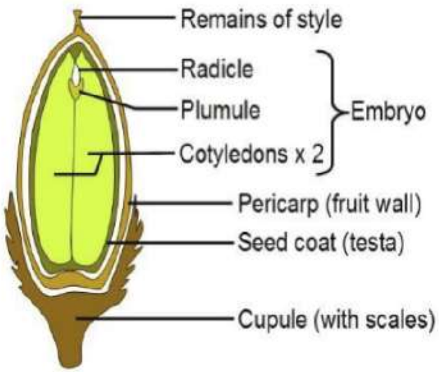
6. Schizocarp (simple fruit)

Dry fruit, multicarpellar, derived from a superior ovary, fragmentable longitudinally (pieces at the same level) into monospermous units with a seed-like appearance (mericarps). Frequent in *Malvaceae*, *Lamiaceae*, *Geraniaceae* and *Boraginaceae*.

Fruit types

7a. Achene (simple fruit)

Dry fruit with a coriaceous pericarp, non-dehiscent, mono-multicarpellar, syncarpous, derived from a superior ovary, monosperm.

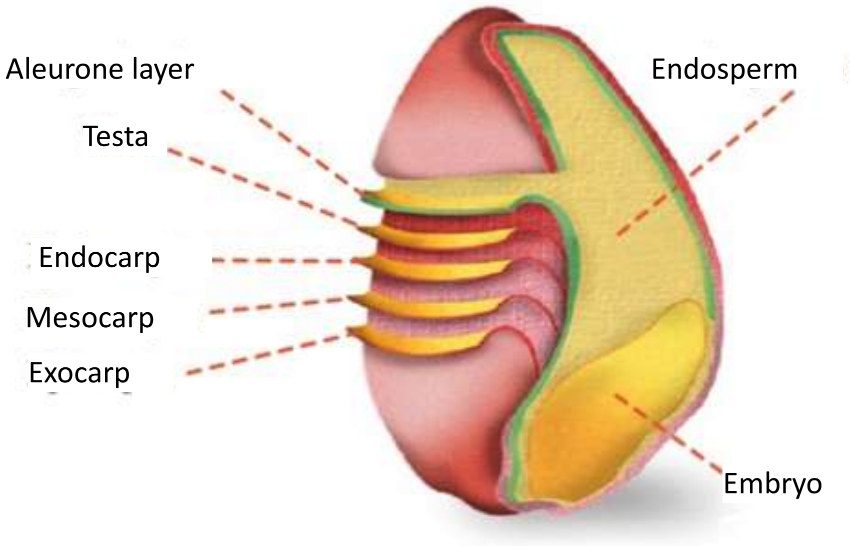


Quercus coccifera (*Fagaceae*)

8. Caryopsis (simple fruit)

A modification of an achene in which the pericarp is fused to the seed episperm. Typical of *Poaceae* (graminoid plants).

Caryopsis of *Hordeum vulgare*



9. Samara (simple fruit)

A type of achene in which wing expansions emerge to facilitate anemochore dispersion. Present in *Acer*, *Ulmus*, *Fraxinus*, etc.

Disamara of *Acer opalus* (*Aceraceae*)

Samara of *Fraxinus ornus* (*Oleaceae*)

Samara of *Ailanthus altissima* (*Simaroubaceae*)

Ulmus minor (*Ulmaceae*)

10. Nucule or nutlet (simple fruit)

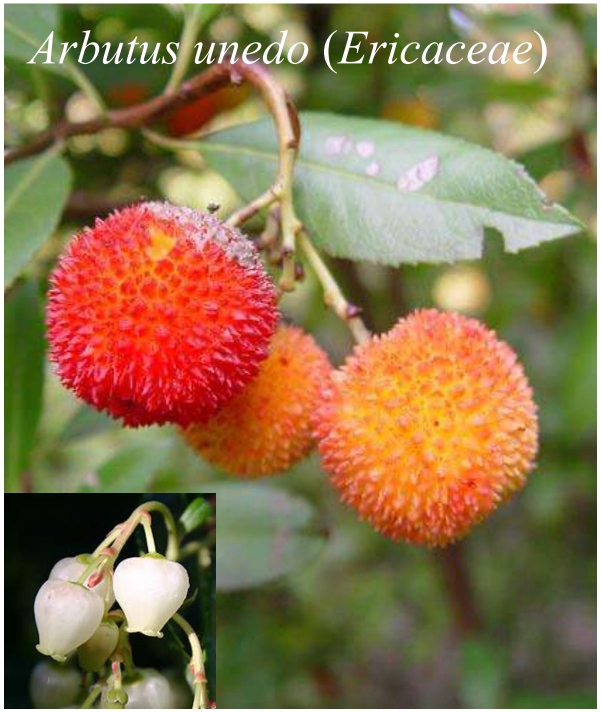
A type of achene with a lignified exocarp. Generally heavy fruits with abundant amylaceous reserves. E.g. *Corylus*.

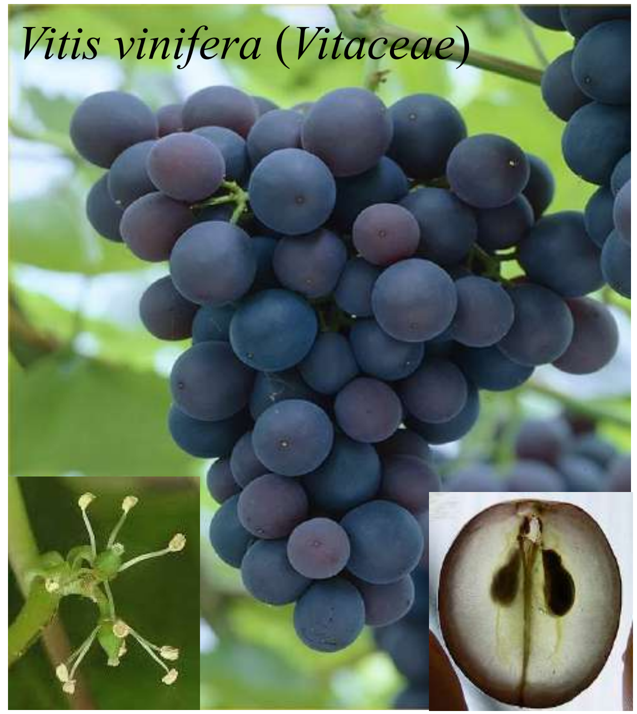
Corylus avellana (*Corylaceae*)

Fruit types

11. Berry (simple fruit)

Fleshy, with sarcocarp, without sclerocarp, mono-multicarpellar, syncarpous, mono-polyspermous, non-dehiscent. Widespread in many families (*Ericaceae*, *Vitaceae*, *Arecaceae*, *Solanaceae*, etc.).


Arbutus unedo (*Ericaceae*)


Vitis vinifera (*Vitaceae*)

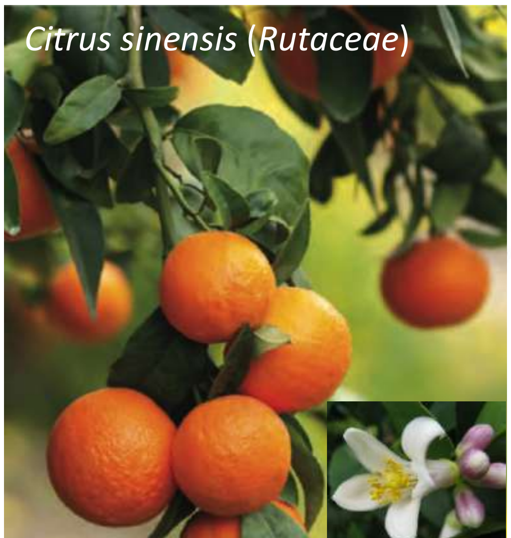

Chamaerops humilis (*Arecaceae*)

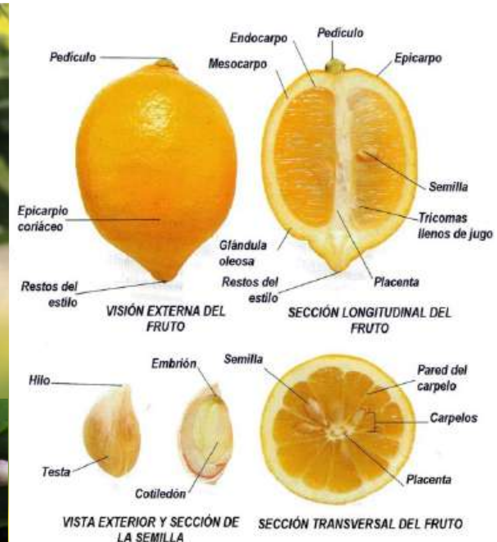

Solanum lycopersicum (*Solanaceae*)


Solanum nigrum (*Solanaceae*)

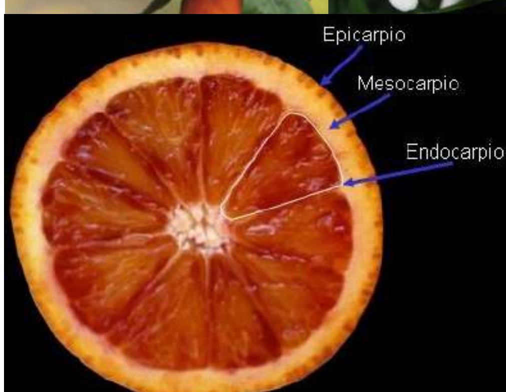
12. Hesperidium (simple fruit)

A berry modification. Multicarpellar berry deriving from a superior syncarpous ovary, with a thin exocarp and rich in scents, spongy mesocarp and membranous endocarp formed by septa that correspond with carpels, and covered with hairs full of juice containing the seeds.
Characteristic of *Rutaceae*, citrics: orange, lemon, grapefruit, tangerine, etc. and some *Clusiaceae*.


Citrus sinensis (*Rutaceae*)




Garcinia mangostana (*Clusiaceae*)




Citron (*Citrus medica*)

Fruit types

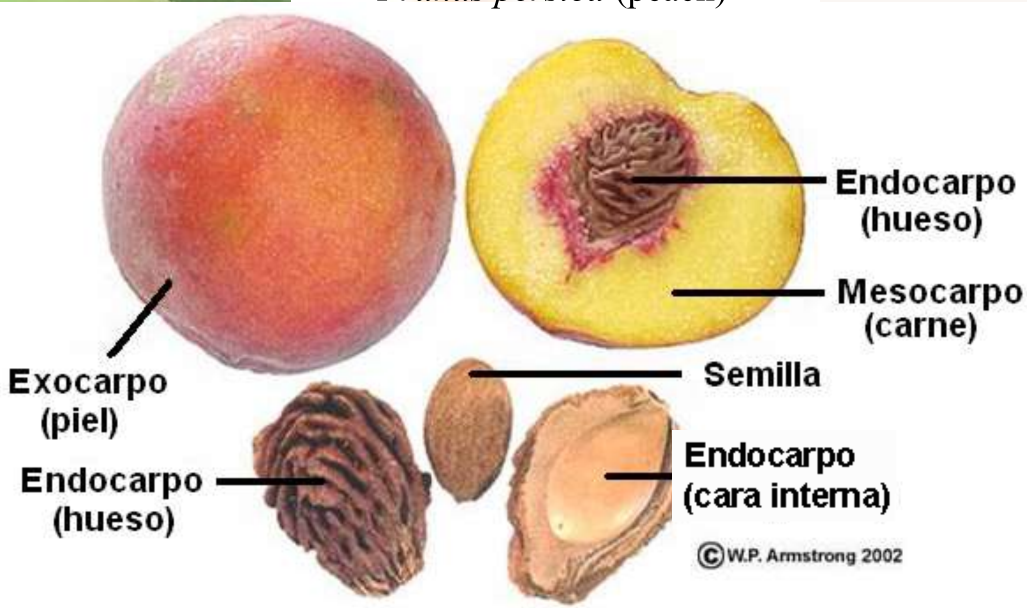
13. Drupe (simple fruit)

Fleshy fruit, non-dehiscent, monospermous, with sarcocarp and sclerocarp. Frequent in *Rosaceae* (*Prunus*, cherry, plum, peach), *Anacardiaceae* (*Pistacia, Mangifera*), *Piperaceae* (*Piper*), etc.

Prunus avium (cherry)

Prunus persica (peach)

Prunus domestica (plum)



Piper nigrum (*Piperaceae*)

Fruit types

1. Polyfollicle (aggregate fruit)

From a single flower with several free carpels with superior ovaries, these fruits develop as independent fruits in the same flower.

Helleborus foetidus (*Ranunculaceae*)

Brachychiton sp. pl. (*Sterculiaceae*)

Magnolia grandiflora (*Magnoliaceae*)

Illicium verum (*Illiciaceae*)

2. Polyachene (aggregate fruit)

A flower with various free carpels, each of which turns into an achene. E.g. *Ranunculus*, *Clematis* (*Ranunculaceae*).

Clematis flammula (*Ranunculaceae*)

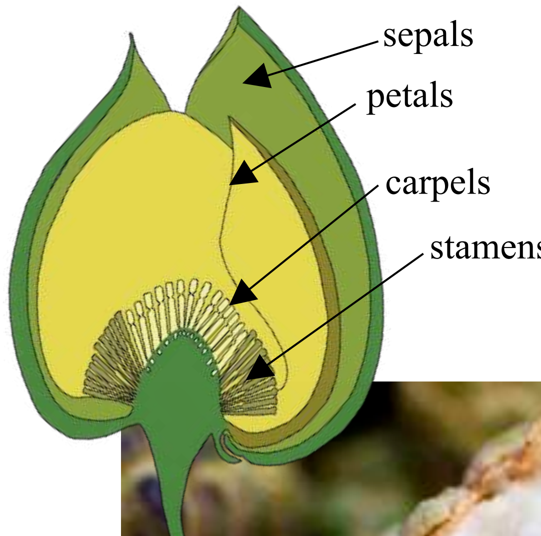
Ranunculus sp.

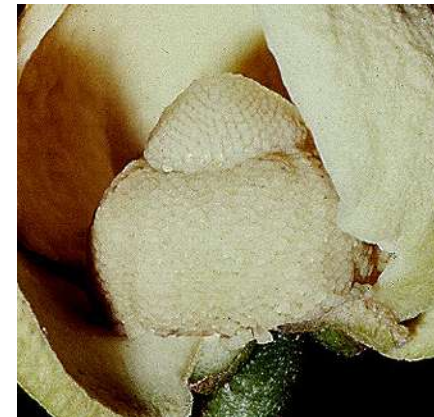
Aggregate fruits

3. Polydrupe: a flower with various free carpels, each of which turns into a drupe, e.g. *Rubus* (*Rosaceae*).


Rubus ulmifolius (*Rosaceae*)

4. Polyberry: a flower with various free carpels, each of which turns into a berry, e.g. *Annona* (*Annonaceae*).





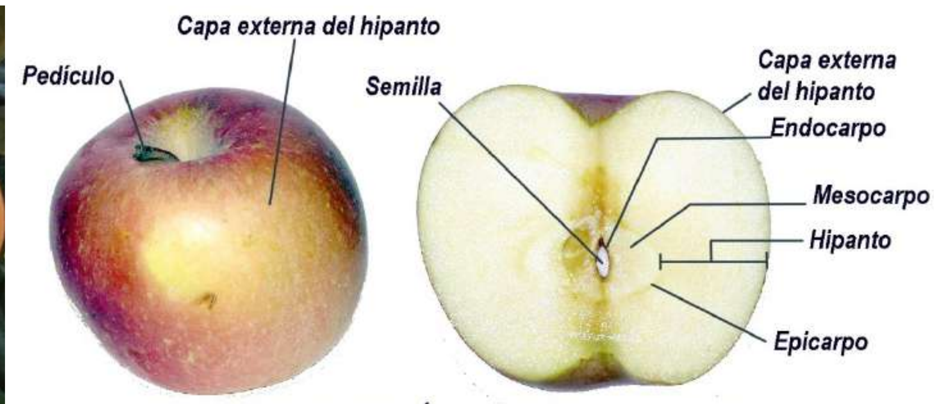
Fruit types

1. Pome (compound fruit)

Not only the ovary but also other floral components participate in fruit formation.

Fleshy fruit derived from an inferior gynoecium, multicarpellar, often polysperm, enveloped by and fused to a fleshy receptacle (**hypanthium**). They are found in several families: *Rosaceae* (*Malus*, *Pyrus*, *Eriobotrya*, *Mespilus*), *Ericaceae* (*Vaccinium*), *Myrtaceae* (*Myrtus*), etc.

Eriobotrya japonica (*Rosaceae*)



Pyrus sp.

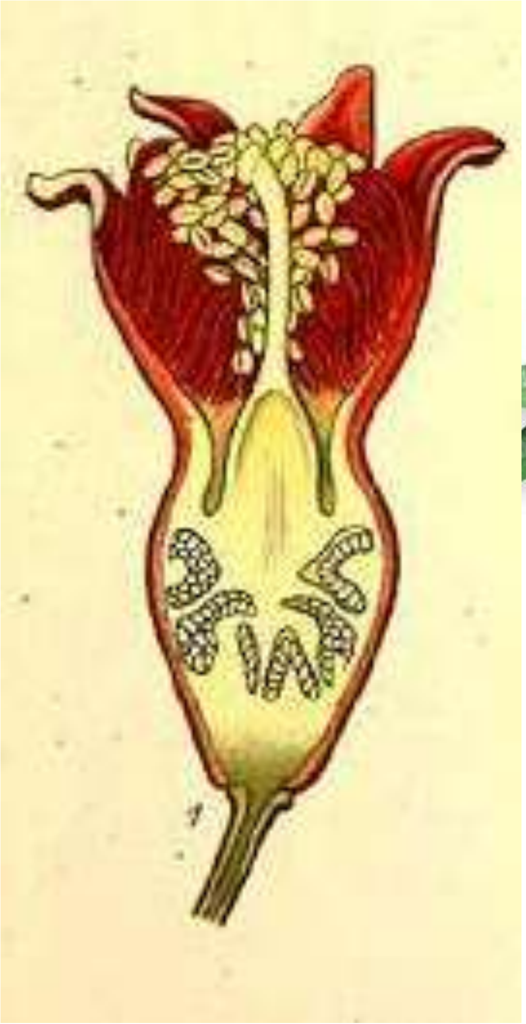
Vaccinium corymbosum (*Ericaceae*)

Myrtus communis (*Myrtaceae*)

Cydonia oblonga (*Rosaceae*)

2. Balausta (compound fruit)

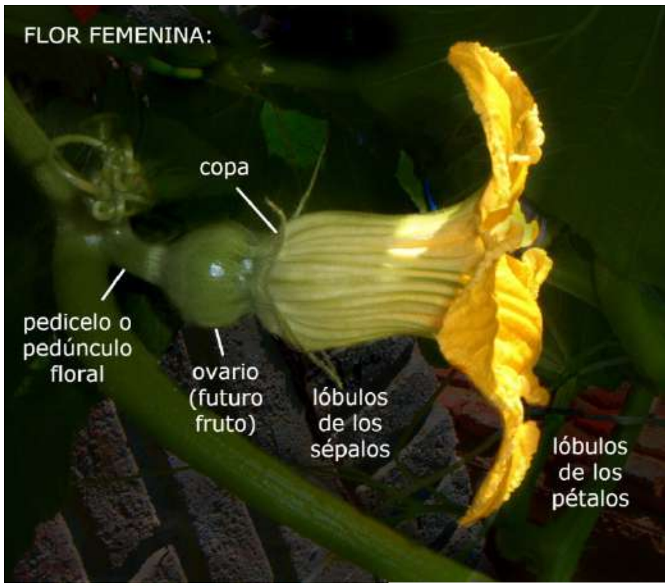
A pome modification. Fleshy, multicarpellar, syncarpous, with carpels arranged in two strata, with a coriaceous covering, spongy mesocarp, and endocarp separating clusters of seeds that present a sarcotesta, e.g. *Punica granatum* (*Lythraceae*).

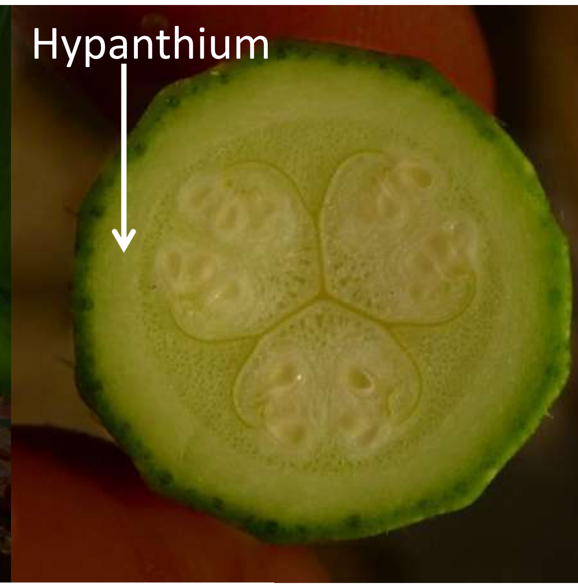




3. Pepo (compound fruit)

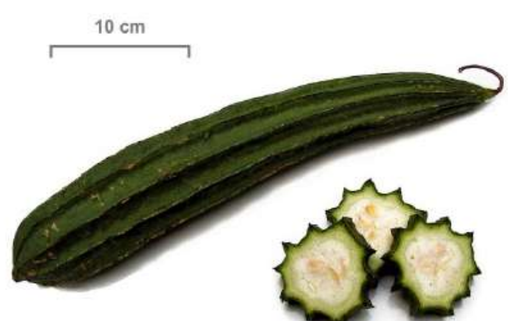
A type of pome originating from an inferior, syncarpous gynoecium, formed by three or five carpels. This fruit has a coriaceous covering, well-developed placentas extending to the carpel walls, and abundant seeds, e.g. *Cucurbitaceae* (*Cucurbita*, *Cucumis*, *Luffa*, etc.).






Cucurbita maxima

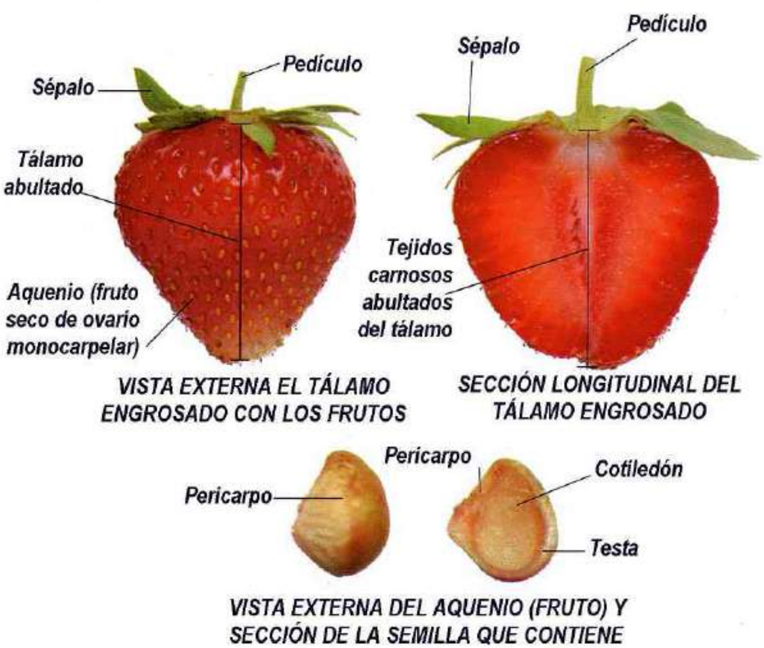

Cucumis melo



Luffa acutangula

Fruit types

4. Etaerio: this polyachene originated from a hypogynous flower (superior gynoecium) with a fleshy receptacle.



5. Cynarrhodium: this polyachene originated from a peryginous flower (mid-gynoecium) within a fleshy hypanthium, e.g. *Rosa*.

6. "*Trima*" (compound fruit)

A variety of drupe. This fruit derived from a monocarpellar or syncarpous multicarpellar (inferior or mid-) gynoecium, with a hypanthium, leathery or coriaceous exocarp and mesocarp split at maturity along more or less defined lines. Woody endocarp (sclerocarp), non-dehiscent, monospermous. *Rosaceae* (*Prunus dulcis*), *Juglandaceae* (*Carya*, *Juglans*).

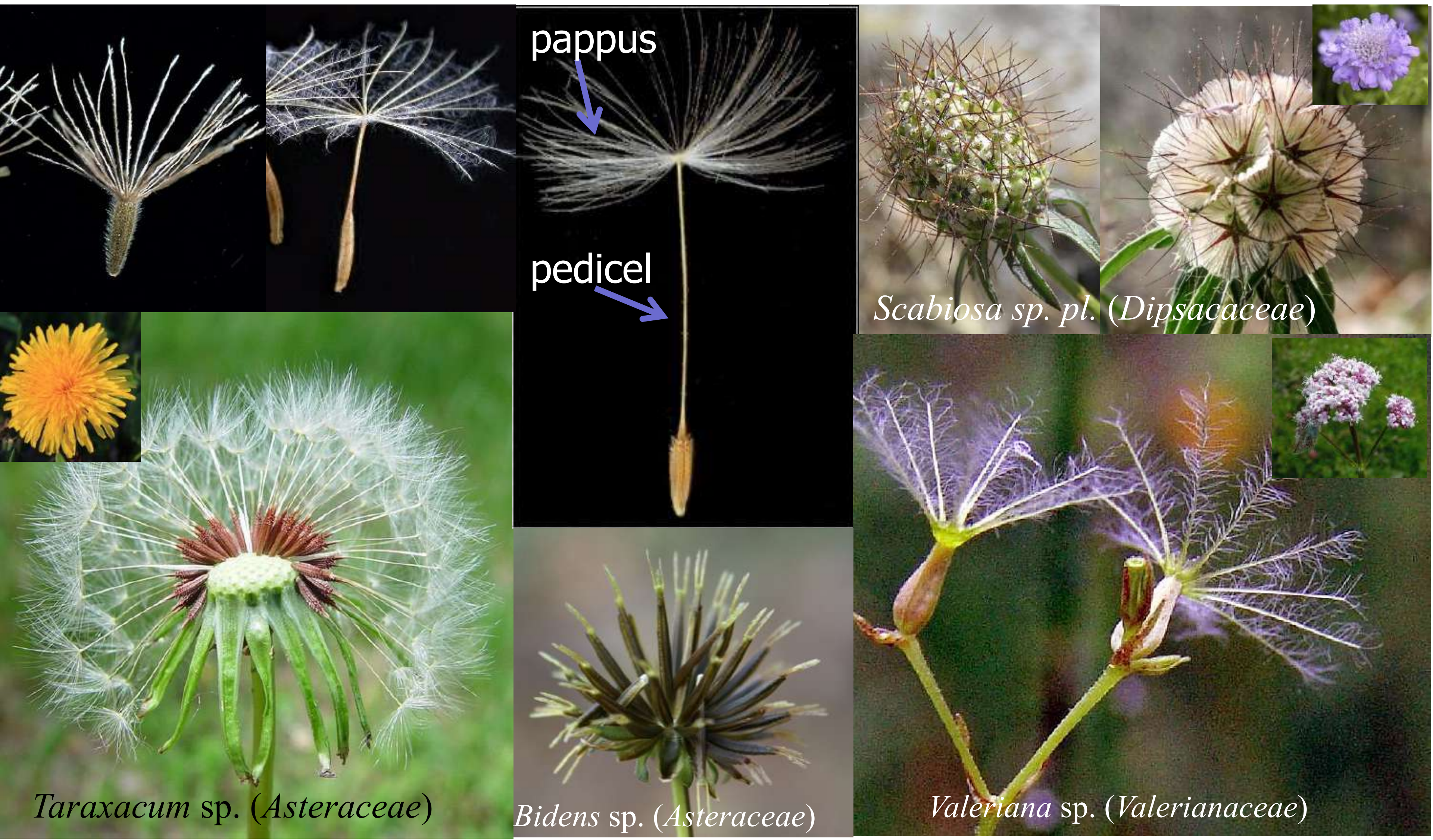
Prunus dulcis (almond tree)

Carya illinoinensis (pecan)

Juglans regia (walnut)

7. Cypsella (compound fruit)

A variety of achene (dry, monospermous and non-dehiscent) but originating from an inferior ovary, e.g. *Asteraceae*, *Dipsacaceae*, *Valerianaceae*.



Scabiosa sp. pl. (*Dipsacaceae*)

Taraxacum sp. (*Asteraceae*)

Bidens sp. (*Asteraceae*)

Valeriana sp. (*Valerianaceae*)

Infructescences

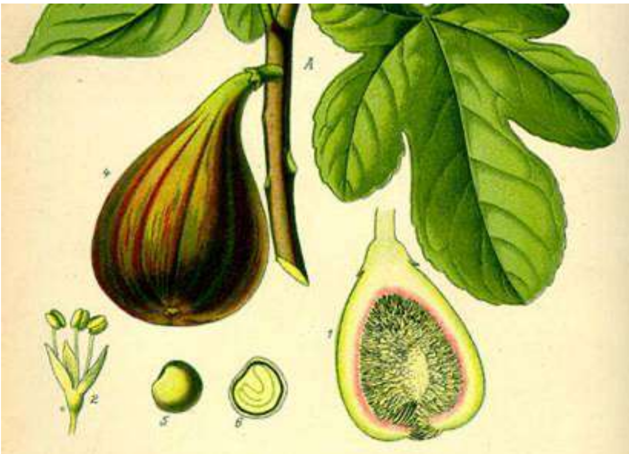
- Infructescences are groups of fruits that cluster and disperse together.
- Sorosis: on an elongated axis and with the fruits more or less fused but visible from the outside.
- E.g. *Morus*, *Ananas*, etc.


Ananas sp.

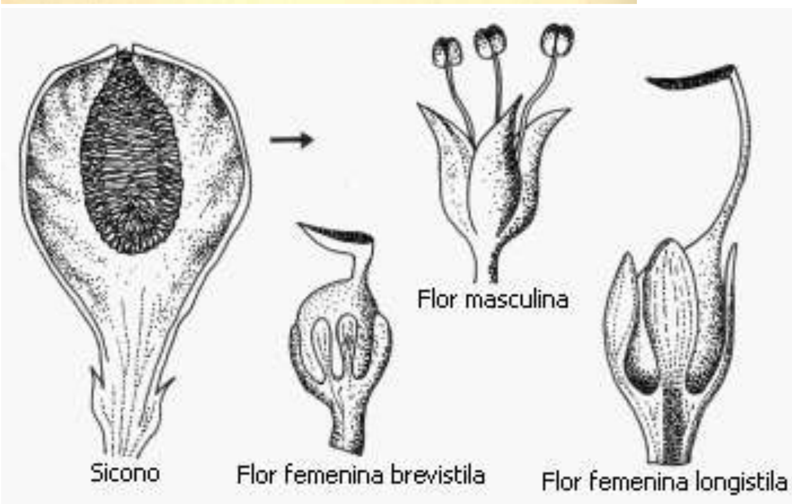
Morus nigra

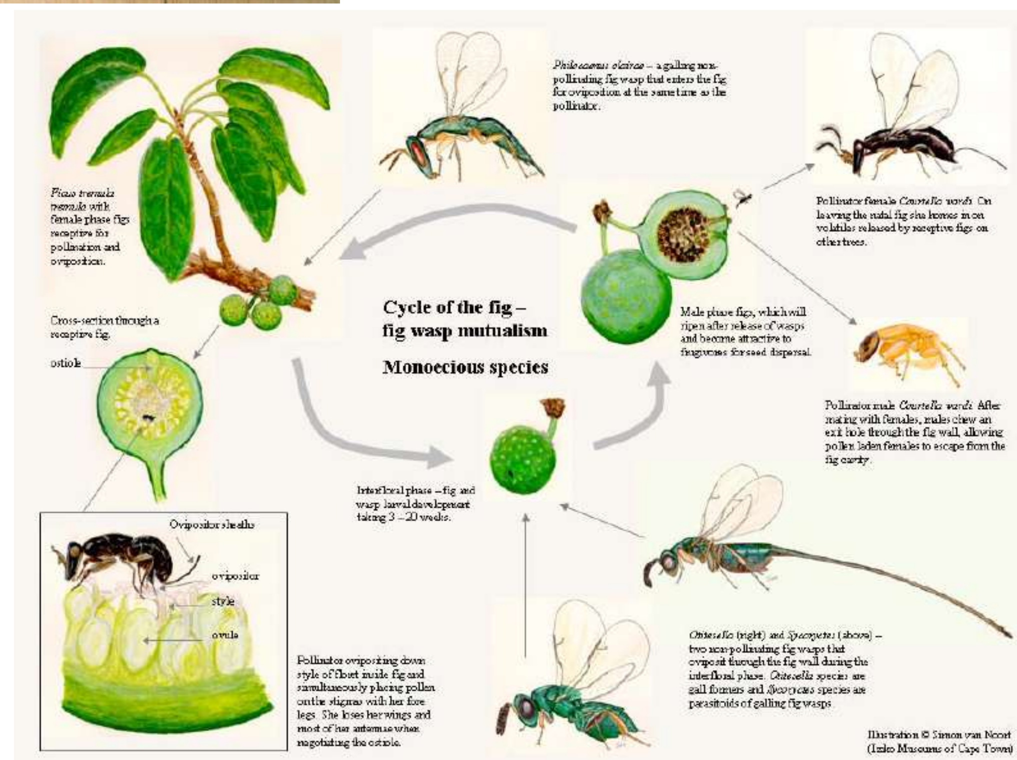
Infructescences

Syconium: fruits on a flattened or concave receptacle, often enclosed in a cavity connected to the outside by a semi-closed pore, e.g. *Ficus*.

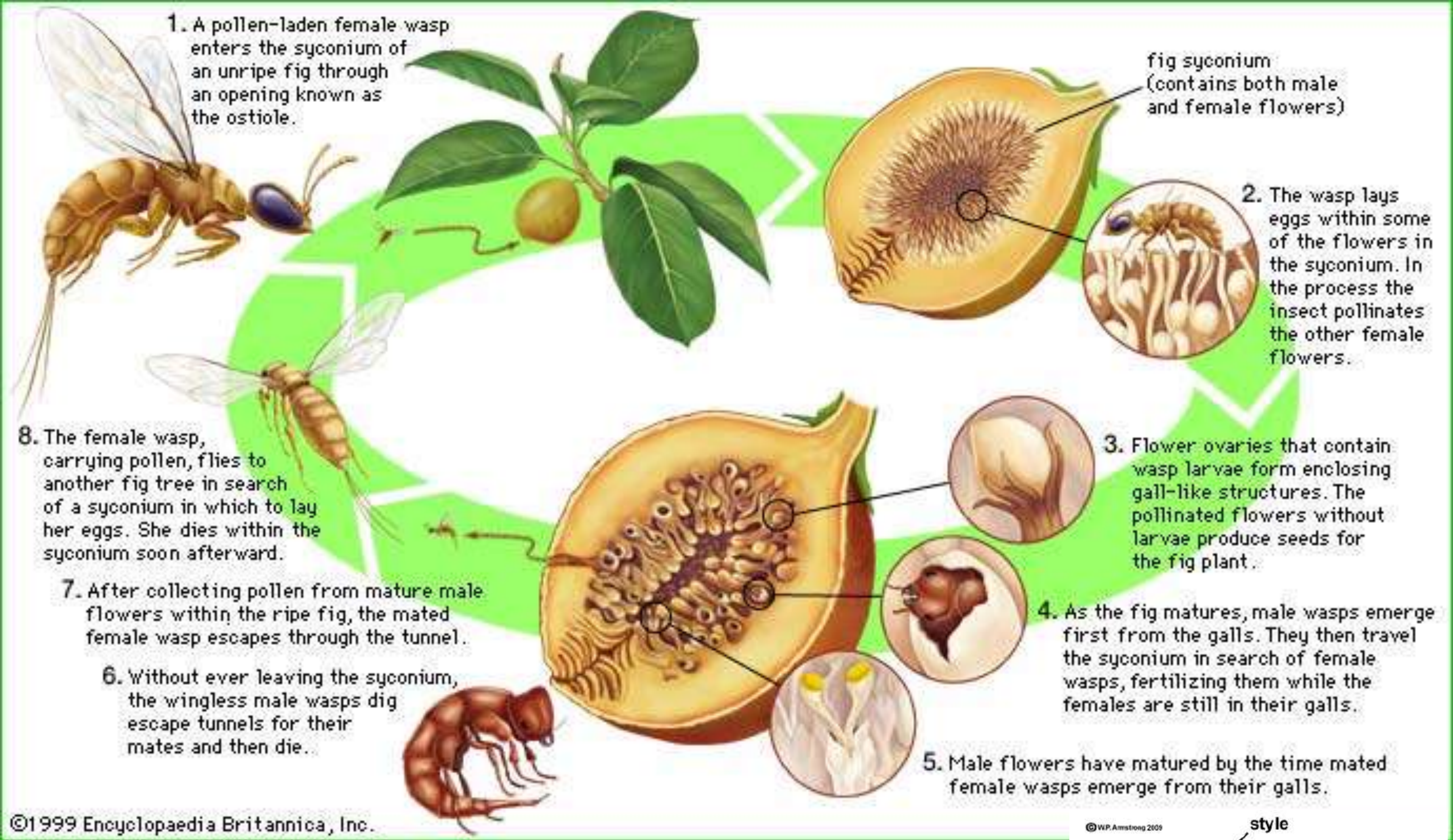


Ficus sp.

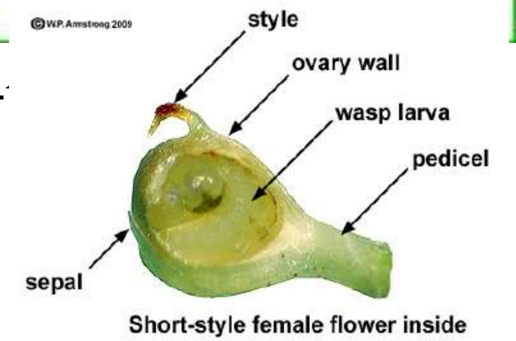




Ficus carica



http://www.britannica.com/EBchecked/media/19378/The-life-cycle-of-



Short-style female flower inside mamme syconium of a caprifig.

The seed

After fertilisation of the egg cell and polar nuclei, the seed primordium undergoes modifications that result in an increase in size and consistency; its teguments become a testa or episperm (protective components), and a nutritive endosperm (3n) and an embryo (2n) develop.

Its characteristics enable nutrition, protection, and enhancement of the dispersal of offspring.


Bixa orellana


Seed bank

The seed

Seed primordium → seed

Teguments → Teguments (testa and tegmen)

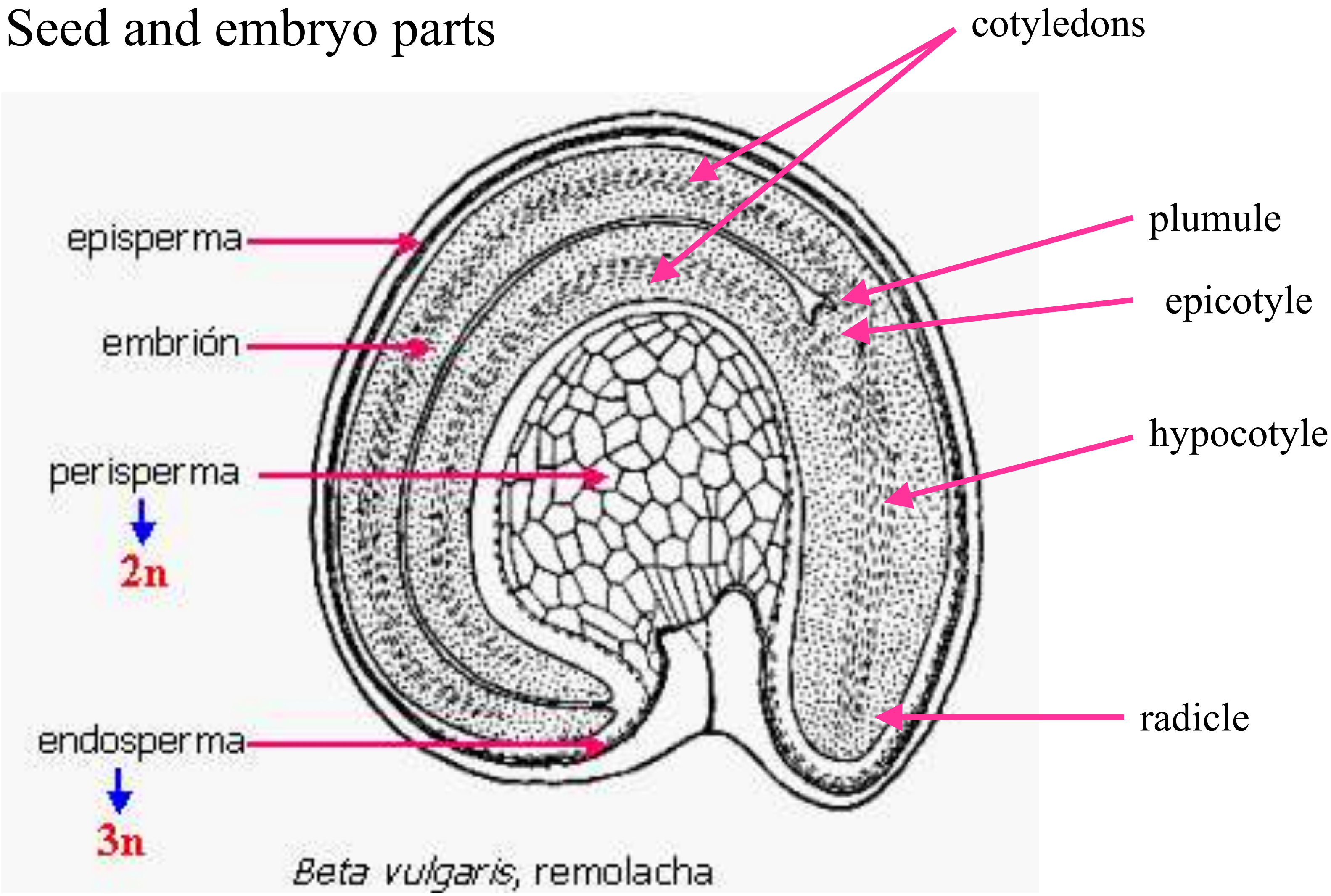
Nucellus → Perisperm (2n)
⇢ It is consumed

Zygote 2n → Embryo: plumule, cotyledons, epicotyle, hypocotyle and radicle

Zygote 3n → Secondary endosperm
⇢ It is consumed

The seed

Seed and embryo parts

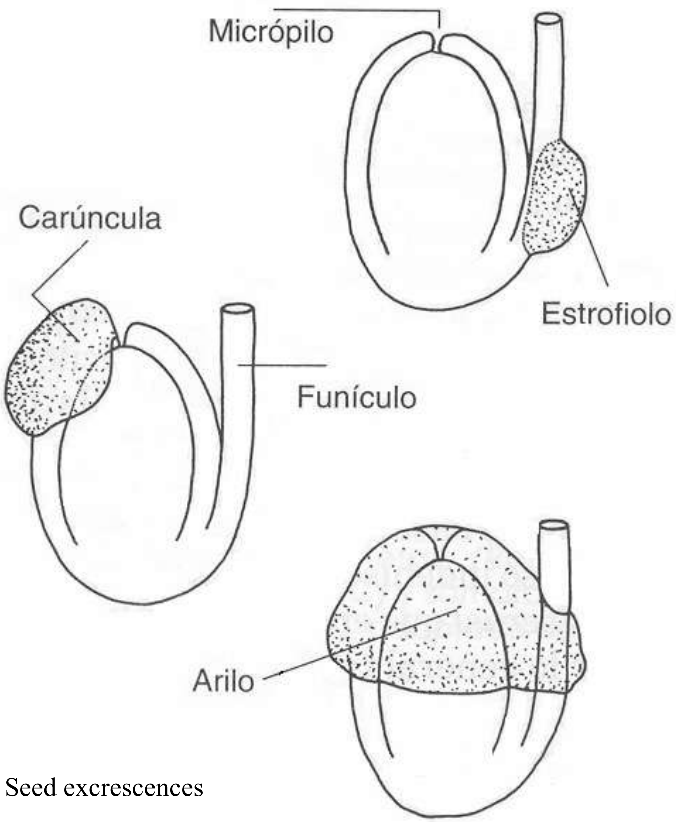


The testa (episperm)

- Woody: sclerotesta.
- Fleshy:
  - Sarcotesta (whole).
  - Aril (annular).
  - Caruncular (local, derives from the micropyle).

Caruncle in *Euphorbia* sp.

Aril in the seed of *Myristica fragrans,* the nutmeg.



Seed excrescences

Edible sarcotestas in the Asian rambutan (*Nephelium lappaceum*), litchi (*Litchi chinensis*) and pomegranate (*Punica granatum*)

Fruit and seed dispersal

When seeds are ripe, the plant's dispersal mechanisms begin.

The unit of dispersion is called the **diaspore**:
- This is a *seed* in dehiscent fruits.
- It is a *fruit fragment* if the fruit is fragmentable.
- It is a *whole fruit* if it is not dehiscent.
- Eventually, *infructescences* are involved, or plants are *"steppe runners"* ("estepicursores").

There are four basic mechanisms: autochory, hydrochory, anemochory and zoochory.

Typha sp.

Fruit and seed dispersal: steppe runners

The unit of dispersal or diaspora is the whole plant or a large part of it.

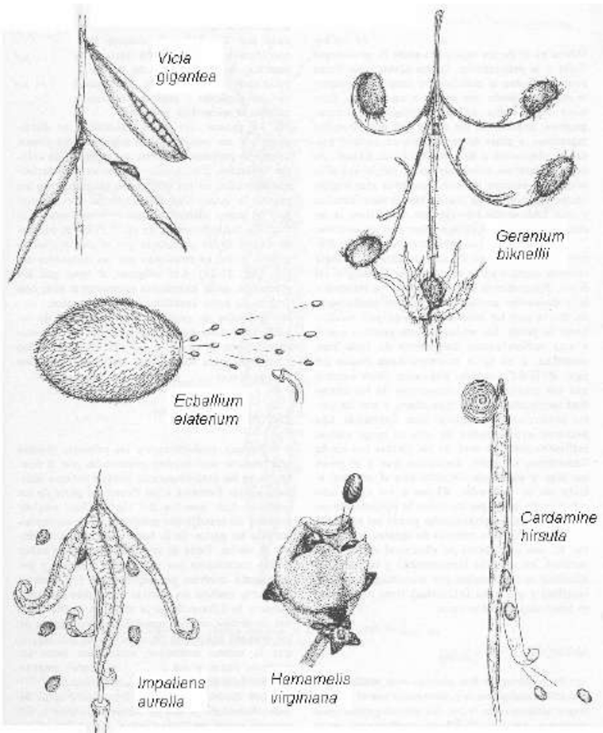
When the seeds mature, a plant with a spheroidal tendency dries out as a whole if it is an annual (*Salsola kali*) or just the aerial part does if it is a perennial (*Eryngium campestre*). It is then transported by the wind before gradually releasing its seeds.

Oenothera deltoides

Salsola kali

Eryngium campestre

Fruit and seed dispersal: autochory (fruits which, when ripe, eject their seeds some distance away)



Geranium sp.

Impatiens aurella

Ecballium elaterium

Fruit and seed dispersal: hydrochory

Freshwater, flowing or otherwise (*Carex*, *Juncus*).
Marine (*Cocos*, *Cakile*).
Impact of raindrops.


Carex vesicaria


Juncus acutus

Impact of raindrops


Mitella sp. (*Saxifragaceae*)



Cocos nucifera


Cakile maritima

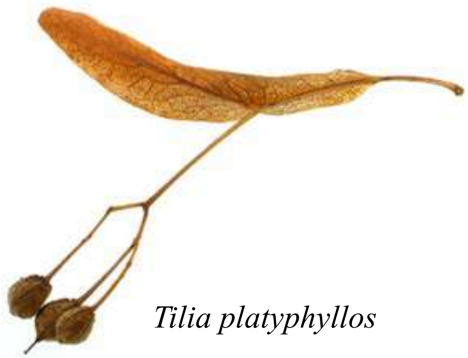
Fruit and seed dispersal: anemochory

- **Wind** is an important agent of dissemination.
- A wide range of adaptations exist in this respect involving an increase in surface area and a decrease in weight.
- Hairs (edges in grasses, pappus in *Compositae*).

Fruit and seed dispersal: anemochory (wings and other expansions: samaras, bracts)

Dipterocarpus indicus (*Dipterocarpaceae*)

Triplaris cumingiana (*Polygonaceae*)



Tilia platyphyllos

Taraxacum sp.

Ulmus minor

Acer sp.

Dioscorea sp. (seed)

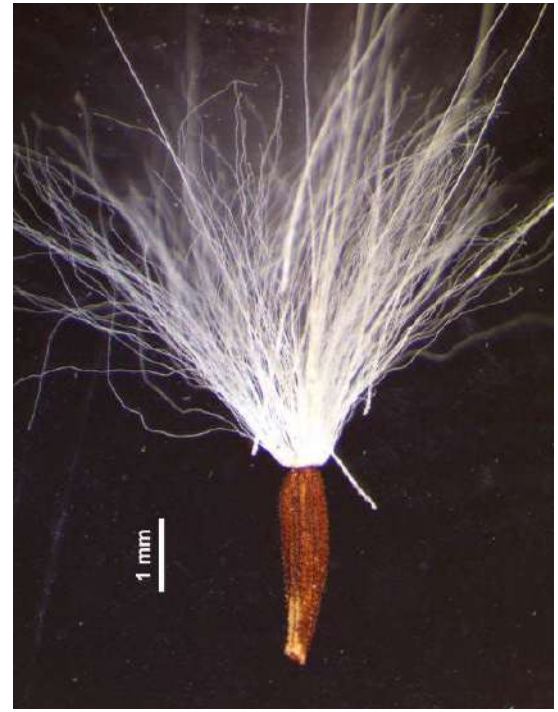
Catalpa sp. (seed)

Fraxinus sp.

Alsomitra macrocarpa (seed)

Airborne fruits and seeds


Sonchus tenerrimus: cypsella with pappus




Acer opalus: disamara


Ulmus minor: samara

Fruit and seed dispersal: zoochory (the active (endo-) or passive (exo-) involvement of animals)

1) Endozoochory

- The plant provides attractive diaspores for an animal to feed on or collect. For this purpose:

 * plants have attractive colours, smells and flavours, i.e. attractive devices.

Elephants feed on the fruit of the marula (*Slerocarya birrea*, *Anacardiaceae*) and the tree seedlings after passing the seeds through their digestive tract.

 * the seeds have protective structures, i.e. sclerocarp, sclerotesta.
 * germination-inhibiting substances are destroyed by passage through the digestive tract.
 * the seeds have coatings that soften in the digestive tract.
 * the seeds are expelled with excrement; therefore, they are prepared for germination and the seedling gets fertilised.

Fruit and seed dispersal: zoochory (ornithochory)

With their great mobility, birds are the ideal agents for dispersing seeds.
They mainly consume small berries and the light, showy fruits of trees and shrubs.


Coal tit (*Parus ater*)


Yellow-eared toucanet (*Selenidera spectabilis*)

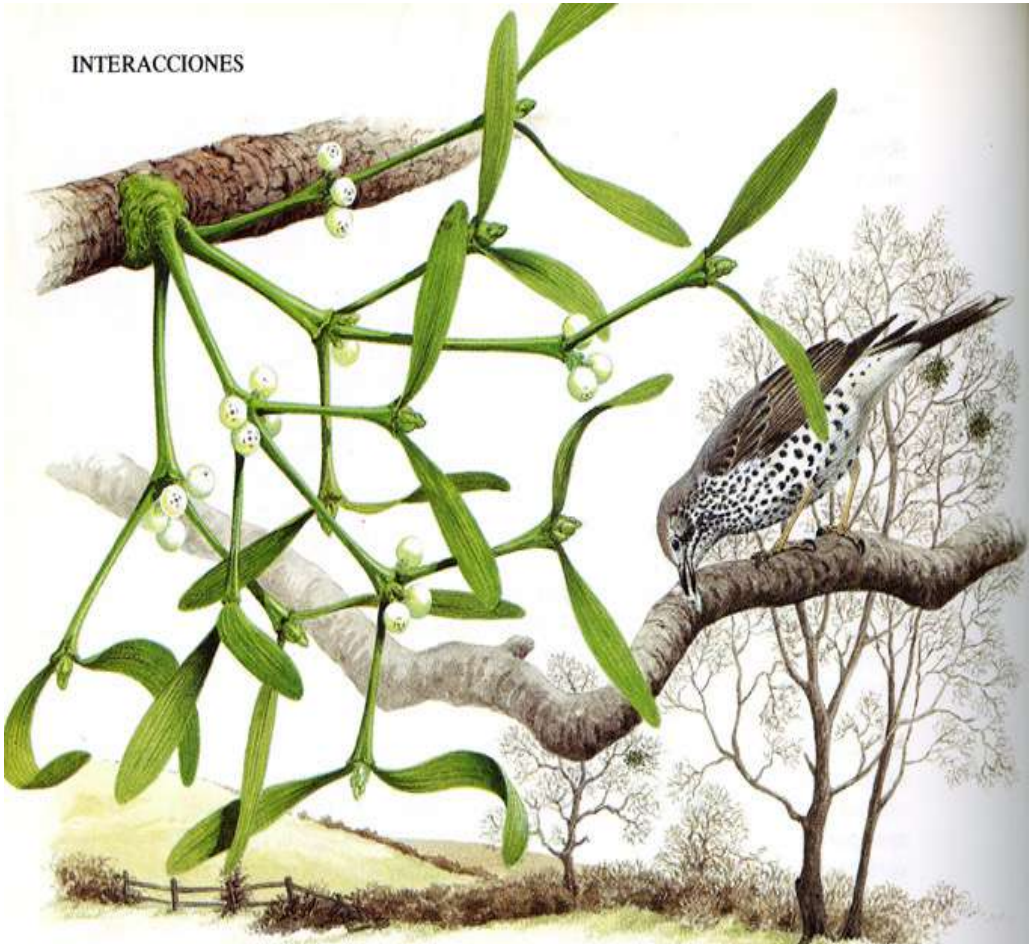

Redwing (*Turdus iliacus*)

Fruit and seed dispersal: zoochory (ornithochory)

The Eurasian jay (*Garrulus glandarius*) hides acorns for food, some of which survive.

Fruit and seed dispersal: zoochory (ornithochory)

A particular case is that of slimy seeds, which stick to the beaks of birds when they are eating their fruits (*Viscum*).



Turdus viscivorus come bayas de muérdago, luego se limpia su pico sobre una rama de árbol para eliminar el mucílago pegajoso de las bayas; algunas de las semillas germinarán en las grietas de la corteza y penetrarán en el tronco del árbol mediante una nueva raíz

The *Rosa* genus has a positive relationship with birds (i.e. they help in seed dispersal) whereas it shows obstacles for unwanted animals such as rodents.

Fruit and seed dispersal: zoochory (mammalichory)

- Mammals are essential for the dispersal of large or heavy fruits.
- Primates and bats predominate in tropical environments while rodents predominate in temperate environments.
- Other frugivores and omnivores take advantage of fruits and seeds that fall from trees or those available at low altitudes.

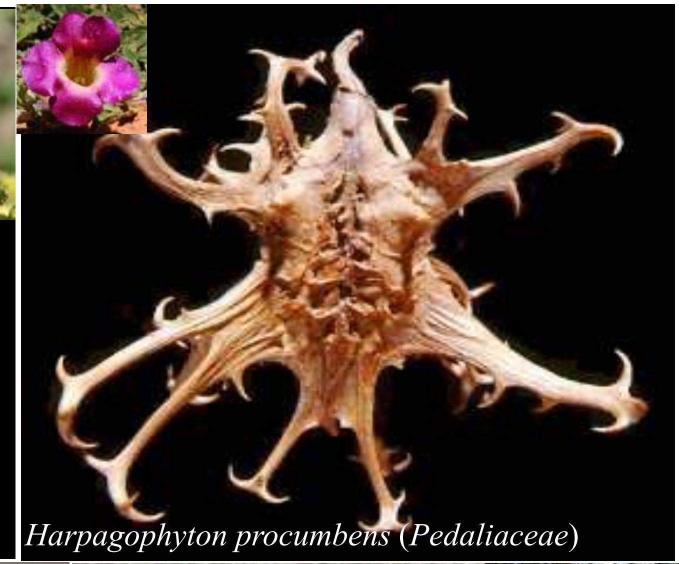
Fruit and seed dispersal: zoochory

2) Exozoochory

Exozoochory is the involuntary transportation of diaspores that adhere to or hook onto the skin, hairs, feathers or scales of animals. These diaspores have hooks, some of which are very fine, or harpoons (which are exceptionally large in the case of *Harpagophyton*).


Krameria bicolor (*Zygophyllaceae*)


Ambrosia ambrosioides (*Asteraceae*)


Harpagophyton procumbens (*Pedaliaceae*)


Proboscidea louisianica (*Martyniaceae*)


Cynoglossum officinale (*Boraginaceae*)

Lecture 12

Basal angiosperms

Photograph of *Aristolochia pistolochia* (Isaac Garrido)

Topics

The origin and success of angiosperms

The phylum *Magnoliophyta* and the basal angiosperms

ANA grade: diversity and uses for humans

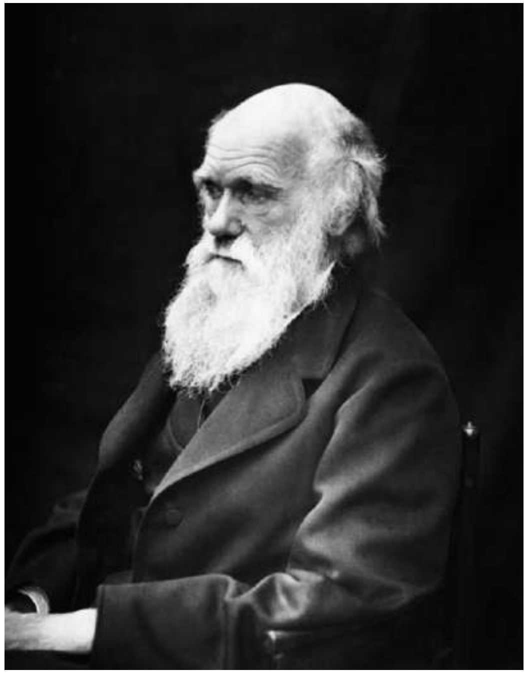
Magnoliids: diversity and uses for humans

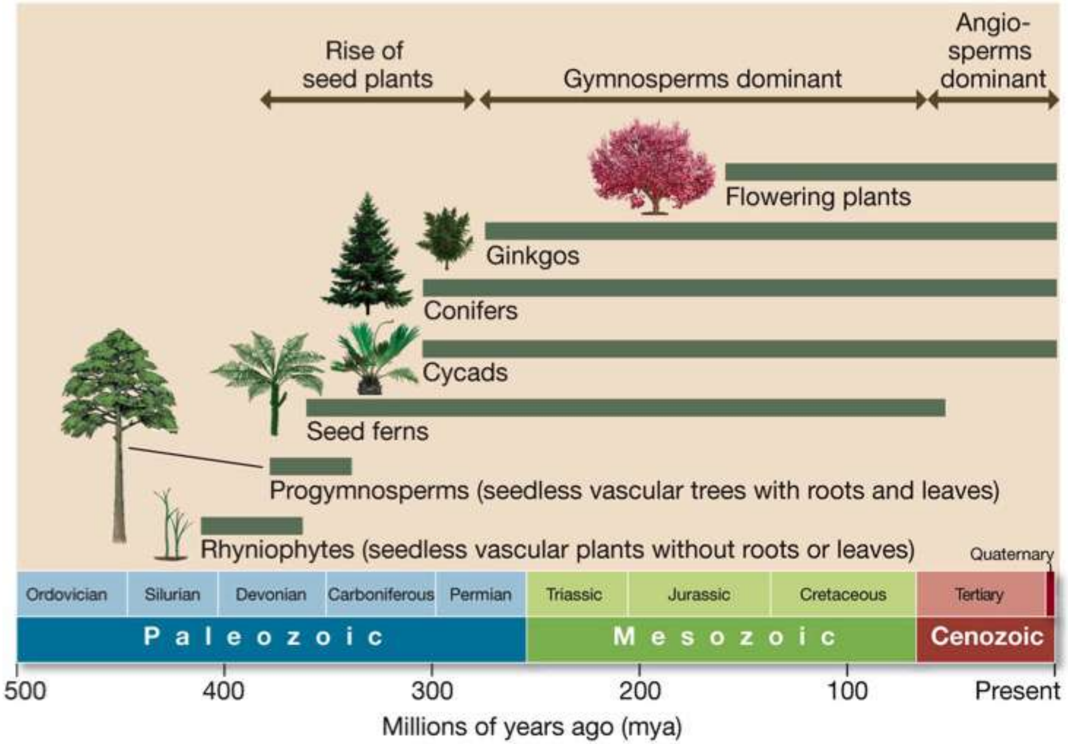
The origin of angiosperms

Flowering plants **appeared in the Jurassic** roughly 150 million years ago. There are **no fossils** that mark a **transition between gymnosperms and angiosperms**.

A possible relationship has been suggested with *Bennettitales*, a group of plants superficially similar to the *Cycadaceae* (though not related to them) with bisexual reproductive structures resembling flowers.

"The rapid development as far as we can judge of all the higher plants within recent geological times is an abominable mystery."
—Charles Darwin in a letter to Sir Joseph Hooker, 1879.
D.H. Scott (1911) The Evolution of Plants, p. 37.





LIFE 9e, Figure 29.1

At present the relationship remains unclear. The fossil record suggests that angiosperms expanded towards the end of the Cretaceous. **By roughly 75 million years ago, most of today's clades of flowering plants had already evolved.**

The first angiosperms

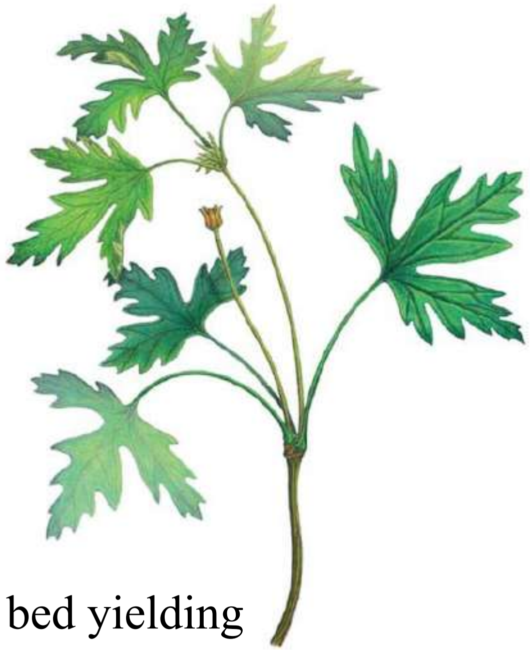
Archaefructus liaoningensis
127.4 M.a.

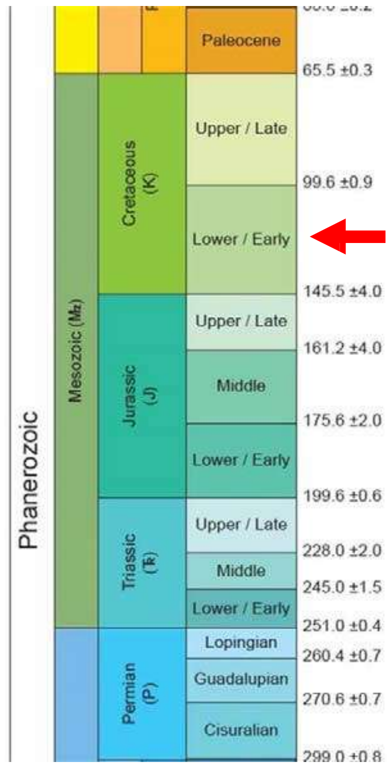
A: ***Archaefructus sinensis*** Sun, Dilcher, Ji et Nixon Whole specimen (holotype) (Photograph courtesy of David Dilcher).

125 M.a.

B: **Reconstruction** of ***Archaefructus sinensis*** showing terminal shoots. Diagram by K. Simons and D. Dilcher (Sun et al., 2002).

Reconstruction of ***Leefructus mirus*** Sun, Dilcher, Wang et Chen.



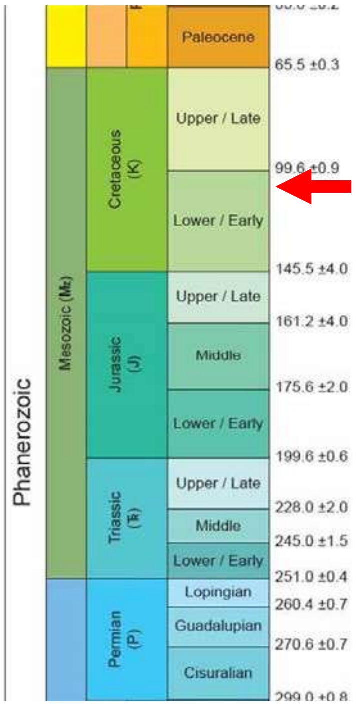


Lower Cretaceous. Yixian Formation dates the bed yielding this fossil as **122.6-125.8** million years old.

Sun *et al.* *Nature* **471**, 625-628 (2011) doi:10.1038/nature09811

The first angiosperms

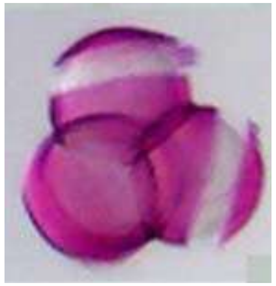
Archaeanthus linnenbergeri **100-125 M.a.**



Similar to extant *Magnolia*

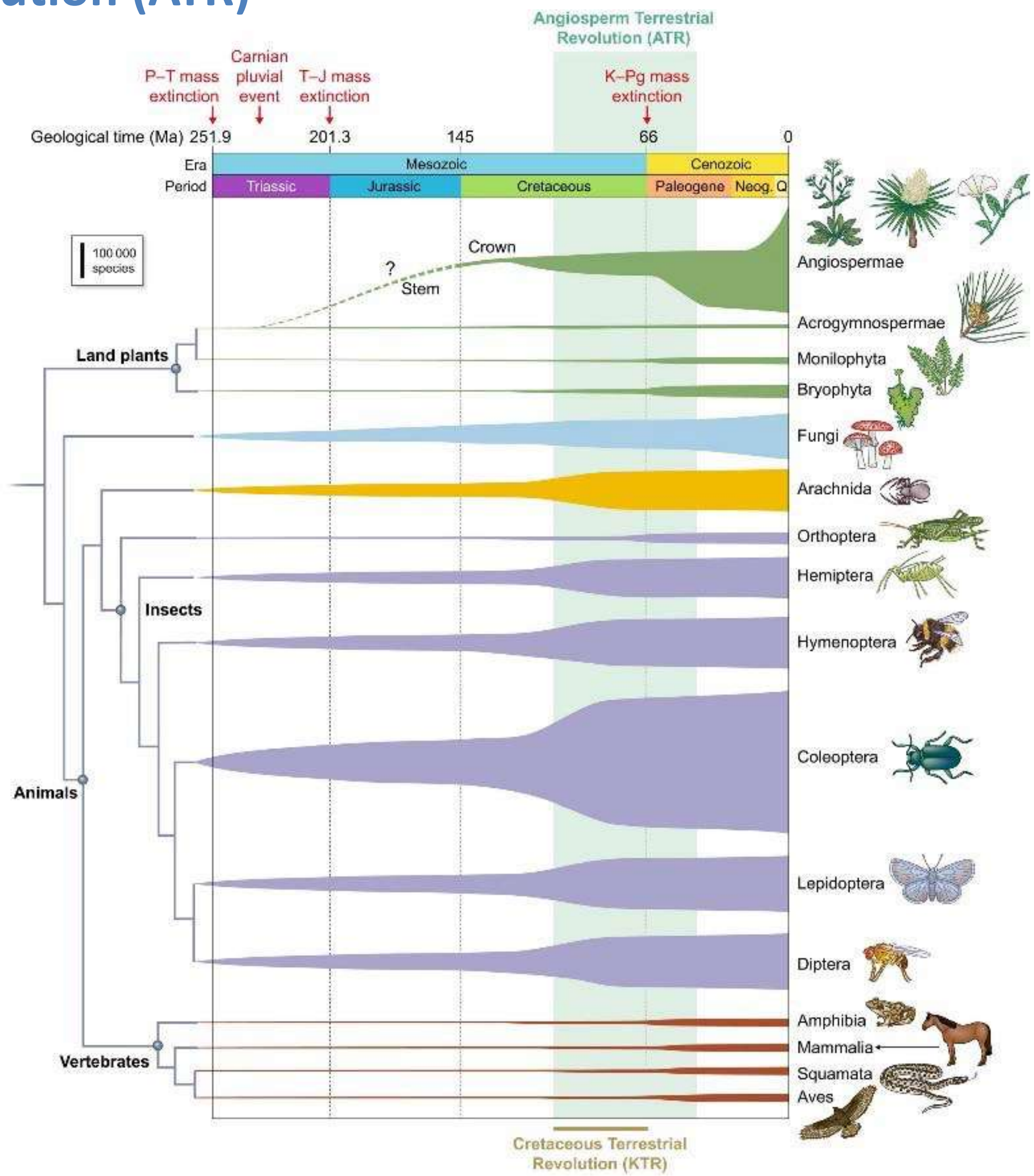
Floral traits

Ancestral traits	Derived traits
The number of perianth pieces is variable	The number of perianth pieces is constant
Flowers are acyclic (rarely cyclic)	Flowers are cyclic
When cyclic, flowers have 4 whorls	Cyclic flowers have 3, 2 or 1 whorl
Perianth is composed of tepals	Perianth is composed of calyx and corolla
The anthers and filaments of stamens are not clearly differentiated	The anthers and filaments of stamens are clearly differentiated
Monosulcate pollen	Pollen with other types of openings and in large number
Superior ovary. Style is not very different from the ovary	Inferior ovary. Style is different from the ovary
Actinomorphic flowers	Zygomorphic flowers
Free pieces (not fused)	Fused pieces



The Angiosperm Terrestrial Revolution (ATR)

Many of today's most diverse organisms, including angiosperms, spiders, arthropods (bugs, beetles, bees, wasps, butterflies, moths and flies) and vertebrates (lizards, birds and mammals) have their origins in the early Mesozoic but diversified in the Cretaceous and Paleogene, apparently **driven by the Angiosperm Terrestrial Revolution (ATR)**. The diagram on the right shows recent diversity (species richness) on the right axis.

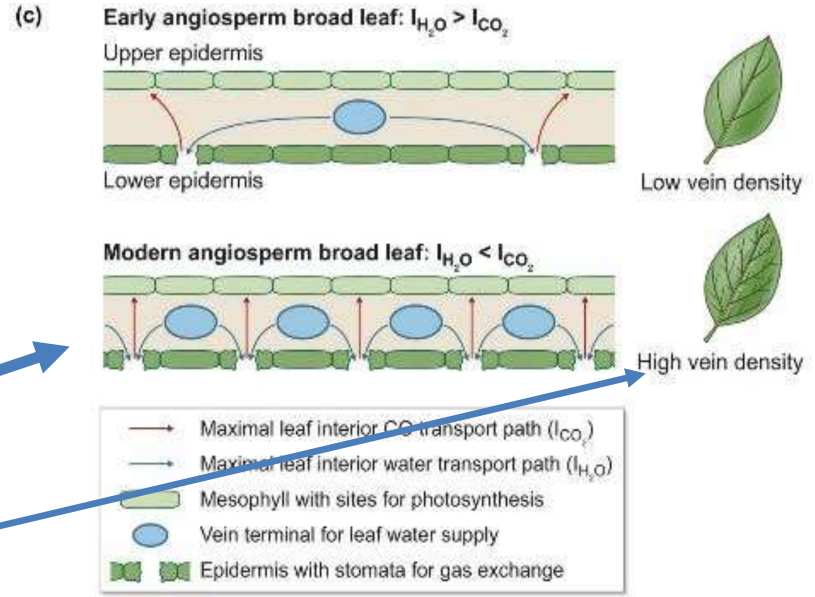


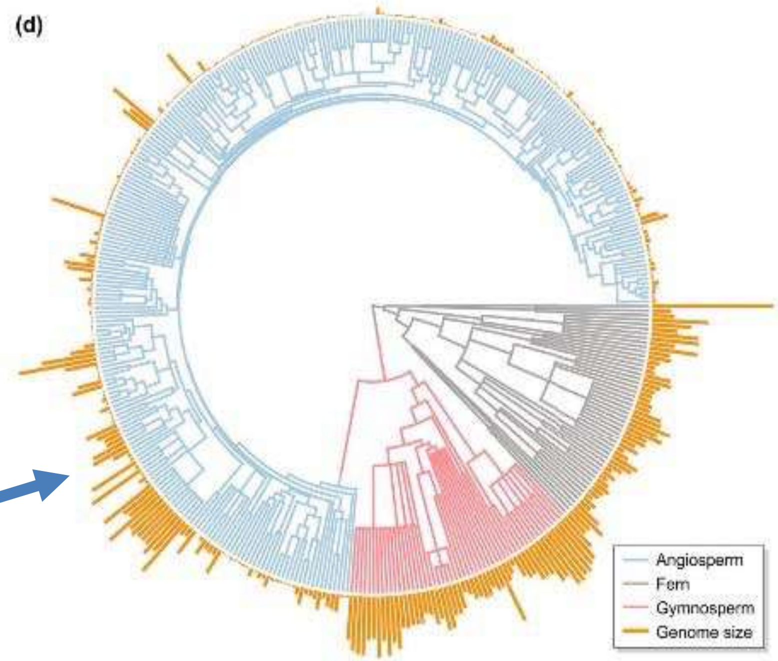
Benton et al. (2021, New Phytologist
https://nph.onlinelibrary.wiley.com/doi/epdf/10.1111/nph.17822

Key characteristics responsible for the success of angiosperms

Vegetative innovations

1. Resistance to drought and low temperatures due to the plasticity of the vegetative apparatus.
2. Xylem with conducting vessels, efficiently conducting tracheae.
3. **Stomata density** 10 times **higher** and higher photosynthetic efficiency.
4. **Leaves with denser venation** (10 times greater than in gymnosperms).
5. Hardened leaves. **Possibility of deciduous leaves**.
6. Herbaceous and annual species.
7. **Secondary metabolites**: chemical defence against fungal diseases and herbivores.
8. Plant phylogeny: angiosperms (blue, figure d on the right) show **lower genome sizes** (orange bars), which correlates (graphs) with higher stomata density and venation, and higher photosynthetic efficiency.



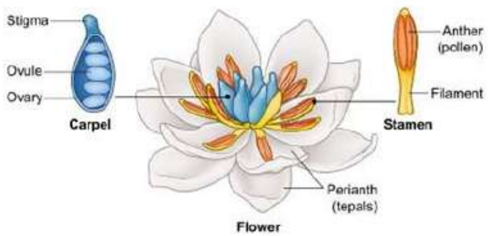


Benton et al. (2021, New Phytologist
https://nph.onlinelibrary.wiley.com/doi/epdf/10.1111/nph.17822

Key characteristics responsible for the success of angiosperms

Reproductive innovations

1. Plants and insects have co-evolved. Efficient **zoophilic pollination systems** and seed and fruit dispersal.
2. **Seed and fruit dispersal by animals** favours animal diversification.
3. Plants with brightly coloured flowers and pollen and nectar production had an advantage since they were more visited by insects, leading to a greater possibility of pollination and greater seed production.
4. **Hermaphrodite (bisexual) flowers make pollinator visits more effective**.
5. Extreme protection of the haploid phase and neoteny or reproduction in juvenile stages.
6. Rapid shortening of the life cycle.
7. **Double fertilisation** with the production of endosperm and embryo nutrition.



Angraecum sesquipedale **and its pollinator: *Xanthopan morganii*.**

Topics

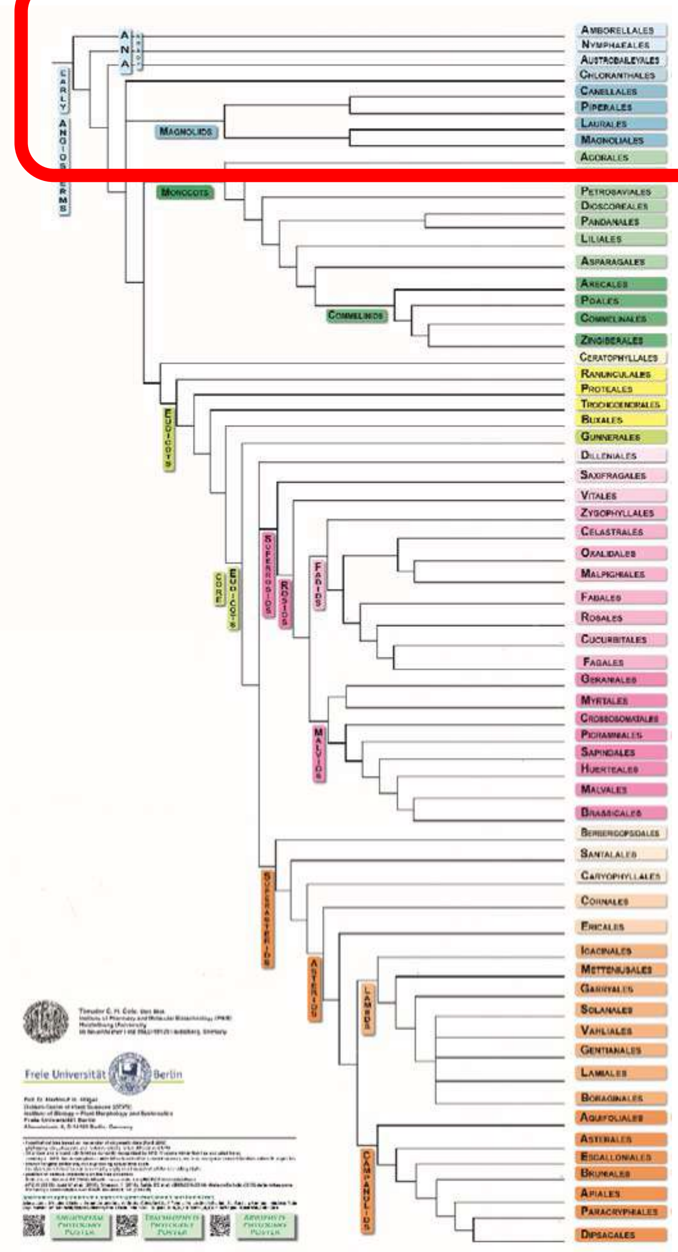
The origin and success of angiosperms

The phylum *Magnoliophyta* and the basal angiosperms

ANA grade: diversity and uses for humans

Magnoliids: diversity and uses for humans

Phylum *Magnoliophyta*



Cole *et al.* (2019)

Basal angiosperms

The **ANA** grade

Magnoliids

Monocots

Basal Eudicots

Rosids

Asterids

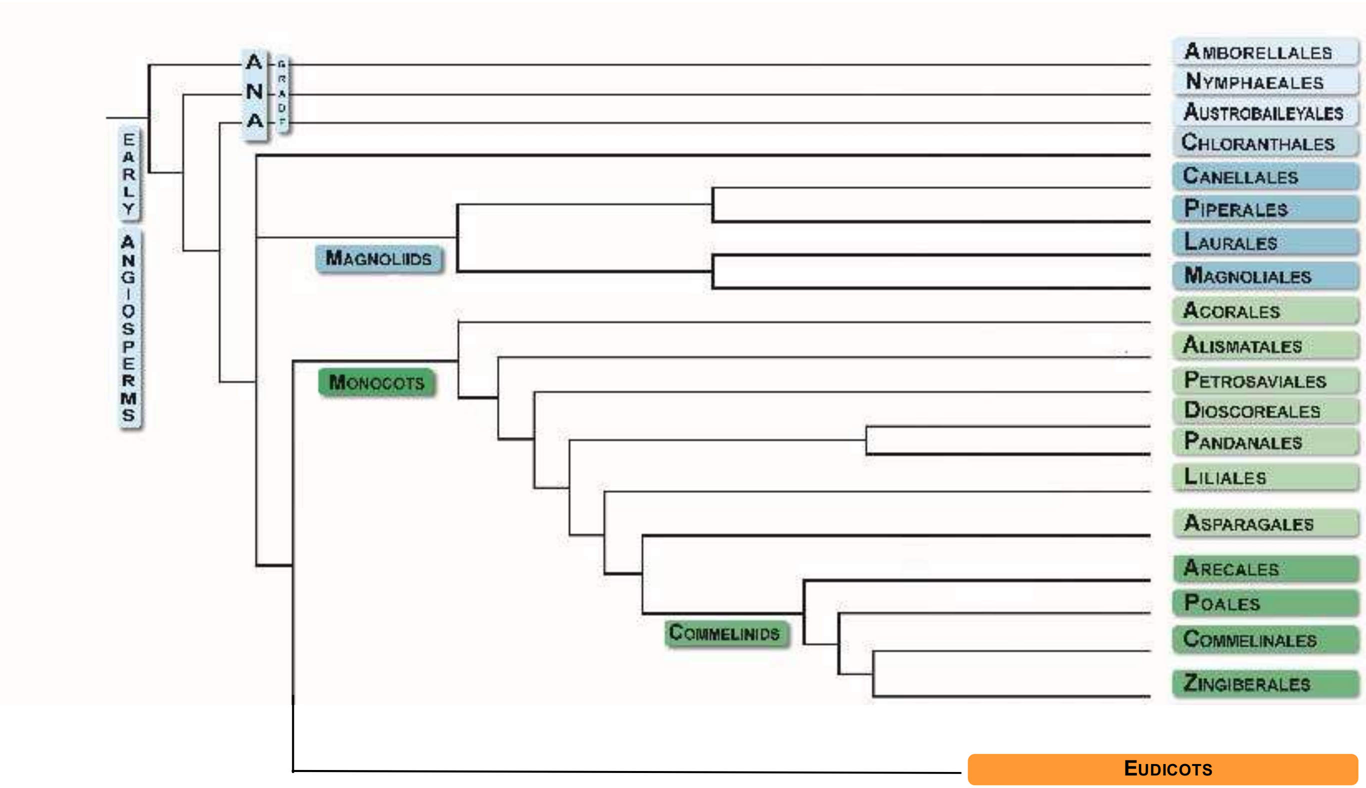
Main corpus of Eudicots

Angiosperms: 64 orders and 420 families

The systematics of angiosperms has been subject to numerous changes in recent years thanks to molecular phylogenetics and phylogenomics.

(See APG IV. https://www.mobot.org/MOBOT/research/APweb/)

Basal angiosperms: ANA grade and Magnoliids



The **ANA** grade

Magnoliids

Magnoliales

Laurales

The term "ANA grade" is used to refer collectively to the three basally-diverging groups of angiosperms: ***Amborellales*** **(A),** ***Nymphaeales*** **(N), and** ***Austrobaileyales*** **(A)**.

Amborellales

Nymphaeales

Austrobaileyales

Canellales

Piperales

Topics

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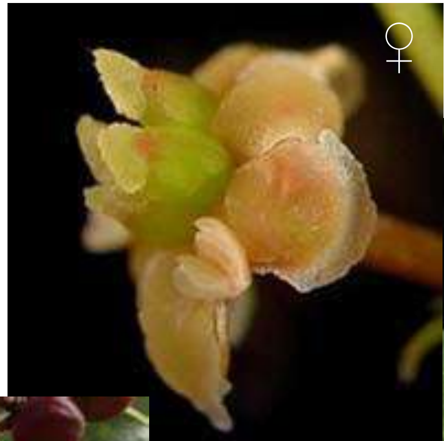
ANA grade: diversity and uses for humans

Magnoliids: diversity and uses for humans

The ANA grade: order *Amborellales*

-Monotypic.
-Small shrubs.
-Xylem with tracheids.
-Dioecious.
-Flowers acyclic, sepaloid perianth.
-Lamellar stamens.
-Carpels not totally closed, with stigmatic crest.
-Embryo sac with 9 nuclei.
-Fruit in drupe.
-Seed with immature embryo during dispersal.
-New Caledonia.

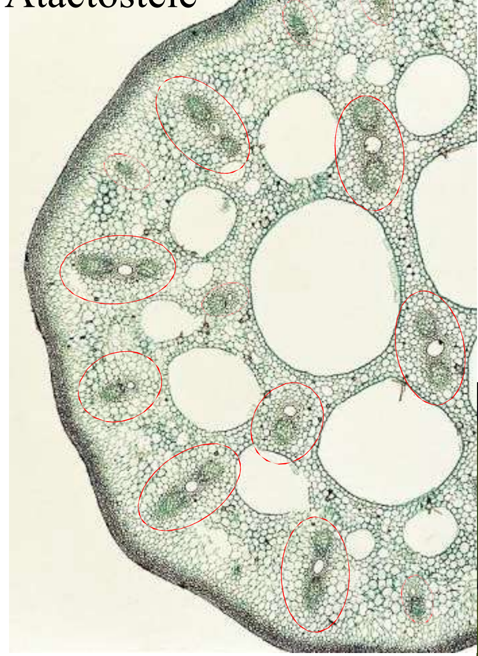
Amborella trichopoda



The ANA grade: order *Nymphaeales*

-Three families.
-**Aquatic, herbaceous plants**.
-Xylem not highly developed, with tracheids.
-**Atactostele** in stem.
-**Cyclic flowers, with progressive differentiation of perianth pieces**.
-**Embryo sac with 4 nuclei**.
-Operculate seeds, with perisperm.
-Embryo not highly developed.
-No oil cells.
-**Presence of benzylisoquinoline alkaloids**.
-Subcosmopolitan

Atactostele



Worldwide distribution of *Nymphaeaceae*

Nymphaea alba

Nuphar lutea

Victoria regia

The *Nymphaeales* are an early group traditionally named "**paleoherbs**". One line of evidence to support this is that they carry a mix of traits normally not found together in the same plant. Specifically, **they have traits of both monocots and dicots**, the two groups into which flowering plants can be divided.

The ANA grade: order *Austrobaileyales*, family *Schisandraceae*

- The genus *Illicium* is made up of shrubs with coriaceous leaves and flowers with numerous pieces.
- Found within the group is **star anise** (*Illicium verum*), whose fruits contain **essential oils** (e.g. **anethole – anise flavour**) used to flavour food and wine. Its fruit is a traditional Chinese medicine called *pa-chio-hui-hsiang*, which is used to **treat abdominal pain and vomiting**.
- Although essential oils of several species are used as flavouring and carminatives, the oils of *I. anisatum* and *I. floridanum* are toxic (e.g., **shikimitoxin**).

Worldwide distribution of the genus *Illicium*

Polyfollicles of *I. verum*

Illicium verum (star anise)

Illicium anisatum

Topics

The origin and success of angiosperms

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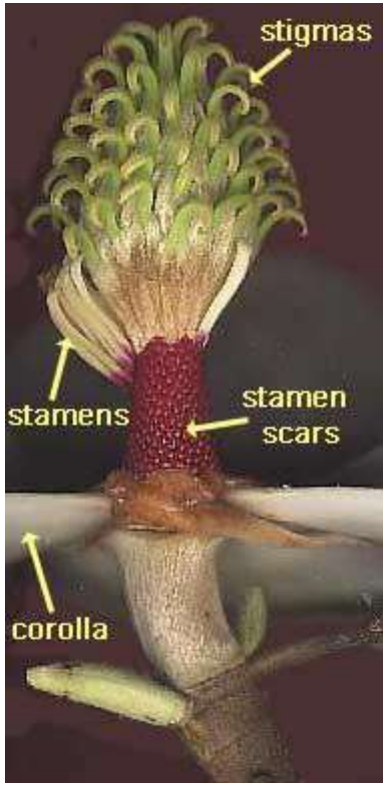
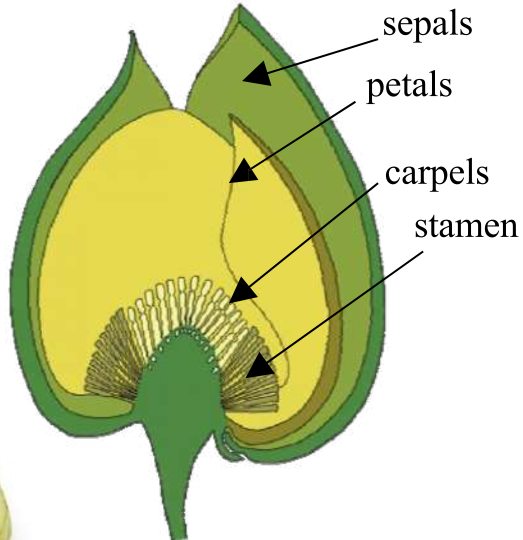
ANA grade: diversity and uses for humans

Magnoliids: diversity and uses for humans

Magnoliids (subclass *Magnoliidae*)

- A small group of plants with **primitive characters**: **woody** (*Magnoliales*, *Laurales*, *Canellales*) or **lianas** (*Piperales*).
- **Plants with aromatic essences** and **benzylisoquinoline alkaloids**, many known as spices (*Piperales*, *Canellales*, *Laurales*), from tropical or subtropical areas.
- **Acyclic** or **cyclic flowers**.
- **Embryo sac with 8 nuclei**.





Examples of *Magnoliales*

Nutmeg, ***Myristica fragrans*** (*Myristicaceae*)

Nutmeg is a well-known aromatic perennial plant with a characteristic scent that possesses multiple medicinal applications and is used **to treat stomach ulcers, indigestion and liver disorders and as an emmenagogue, nervine, diuretic, diaphoretic, and aphrodisiac**.

Cherimoya (***Annona cherimola***, *Annonaceae*)

Magnoliids (subclass *Magnoliidae*)

Examples of ***Magnoliales***

Liriodendron tulipifera. The intensely acrid bitter inner bark, especially of the roots, is used domestically as a diuretic, tonic and stimulant. The raw green bark is also chewed as an aphrodisiac. The bark contains 'tulipiferine', which is said to exert powerful effects on the heart and nervous system. **A tea is used to treat ailments such as indigestion, dysentery, rheumatism, coughs and fevers**. Externally, the tea is used as a wash and poultice for wounds and boils (https://pfaf.org/).

Magnoliids (subclass *Magnoliidae*)

Examples of ***Laurales***

Other species of interest are the camphor tree ***Cinnamomumn canfora*** – from which camphor is obtained – and the cinnamon tree ***C. zeylanicum***, whose bark supplies cinnamon.

Magnoliids (subclass *Magnoliidae*)

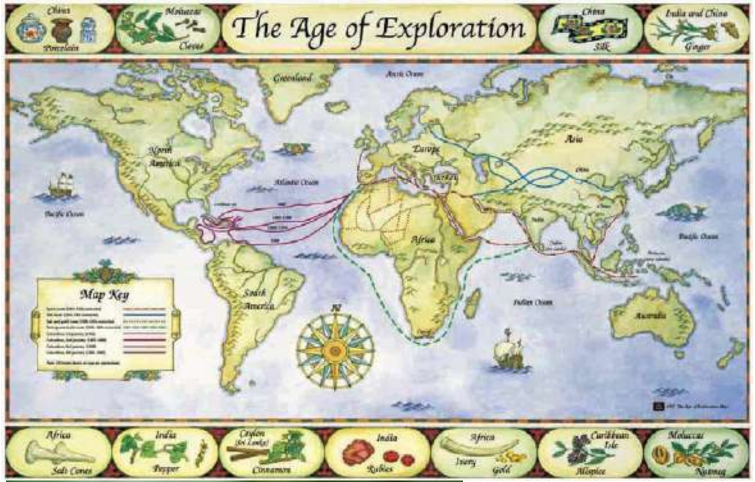
Examples of ***Laurales***

Peumus boldus (*Monimiaceae*). Native of Chile. Boldo is used to treat mild gastrointestinal (GI) spasms, gallstones, achy joints (rheumatism), bladder infections, liver disease, and gonorrhoea. It is also used to increase urine flow to rid the body of excess fluids, reduce anxiety, increase bile flow, and kill bacteria.

Magnoliids (subclass *Magnoliidae*)

Examples of ***Piperales***

Herbaceous plants forming the “paleoherbs core” and closely related to Monocots. Tropics.



Piper nigrum

Piper longum

Piper cubeba

Piper nigrum

Piper longum

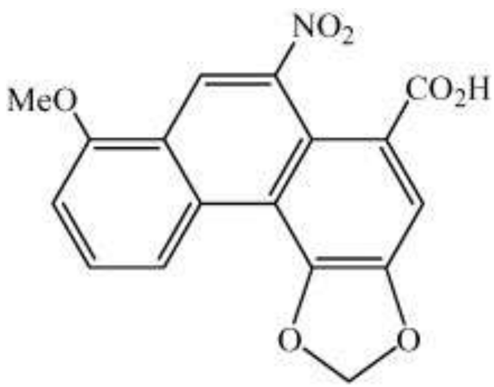
Piper cubeba

Examples of ***Piperales***

Piper nigrum (black pepper, *Piperaceae*) is a flowering plant belonging to the *Piperaceae* family. It is cultivated to obtain fruits, which are then dried and used as a spice and for seasoning. It grows in southern parts of India and other tropical regions. Dried pepper has been used extensively for its flavouring properties as well as in traditional medicine. The active constituent present in *P. nigrum* is **piperine**. Other phytochemicals present are amides, piperidine, pyrrolidines, and trace amounts of safrole. Piperine has been used as a natural bioenhancer with other drugs to potentiate their therapeutic effects. Its bioenhancer effect has been shown by action on a metabolizing enzyme, enhancing drug transport, affecting blood supply to the gastrointestinal tract (GIT), and/or membrane fluidity (Sharif et al. 2018).

Magnoliids (subclass *Magnoliidae*)

Species of ***Aristolochia*** (*Aristolochiaceae*) have often been reported as important medicinal plants in ethnobotanical studies. In Europe, species of *Aristolochia* were already **mentioned by the Greek scholar Dioscorides. Aristolochic acid** and extracts obtained from European snakeroot (*Aristolochia clematitis* L.) were formerly licensed for use against abscesses, eczemas and other long-lasting skin diseases and as a non-specific stimulant of the immune system. However, in 1982 they were withdrawn due to suspected carcinogenic effects (Heinrich et al. 2009)



(1) Aristolochic Acid I

Examples of ***Piperales***

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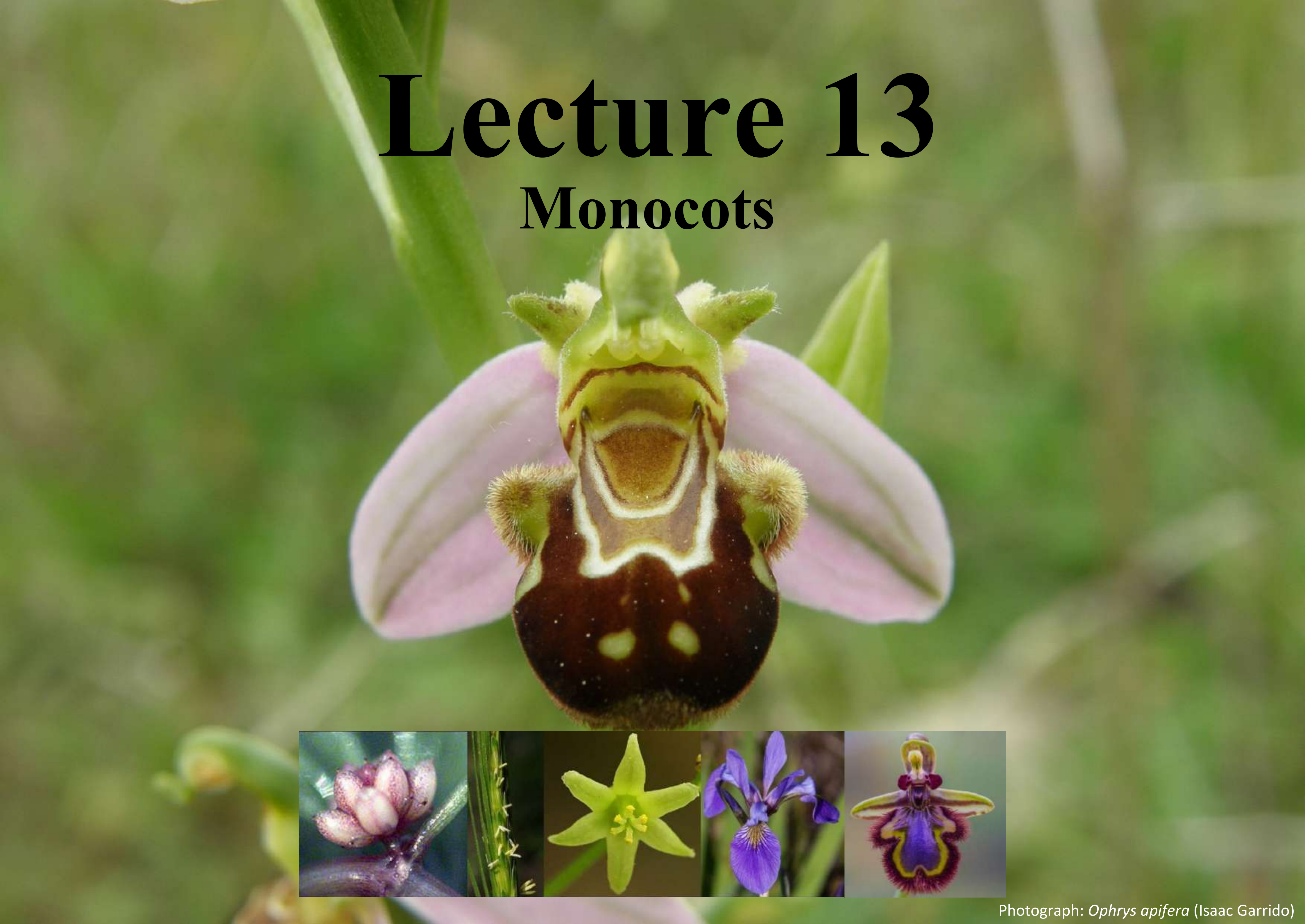
Lecture 13

Monocots



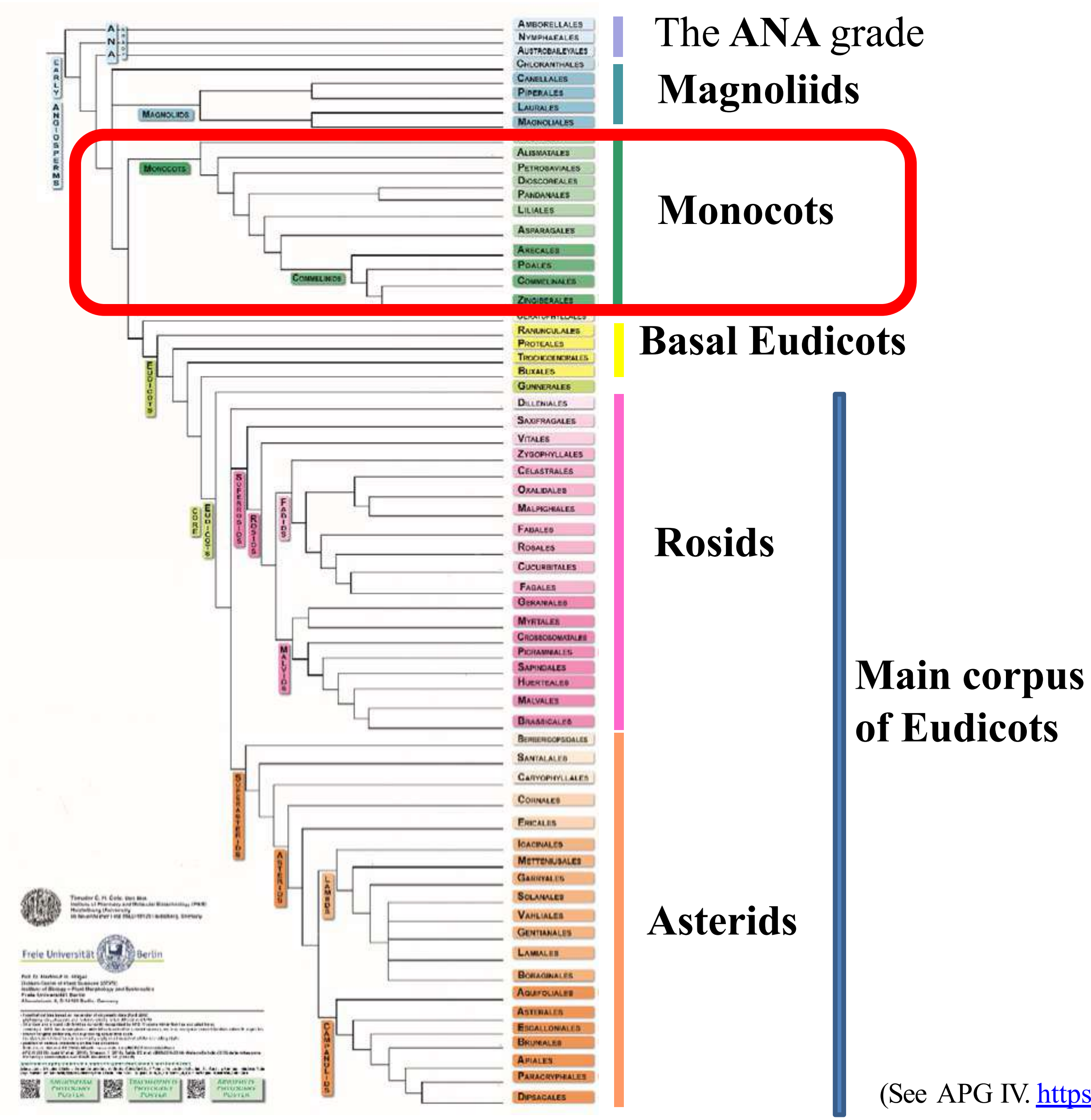
Photograph: *Ophrys apifera* (Isaac Garrido)

Topics

Main traits of Monocots

Monocot diversity and uses for humans

Phylum *Magnoliophyta*



Cole *et al.* (2019)

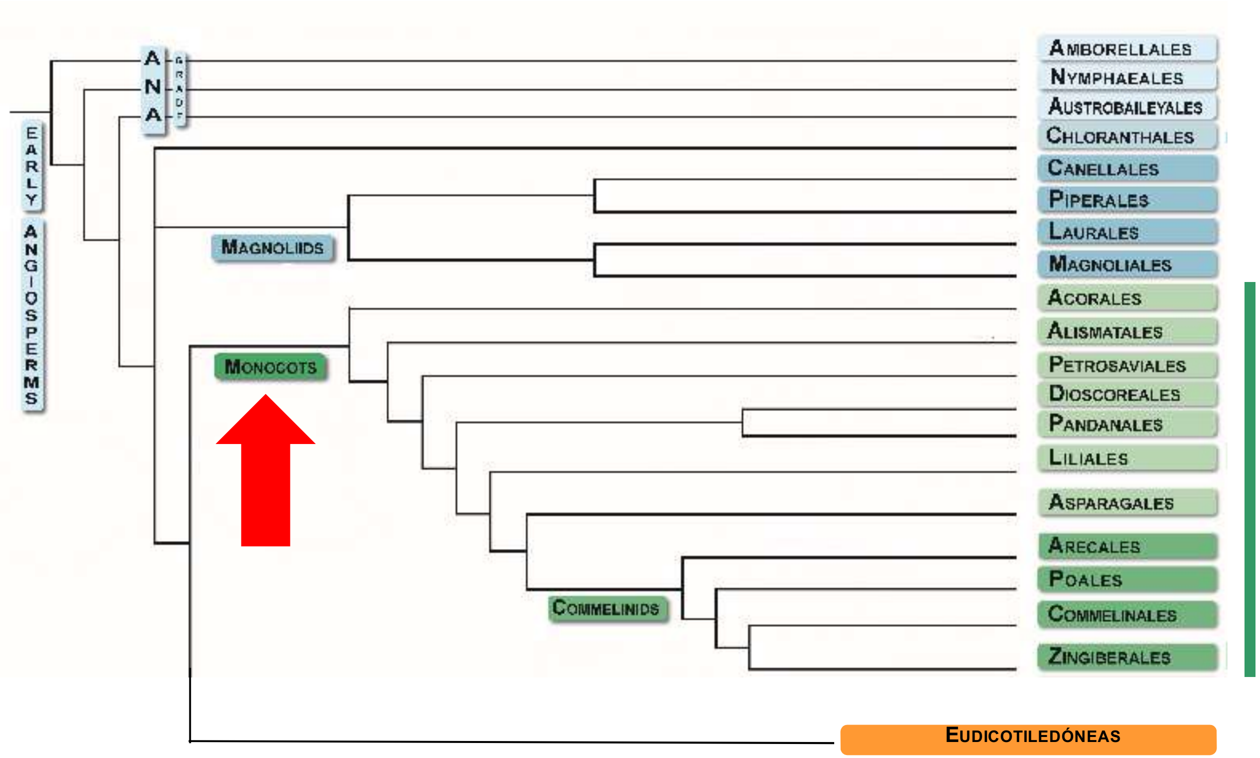
Based on this phylogeny by Cole et al. (2019), Monocots form a monophyletic sister group to Basal Eudicots+Eudicots (Rosids and Asterids)

(See APG IV. https://www.mobot.org/MOBOT/research/APweb/)

Monocots (class *Liliopsida*)

(= class *Monocotyledoneae*)

11 orders



Zingiberales

Poales

Asparagales

Commelinales

Arecales

Acorales

Alismatales

Petrosaviales

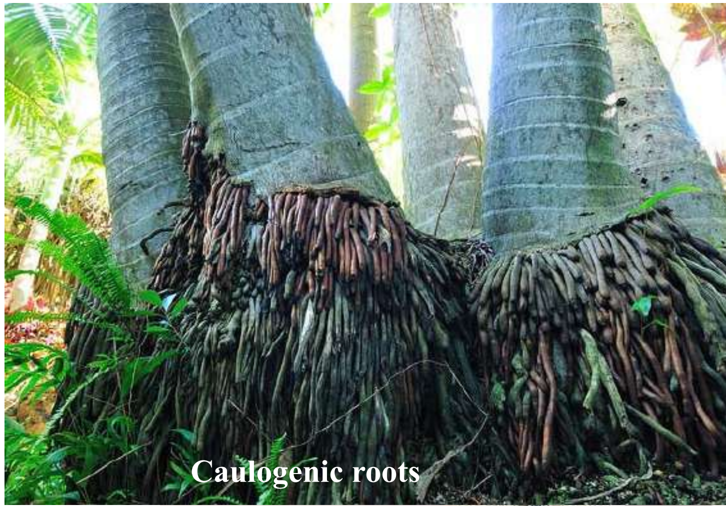
Dioscoreales

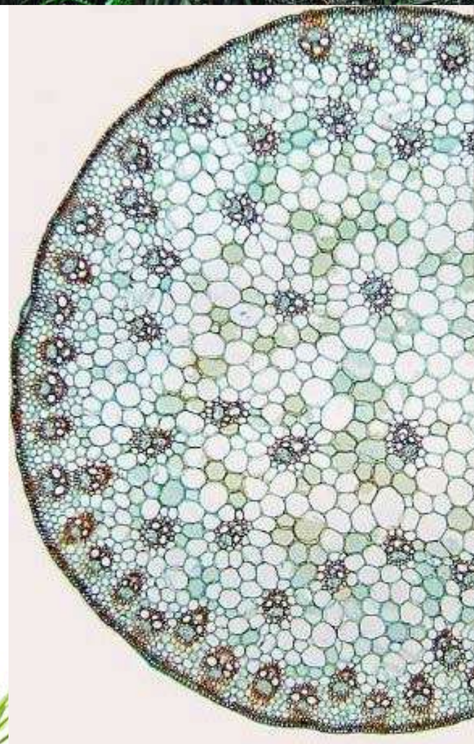
Pandanales

Liliales

Monocots: main traits

- Monophyletic group.
- The group includes familiar plants such as grasses, lilies, irises, orchids, cattails and palms, as well as rice, pineapples and bananas.
- They are usually herbaceous.
- Caulogenic roots with a similiar size (= fasciculate or homorrhizic).
- Atactostele.
- Many produce steroidal saponins and calcium oxalate crystals.
- There are roughly 90,000 species worldwide. Roughly 200 species are parasitic.


Caulogenic roots


Cross-section of the stem showing an atactostele


Fasciculate roots


Grass

Monocots: main traits

- **Secondary growth does not exist in Monocots**.
- In *Dracaena draco* or *Cordyline*, a thickening of stems occurs but by a different mechanism (from that of Eudicots):

  - In the cortical areas, therefore, a **cambium** (tissue whose cells can divide = meristem) appears. By divisions, this forms a **peridermis towards the exterior**, while **parenchyma and closed collateral bundles** are formed **towards the interior**.

Phoenix dactylifera

Dracaena draco

Monocots: main traits

- **The leaves** are generally **alternate** and **distichous** (arranged in two opposite rows) and form a **sheath** around the stem.
- Their shape is linear or lanceolate.
- **Parallel venation**.

Musa acuminata

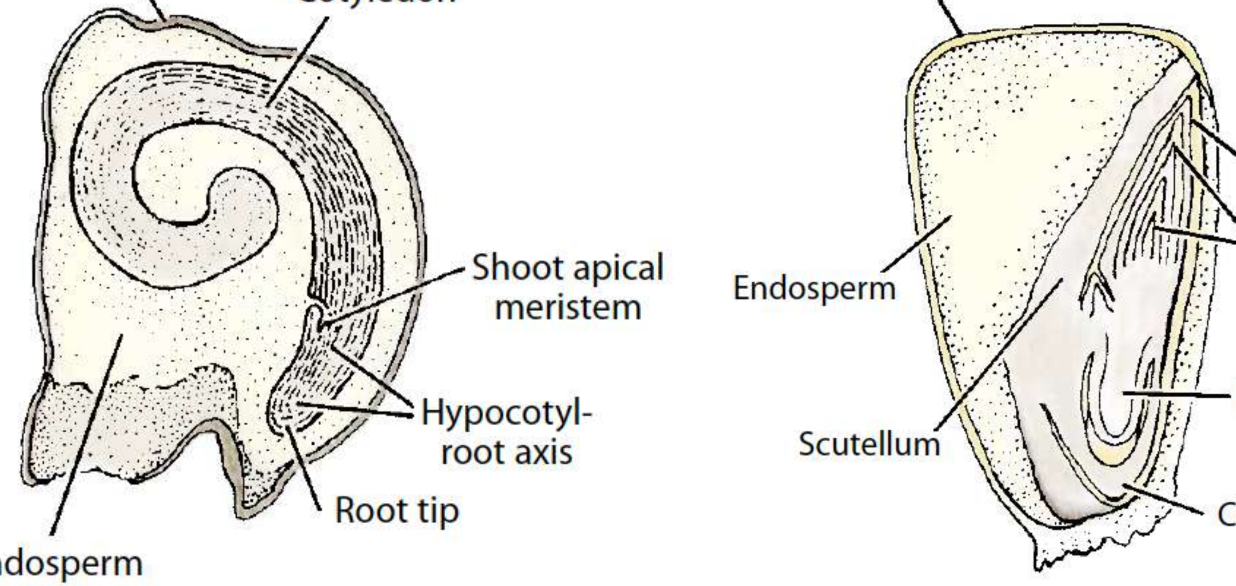
Vanda coerulea

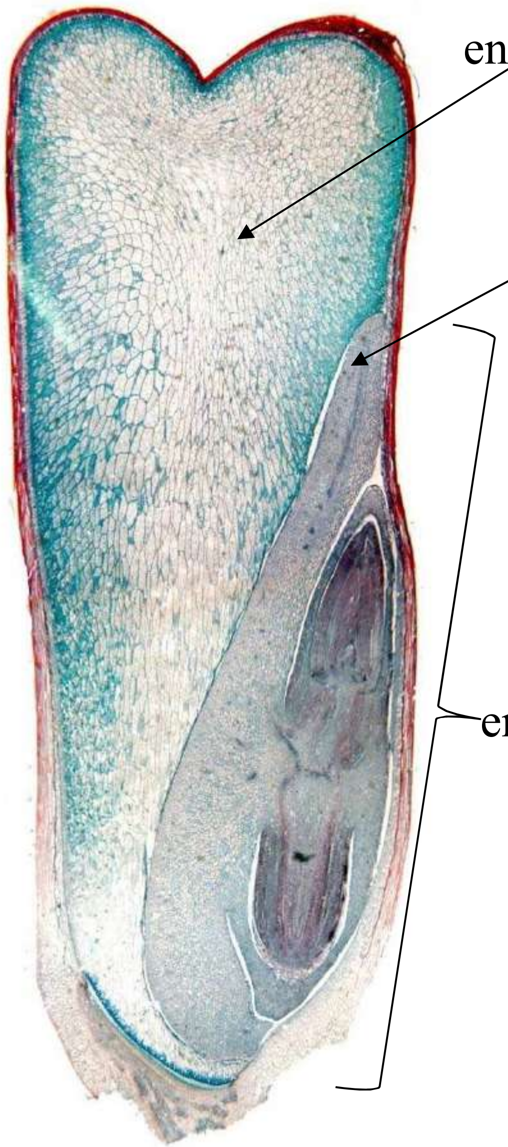
Arundo donax

Strelitzia alba

Monocots: main traits

A **monocotyledoneous embryo**:



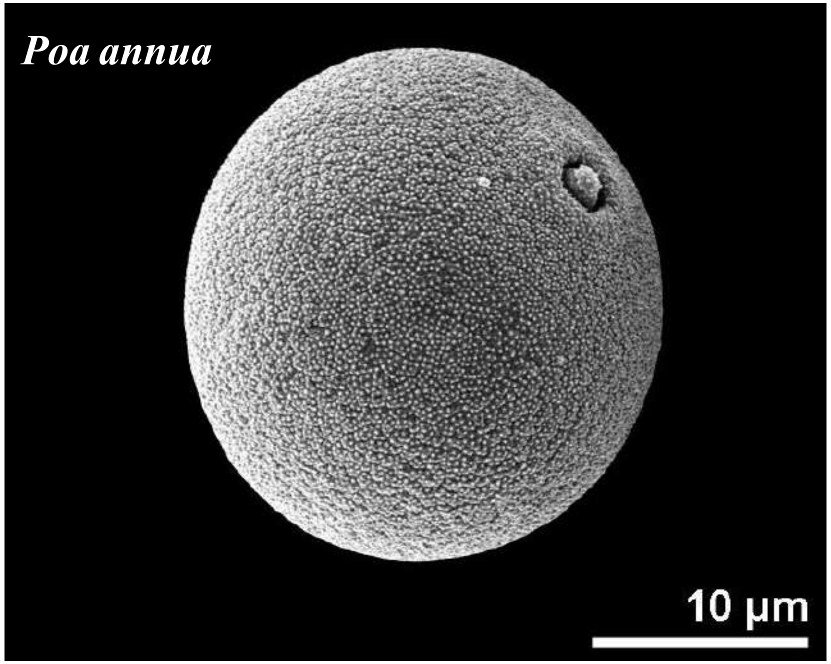


Shown in longitudinal view are embryos of the monocots (c) onion (*Allium cepa*) and (d) maize (*Zea mays*). The shoot apical meristem of the onion embryo lies on one side and at the base of the cotyledon, which is much larger than the rest of the embryo. The maize embryo has a well-developed scutellum (cotyledon) and radicle. The food stored in both seeds is in the endosperm.

Monocots: main traits

- The fowers are sometimes acyclic and **usually trimerous and pentacyclic**. One of the most frequent floral formulas is: P3+3, A3+3, G3.
- The **pollen** is **monoaperturate** (with one pore or furrow).

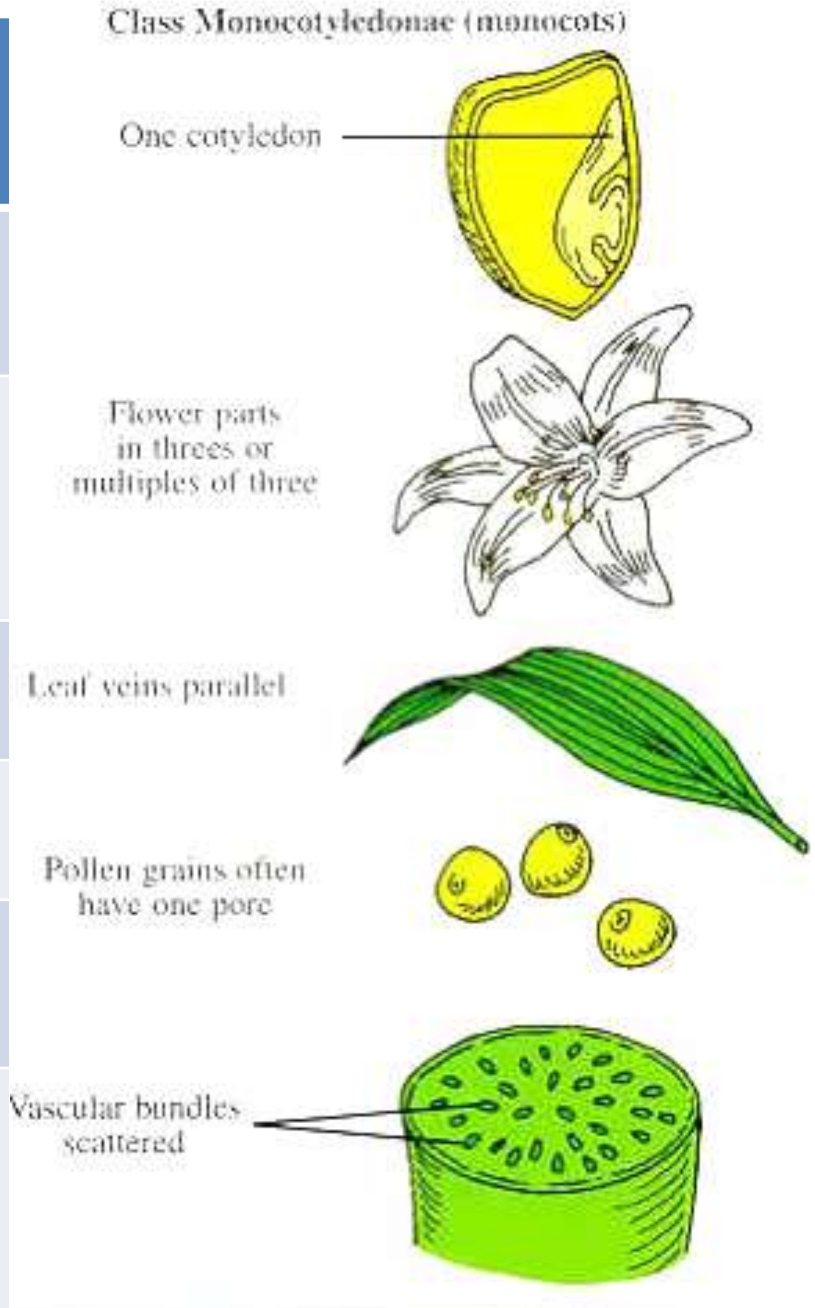
Pollen grain with one furrow



Pollen grain with one pore

Monocots: main traits and differences compared to Eudicots

Trait	Monocots	Eudicots
Flower parts	In threes (usually)	In fours or fives (usually)
Pollen	Monoaperturate (having one pore or furrow)	Triaperturate (having three pores or furrows)
Cotyledons	One	Two
Leaf venation	Usually parallel	Usually netlike
Primary vascular bundles	Scattered arrangement	In a ring
True secondary growth, with vascular cambium	Rare	Commonly present



Topics

Main traits of Monocots

Monocot diversity and uses for humans

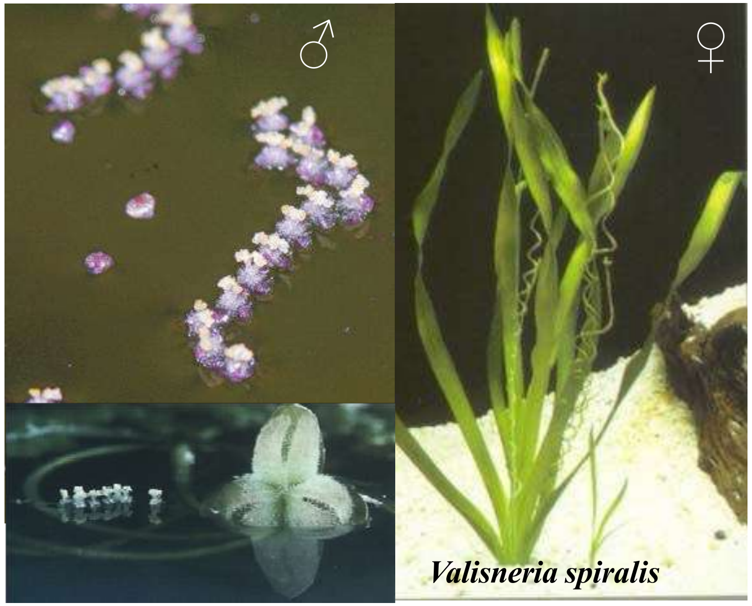
Monocot diversity: order *Acorales*, family *Acoraceae*

Acorus calamus (also called **sweet flag**, **sway** or **muskrat root**) is a herbaceous perennial, 2 m tall, consisting of tufts of basal leaves that rise from a spreading rhizome. A semi-erect spadix emerges from one side of the flower stem. Only plants that grow in water bear flowers. This species has **psychoactive chemicals** (e.g., **asarone** and **beta-asarone**). Although used in **traditional medicine** over centuries to **treat digestive disorders and pain**, there is no clinical evidence for its safety or efficacy – and ingested calamus may be toxic – leading to its commercial ban in the United States. Various pharmacological activities of *A. calamus* rhizome have been reported, including its use as a sedative, CNS depressant, anticonvulsant, antispasmodic, cardiovascular, hypolipidemic, immunosupressive, anti-inflammatory, cryoprotective, antioxidant, antidiarrheal, antimicrobial, anticancer and antidiabetic (Rajput et al. 2014).

Monocot diversity: order *Alismatales*

- Herbaceous plants of wet or **aquatic habitats**, such as *Hydrocharis*, *Valisneria*, *Potamogeton*, *Lemna* and *Wolffia* (the smallest angiosperm, 1 mm). There are also some epiphytes, as well as terrestrial species such as in the genus *Arum*. All these species show **hydrophilic pollination** mechanisms.

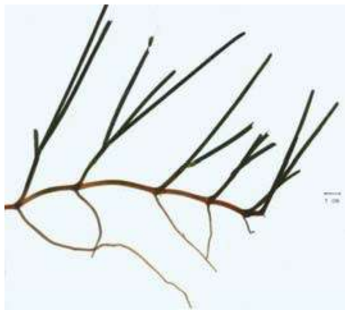
- *Valisneria* lives submerged and is characterised by its female flowers, which have a filiform peduncle that helps them to rise to the surface.



Monocot diversity: order *Alismatales*

Potamogeton (pondweed, or “water spikes”) have floating leaves, though they are radicant at their base.

This order includes the genera of marine angiosperms (*Posidonia*, *Cymodocea*, *Zostera*). The pollen grains are vermiform and can reach 0.5 mm in length.



Monocot diversity: order *Alismatales*, family *Alismataceae*

Alisma plantago-aquatica, the common water-plantain, is an aquatic or semi-aquatic plant unrelated to true plantains, which are members of the genus *Plantago*. The **dried leaves** of the water plantain can be used as both a diuretic and a diaphoretic. They have been used to help treat renal calculus, cystitis, dysentery and epilepsy.
The **roots** have been used to cure hydrophobia and are reputed in America to cure rattlesnake bites. The **powdered seed** is an astringent used in cases of bleeding.

Monocot diversity: order *Alismatales*, family *Araceae*

The ***Araceae*** (the arum family, aroids) contains species whose flowers are borne on **spadix** inflorescences. The spadix is usually accompanied by, and sometimes partially enclosed in, a **spathe** or **leaf-like bract**. This family of 140 genera and roughly 3,750 known species is most diverse in the New World tropics but is also distributed in the Old World tropics and northern temperate regions

Monocot diversity: order *Alismatales*, family *Araceae*

Arisarum vulgare. The root can be cooked. The acrid juice should first be removed by thorough and repeated washing to leave behind a nutritious and innoxious residue. Thorough drying or cooking will also destroy any harmful elements of this root. The root, roughly the size of a walnut, is frequently used as an emergency food in times of scarcity. One report suggests that the leaves may be edible. If they are, they must be well cooked first.

It is used as an aphrodisiac and a diuretic, etc.

Monocot diversity: order *Liliales*, family *Liliaceae*

Plants in the order *Liliales* usually show perianth modifications: **flowers** tend to become **zygomorphic** and more appealing to animals (**zoophilic pollination**). Some have nectaria at the base of stamens or petals (tepals). There are roughly 1,450 species worldwide. In Europe, there are three families (*Liliaceae*, *Colchicaceae* and *Smilacaceae*).

Fam. *Liliaceae*: genera ***Tulipa*** and ***Lilium***. Many are cultivated as ornamentals.

Monocot diversity: order *Liliales*, families *Liliaceae* and *Colchicaceae*

Lilium species (*Liliaceae*). The bulb is **anti-inflammatory, diuretic, emmenagogue, emollient and expectorant**. They are used to relieve heart diseases, pain in the cardiac region, and *angina pectoris*.

Colchicum species (*Colchicaceae*). This species contains the alkaloid **colchicine** in the bulb and seed, which has been used to treat gout. *Colchicum* plants are poisonous due to their colchicine content, causing severe toxicity in large amounts. Colchicine affects the way the body responds to uric acid crystals, which reduces swelling and pain. As a drug, it is therefore used to **treat gout** and an inherited disease called familial Mediterranean fever. Since **colchicine inhibits cellular function and division** (antimitotic), it has a narrow therapeutic index.

Monocot diversity: order *Liliales*, family *Smilacaceae*

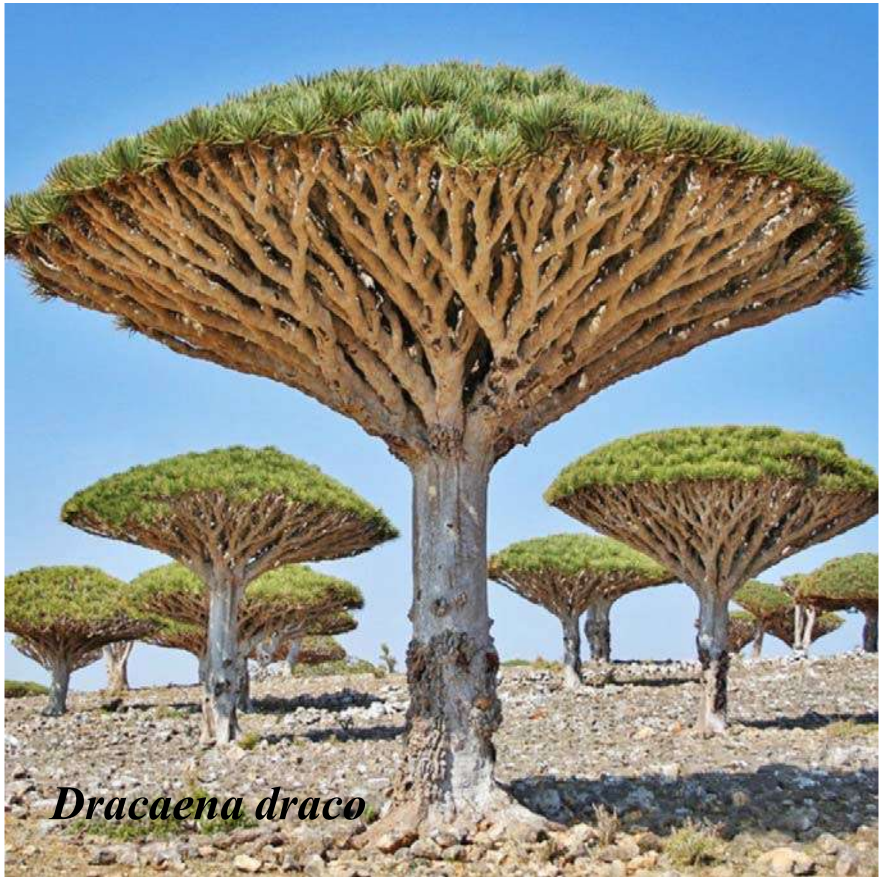
Smilax aspera is a perennial, evergreen climber with a flexible and delicate stem with sharp thorns typical of Mediterranean woodlands. The flowers, which are highly fragrant, small, and yellowish or greenish, are gathered in axillary racemes. The root is alterative, demulcent, depurative, diaphoretic, diuretic, a stimulant and a tonic. It is one of the **best depurative medicines** and is used as a springtime tonic and general body cleanser.

The fruits are globose berries, which gather in clusters and ripen in Autumn.

Monocot diversity: order *Asparagales*

- This order includes species such as **asparagus** (*Asparagus*), **garlic** (*Allium sativum*), **onions** (*Allium cepa*), garden plants such as **gladiolus**, **orchids**, and **lilies**, as well as **aloes**.
- They are distinguished from plants of the order *Liliales* by the fact that their **seeds have a black colouration** due to **phytomelans**.

Agave americana



Dracaena draco

Iris xiphium

Allium cepa

Monocot diversity: order *Asparagales*, family *Asparagaceae*

One genus, 300 species. Perennial, rhizomatous, often woody, climbing plants. Brachyblasts with foliar or thorn-like appearance. **Absence of leaves**. Flowers not very showy but complete. Fleshy spherical fruits in berry. In the Mediterranean scrublands, the most common species are ***Asparagus acutifolius*** and ***A. horridus***. The thick and fleshy aerial shoots ("**spears**") of asparagus are the edible portion of the plant. The scales on the spears are true leaves. ***Asparagus officinalis*** is cultivated in riparian forests for their spears (**diuretic**).

Monocot diversity: order *Asparagales*, family *Iridaceae*

- Members of the family *Iridaceae*, such as saffron (***Crocus***), have actinomorphic flowers with equal petaloid tepals and tuberobulbs.
- Lilies (genus ***Iris***) also have actinomorphic flowers but with inner and outer tepals that are different from each other.


Crocus sativus


Iris germanica

Monocot diversity: order *Asparagales*, family *Asphodelaceae*

Hypogeous area consisting of a set of tuberous rhizomes. Leaves in basal rosette. Racemose inflorescence. Capsular loculicidal fruit. 15 genera and roughly 780 species in the Old World.

- The genus ***Asphodelus*** is widespread in xeric habitats; two common species in our home region are *A. fistulosus* ("gamoncillo") and *A. cerassiferus* ("gamonera").
- The genus ***Aloe*** is cultivated as an ornamental, with crass leaves and spinescent margins. ***Aloe vera*** is cultivated for use in cosmetics and for treating damaged skin. Latex with purgative or tonic functions is obtained from other *Aloe* species.

Monocot diversity: order *Asparagales*, family *Orchidaceae*

- *Orchidaceae* are characterised by their zygomorphic and highly modified flowers.
- Sometimes these flowers are deceptive.
- The roots are in association with fungi (orchidoid mycorrhizae). Sometimes they are not photosynthetic.


Cypripedium calceolus


Dracula sauili


Caleana major


Dracula simia


Drakaea glyptodon

Some orchids from our region: *Ophrys*, *Orchis* and *Cephalanthera*

Ophrys apifera

Ophrys speculum

Orchis mascula

Anacamptis pyramidalis

Barlia robertiana

Cephalanthera rubra

Serapias lingua

Limodorum abortivum

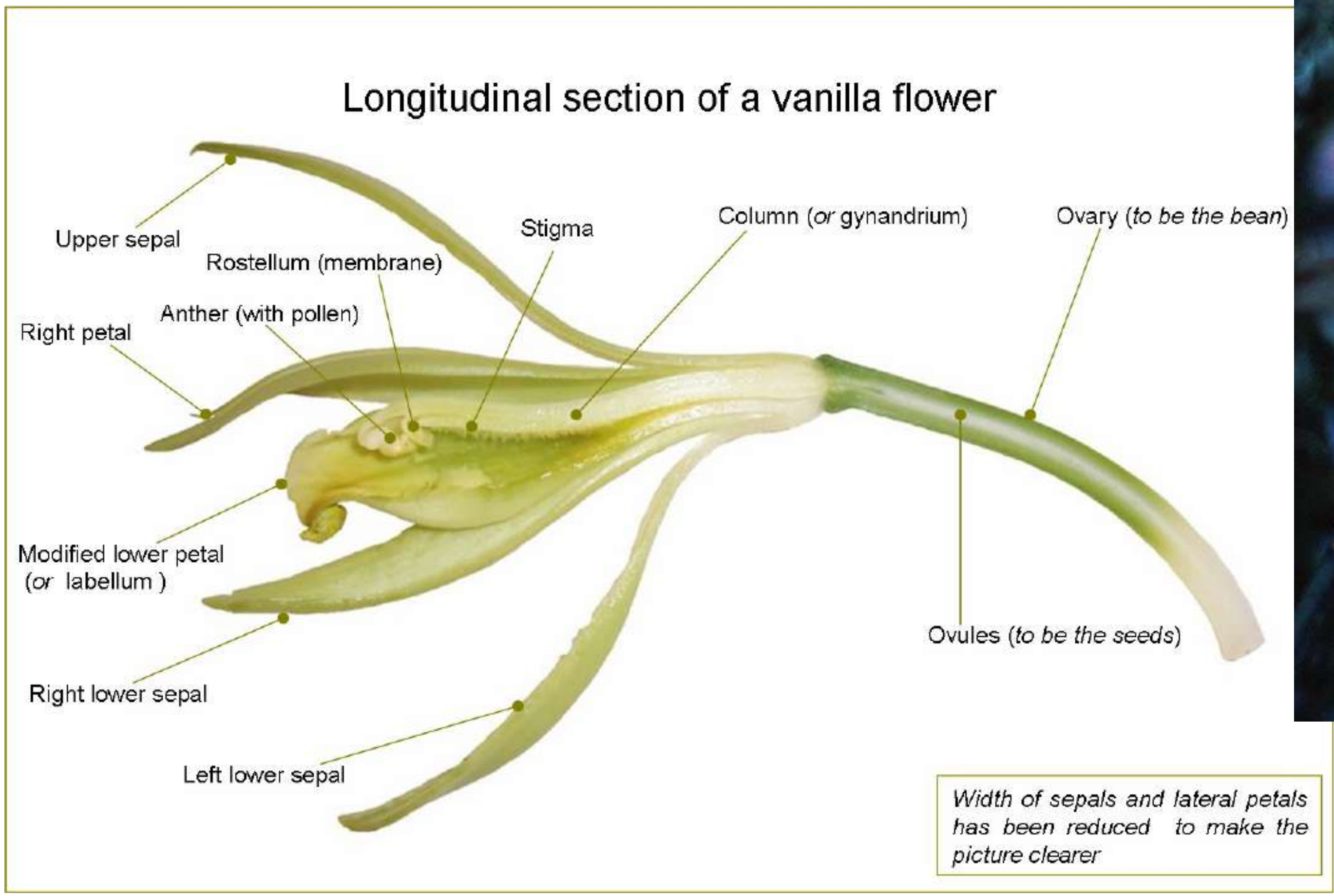
https://www.google.es/search?q=Ophrys&biw=1713&bih=932&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjMqpXXu4PLAhVItxoKHdlKBs8Q_AUIBigB#imgrc=NCIb0bHV-qJlhM%3A

Structure of an *Ophrys* flower

Many orchids are prized as ornamentals and some (e.g. *Vanilla*) are used as foods

Many orchids are prized as ornamentals and some (e.g. *Vanilla*) are used as foods

Vanilla is a spice from the continent of America obtained from the fruit of ***Vanilla planifolia***. When Spaniards arrived in Mexico, they gave it this name because the appearance of its fruit is similar to that of the pod ("*vaina*") of green beans. Vanilla helps to stimulate the nervous system.

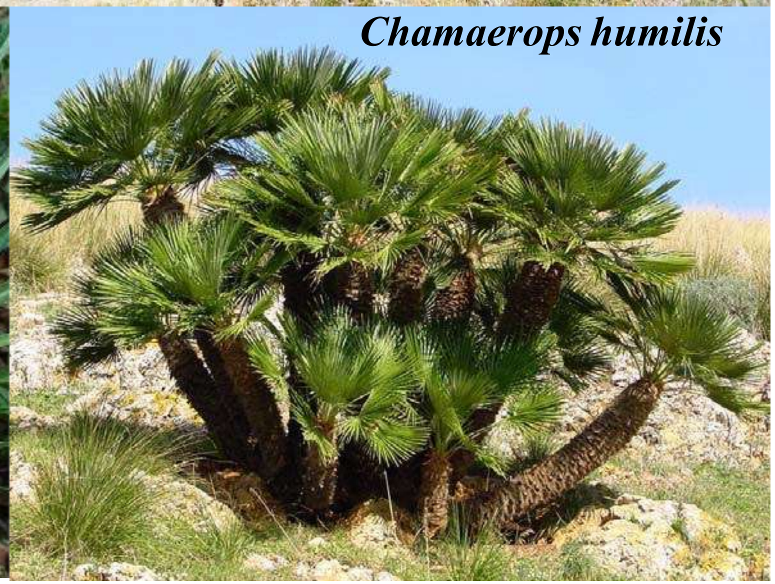


Monocot diversity: order *Arecales*, family *Arecaceae* (*Palmaceae*)

- Palms are plants of warm, tropical and subtropical zones.
- Their stem is columnar.
- Their terminal tuft of leaves can be palmate or pinnate.
- Cyclic flowers are usually unisexual, grouped in inflorescences covered by a spathe or bract.

Phoenix canariensis

Phoenix dactylifera
(inflorescence)



Chamaerops humilis

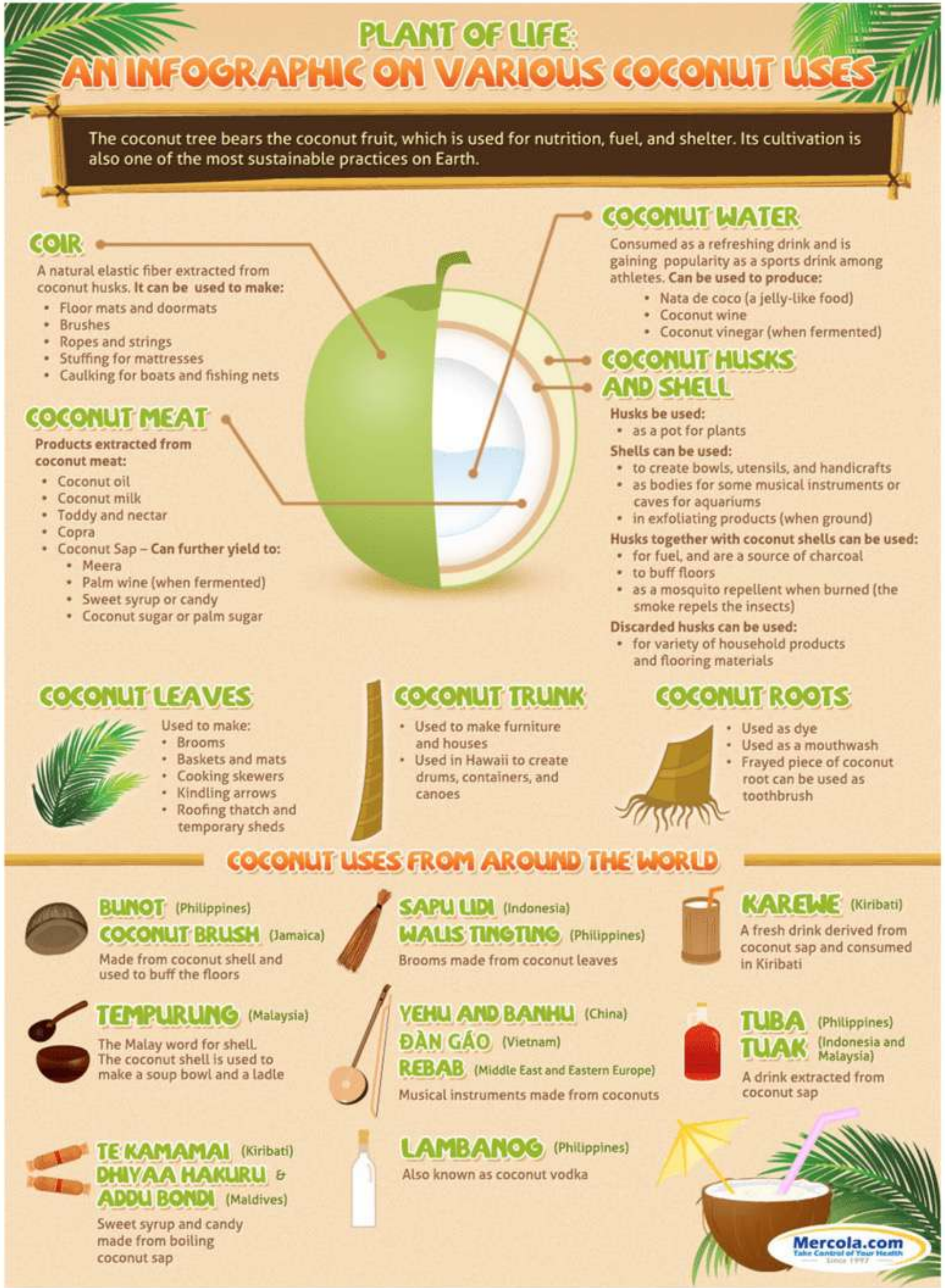
Monocot diversity: order *Arecales*, family *Arecaceae* (*Palmaceae*)

Fleshy fruit in **berry** (**date**) or **drupe** (**coconut**), rich in sugars and oils. This species is useful for food, in gardening and as a source of raw materials.

***Phoenix dactylifera* (DATES)**

***Coccos nucifera* (COCONUTS)**

Uses of coconuts



https://coconutcoalition.org/coconut-tree-and-coconut-plant-uses/

Monocot diversity: order *Poales*

This species includes families of graminoid, wind-pollinated (**anemophylous**) plants that lack nectaries. Four main groups are recognised: ***Juncaceae*** (rush plants), ***Cyperaceae*** (sedges), ***Typhaceae*** (cattails) and ***Poaceae*** or *Gramineae* (grasses).

Arundo donax

Carex pendula

Juncus acutus

Ammophila arenaria

Monocot diversity: order *Poales*, family *Cyperaceae*

Grasses of graminoid appearance, perennial, grass-forming or rhizomatous. They inhabit humid, riverside or semi-submerged areas. They are edible (**tiger nut, *Cyperus esculentus***) and ornamental (*Cyperus papyrus* or *C. alternifolius*).

Cyperus papyrus

"Orxata" is made from soaked, ground and sweetened tiger nuts mixed with sugar and water.

Cyperus esculentus

Monocot diversity: order *Poales*, family *Poaceae* (grasses)

Some species are of great interest because they form the basis of human nutrition: **CEREALS**.

Oryza sativa **(rice)**

Hordeum vulgare **(barley)**

Triticum aestivum **(wheat)**

Zea mays **(maize)**

Avena sativa **(oat)**

Secale cereale **(rye)**

Monocot diversity: order *Zingiberales*

Musaceae (banana tree) and ***Bromeliaceae*** (American pineapples) are tropical families prized for their fruits. Bromeliads adopt particular morphologies so that their rosette leaves form containers that collect rainwater. Uses: **ginger** (genus *Zingiber*) and **turmeric** (genus *Curcuma*). Many others are used as ornamentals (e.g. *Strelitzia*).

***Ananas comosus* (pineapple)**

***Musa* sp. (banana tree)**

***Zingiber officinale* (ginger; rhizomes)**

***Curcuma longa* (turmeric, rhizomes)**

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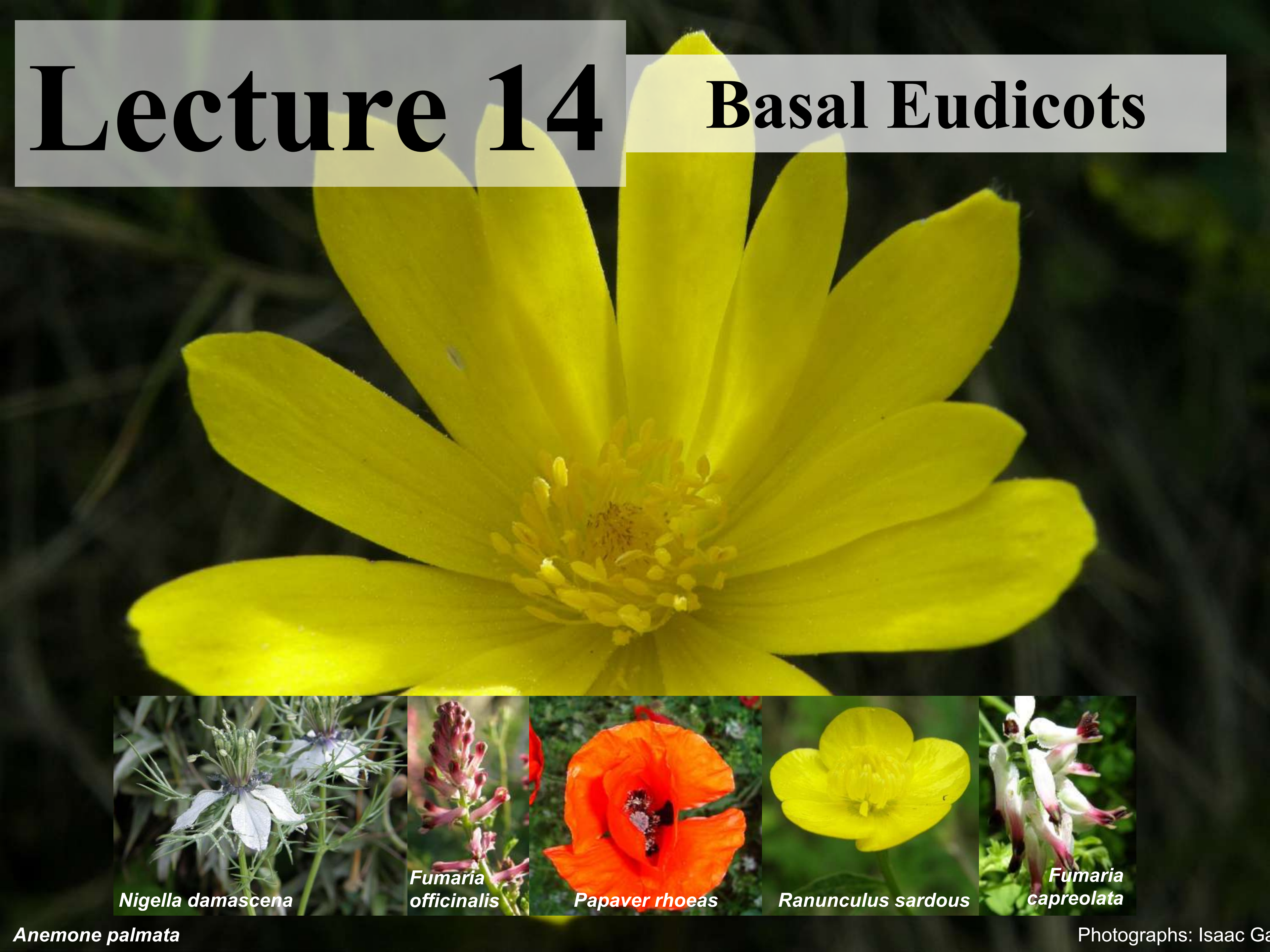
Lecture 14

Basal Eudicots



Anemone palmata

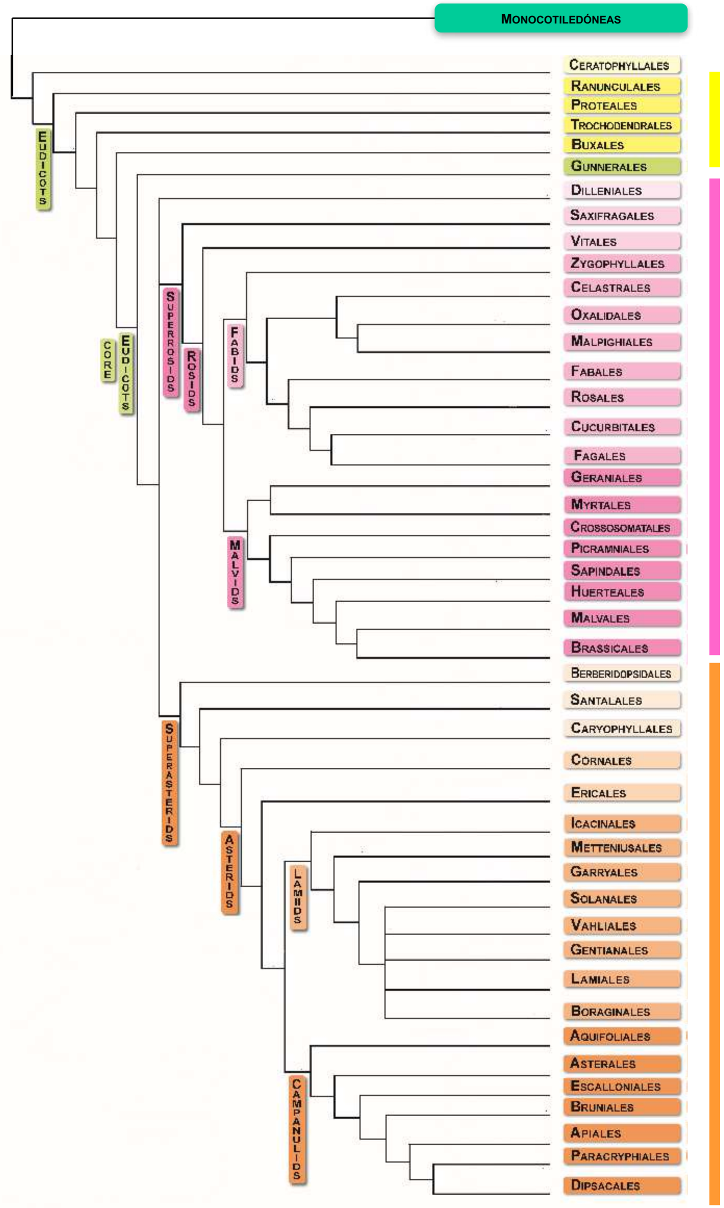
Photographs: Isaac Ga

Topics

Main traits of Eudicots

Diversity of basal Eudicots and their uses for humans

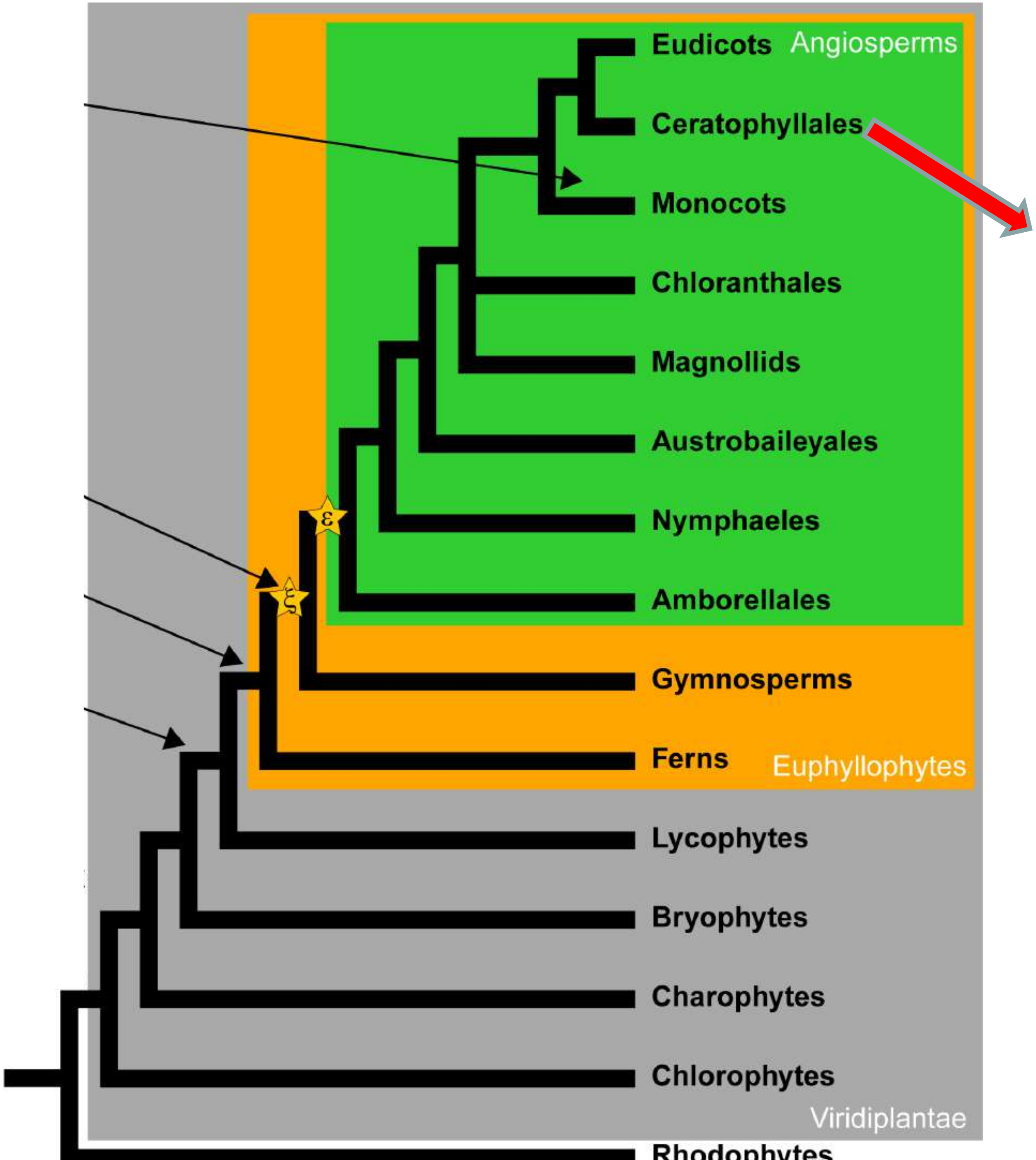
Phylogenetic position of Eudicots within *Magnoliophyta*



Basal Eudicots

Subclass *Rosidae* (Rosids)

Subclass *Asteridae* (Asterids)



According to some phylogenies, *Ceratophyllales* are the group most closely related to Eudicots.

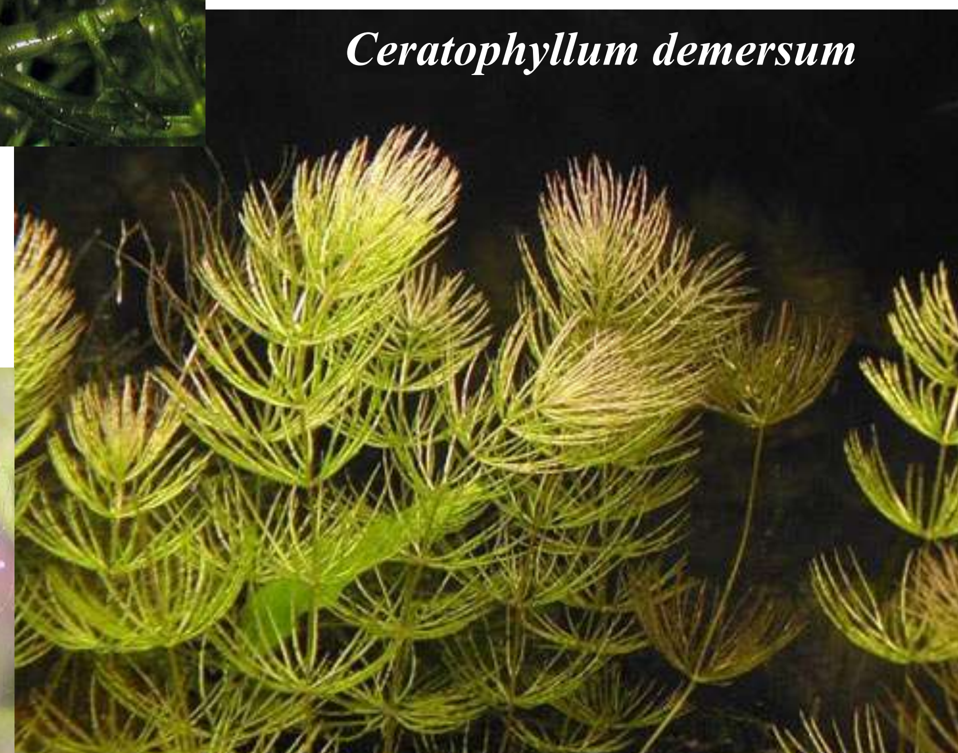
Adapted from Wu et al. (2019)

Order *Ceratophyllales*, family *Ceratophyllaceae*

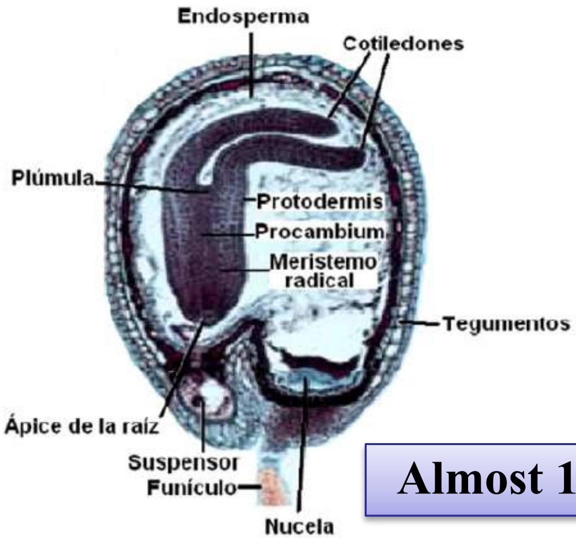
One family.
These are herbaceous plants that live submerged in freshwater ponds.
Divided, verticillate leaves.
Without stomata or **xylem vessels**.
They have no roots and are fixed to the ground by rhizomes.

The flowers are small and unisexual and the perianth is absent.
They have numerous stamens and a single seed primordium.

Hydrophilic pollination.

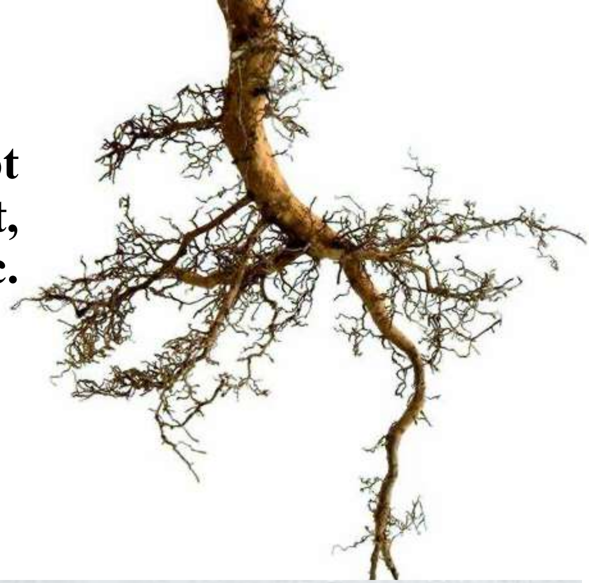


Main traits of Eudicots



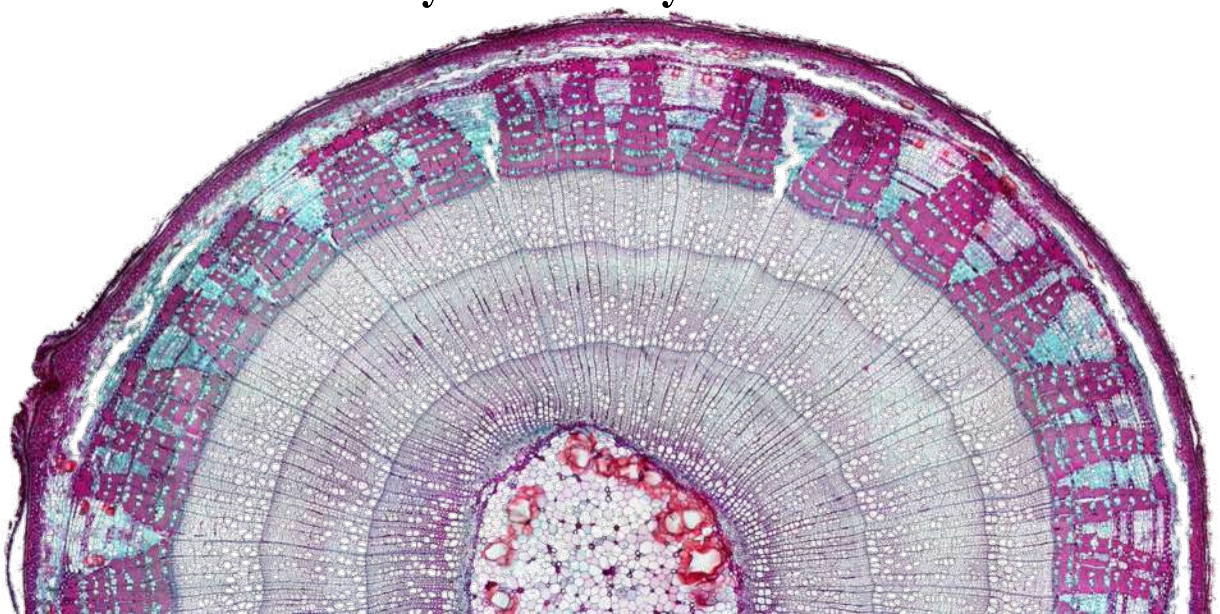
The seed's embryo is made up of two cotyledons.

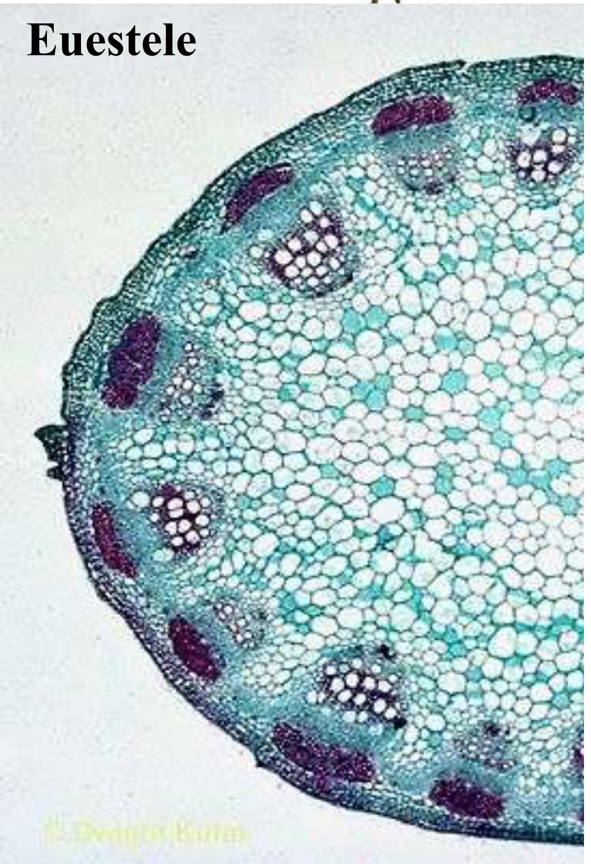
Primary root persistent, axonomorphic.



Almost 199,000 species exist worldwide.

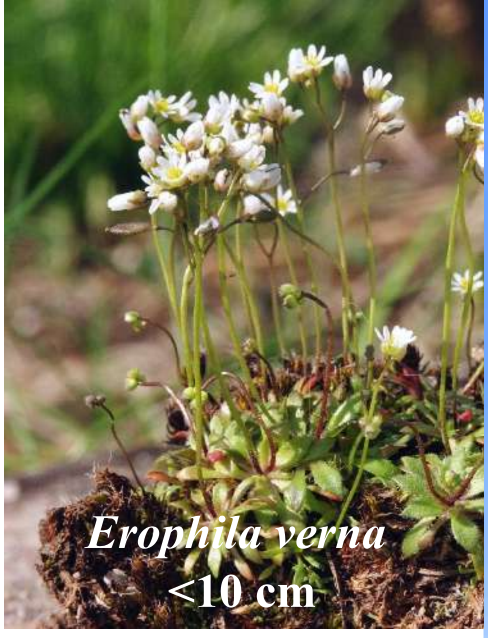
They may show secondary growth by the activity of cambium.





Main traits of Eudicots

- The plants are of variable size, from herbaceous to trees and include all growth forms (e.g. phanerophytes, chamaephytes, terophytes, and geophytes, etc.).
- The leaves are variable in shape and size, generally petiolate, sometimes with stipules, and generally reticulate veins.



Erophila verna
<10 cm

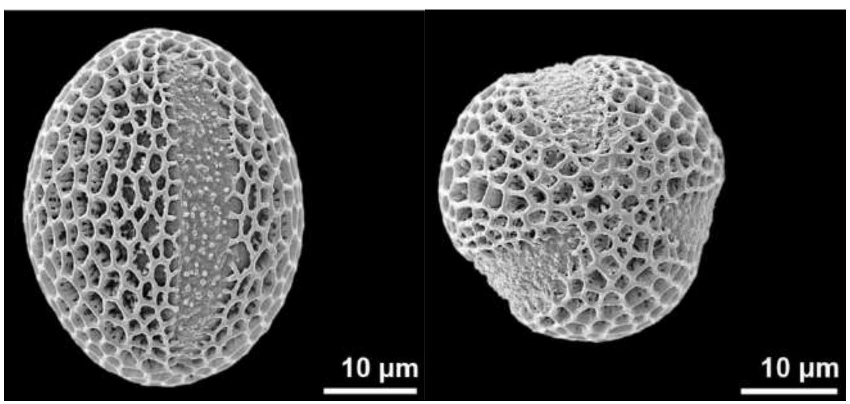
Eucalyptus regnans
"Centurion" >100 m

Main traits of Eudicots

- The flowers are **cyclic** (often tetra- or pentacyclic) and usually tetramerous or pentamerous.
- The pollen grains have three furrows alone (tricolpate), or each of these furrows comprises one pore (tricolporate).

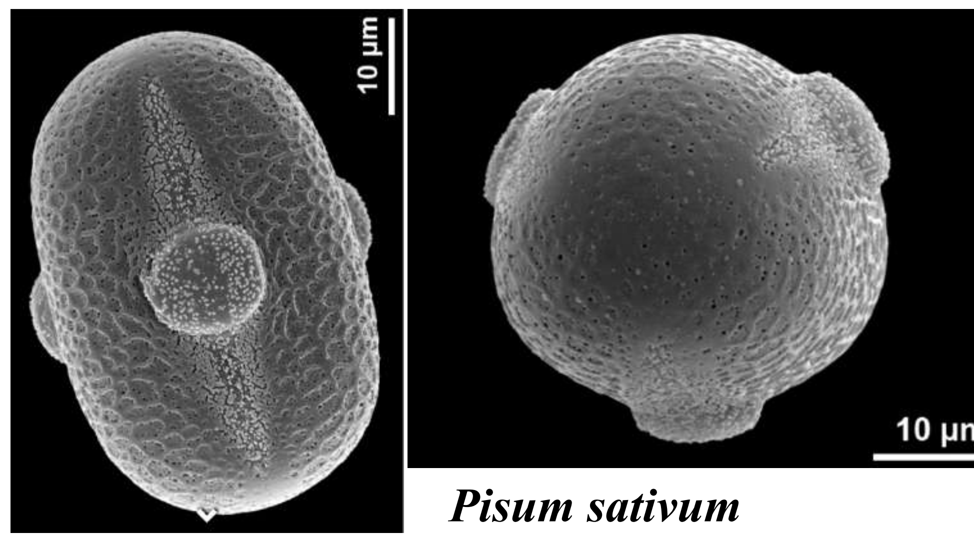
Tetracyclic flower
Anagallis arvensis

Pentacyclic flower
Geranium sp.



Diplotaxis tenuifolia

Tricolpate pollen



Pisum sativum

Tricolporate pollen

Topics

Main traits of Eudicots

Diversity of basal Eudicots and their uses for humans

Basal Eudicots: order *Ranunculales*

- This species comprises woody or herbaceous plants with benzylisoquinolic ("bencilisoquinoleínicos") alkaloids, often with **helically arranged floral organs** (which is why they are usually related to magnoliids); their leaves are **usually divided** and their pollen is tricolpate.
- The most interesting families are *Paeoniaceae*, *Papaveraceae*, *Berberidaceae* and *Ranunculaceae*.

Berberidaceae

Papaveraceae

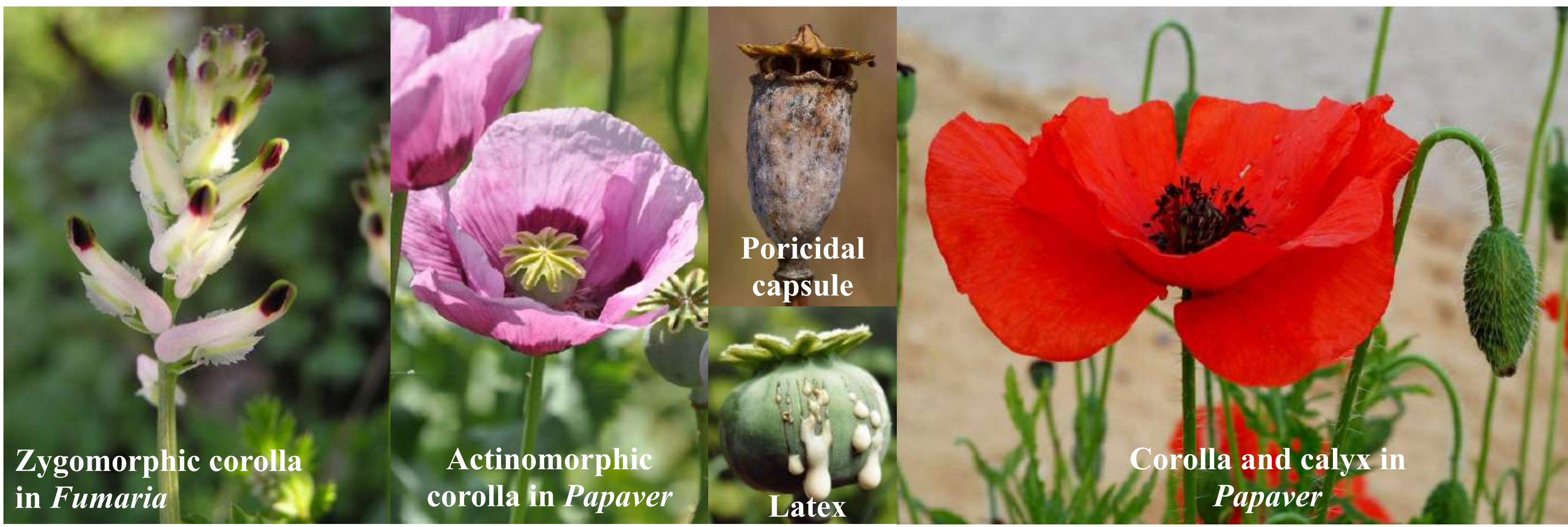
Ranunculaceae

Basal Eudicots: order *Ranunculales*, family *Berberidaceae*

Berberis vulgaris contains a large number of phytochemical materials including ascorbic acid, vitamin K, several triterpenoids, over 10 phenolic compounds and more than 30 alkaloids (e.g. berberine). *B. vulgaris* may therefore have anti-cancer, anti-inflammatory, antioxidant, antidiabetic, antibacterial, analgesic, anti-nociceptive and hepato-protective properties (Rahimi-Madiseh et al. 2017).

Basal Eudicots: order *Ranunculales,* family *Papaveraceae*

Papaveraceae (the poppy family) consist of 43-44 genera/ca. 780 species. These are mostly annual or perennial herbs, shrubs, or small trees, with **milky latex** from articulated laticifers in some taxa. The **leaves** are usually lobed to divided or dissected. The inflorescence is often a solitary flower. The **flowers** are bisexual, actinomorphic, zygomorphic or dissymmetric, and hypogynous. The **perianth** is dichlamydeous. The **calyx** has 2 [3] usually caducous sepals. The **corolla** is biseriate with 2+2 or 3+3 [–16] petals. The **stamens** are usually numerous [4–6], and sometimes in bundles of two or three. The **fruit** is often a longitudinally dehiscent or poricidal capsule. In some taxa the **seeds** are **oily endospermous**, with an **aril**.



Basal Eudicots: order *Ranunculales*, family *Papaveraceae*, subfam. *Papaveroideae*

Papaver somniferum

Their economic importance includes many cultivated ornamentals and taxa used as oil seeds. *Papaver somniferum*, the opium poppy, is an addictive narcotic plant, the source of heroin (which has shaped human history) and is very important medicinally, e.g. as the source of the analgesic morphine and other alkaloids.

Alkaloids from the fruit latex:

- **Morphine** (4-15%). Antidiarrheal, antiemetic, and slightly hypnotic. The most important effects occur at the levels of the central nervous system and the gastrointestinal tract. It induces selective analgesia, modifies the emotional components that accompany pain, and produces a powerful sensation of well-being, reducing agitation and anxiety. It also produces constipation. 80% of morphine is transformed into codeine.
- **Codeine** (0.3%). An analgesic, antitussive that potentiates the action of other analgesics. It has fewer respiratory depressant and spasmogenic effects on smooth muscles than morphine.
- **Readine**. A nervous sedative and antitussive.

Basal Eudicots: order *Ranunculales*, family *Papaveraceae*, subfam. *Papaveroideae*

Papaver rhoeas **("amapola"): petals with readine and mucilage (emollient and soothing)**

Basal Eudicots: order *Ranunculales*, family *Papaveraceae*, subfam. *Papaveroideae*

Chelidonium majus is used to **improve eyesight and in modern times has been used as a mild sedative and antispasmodic in the treatment of bronchitis, whooping cough, asthma, jaundice, gallstones, and gallbladder pain**. The latex is used topically to treat warts, ringworm, and corns.

Glaucium flavum: several alkaloids (glaucine, protopine, chelidonine, etc.).
The whole plant, especially the roots is used

- to increase the secretion of bile
- to treat intestinal and bronchial spams
- to cure hepatic illnesses
- as an antitussive

Basal Eudicots: order *Ranunculales*, family *Papaveraceae*, subfam. *Fumarioideae*

Fumaria officinalis **(Photos: Isaac Garrido)**

Species in the genus *Fumaria* have traditionally been used **as laxatives and diuretics as well as for treating dermatological conditions such as eczema**. Limited evidence suggests that they may be beneficial in hepatobiliary disorders, while *F. officinalis* is approved in Germany for treating colic pain. It is depurative, tonic and antiscorbutic. Hypotensive. Antihistamine.

Phytochemical content: alkaloids (**fumarin**) and flavonoids.

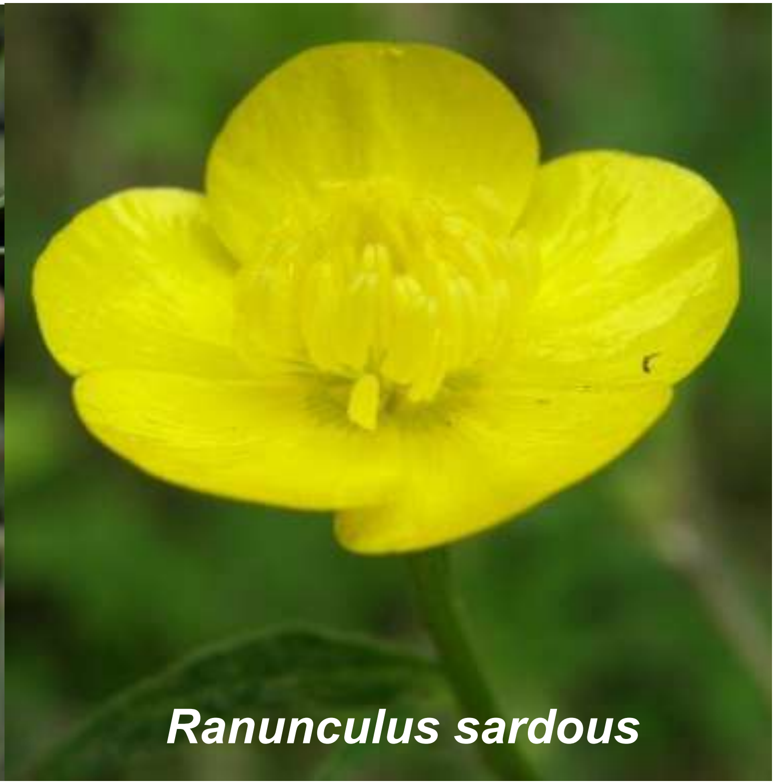
Basal Eudicots: order *Ranunculales*, family *Paeoniaceae*

Paeonia officinalis (European peony, common peony) has been cultivated in Europe for many years. The roots contain asparagin, benzoic acid, flavonoids, paeoniflorin, paeonin, paeonol, protoanemonin, tannic acid, triterpenoids, and volatile oils. It is used **to treat epilepsy and to promote menstruation**. The root is also antispasmodic, diuretic, sedative and tonic and has been successfully employed to treat convulsions and spasmodic nervous affections such as epilepsy (Ahmad 2012).

https://floressilvestresdelmediterraneo.blogspot.com/2014/05/paeoniaceae-paeonia-officinalis-subsp.html

Basal Eudicots: order *Ranunculales*, family *Ranunculaceae*

Ranunculateae (buttercups family) are herbaceous plants which are usually perennial and rarely woody. The **leaves** are alternate and often divided. The **flowers** are solitary or clustered in relatively simple inflorescences. The **perianth** is simple or double, sepaloid or petaloid. They have numerous **stamens**, which are free and arranged in a spiral. Superior **gynoecium**, with one to multiple, free carpels. The **fruit** is in polyfollicle (follicle, berry) or polyachenium (if the carpels are monosperms). **Plants of this family are often toxic**.



Photos: Isaac Garrido

Basal Eudicots: order *Ranunculales*, family *Ranunculaceae*

Species of aconite contain a variety of diterpene alkaloids. ***Aconitum napellus*** (monkshood) contains **aconitine**, isonapelline, luciculine, and napelline.
Aconite roots can cause serious heart failure. Other symptoms of aconite poisoning include numbing of the mouth and tongue, gastrointestinal disturbances, muscular weakness, incoordination, and vertigo. At low doses they are used as analgesics and for treating headaches.

Delphinium gracile.
Bisexual flowers with a posterior spur.
Used to kill parasites.

Photographs: Isaac Garrido

Basal Eudicots: order *Ranunculales*, family *Ranunculaceae*

Helleborus foetidus contains cardiotonic heterosides (helleborine and helleborein). The whole plant has been used in homemade medicine as a cardiotonic in the treatment of heart weakness (hypotension, heart failure). Cardiotonic glycosides exercise this function, which is increased by saponins.

It has also been used to combat constipation, as a cathartic for purging the bowels, and to eliminate roundworms.

Photographs: Isaac Garrido

Basal Eudicots: order *Ranunculales*, family *Ranunculaceae*

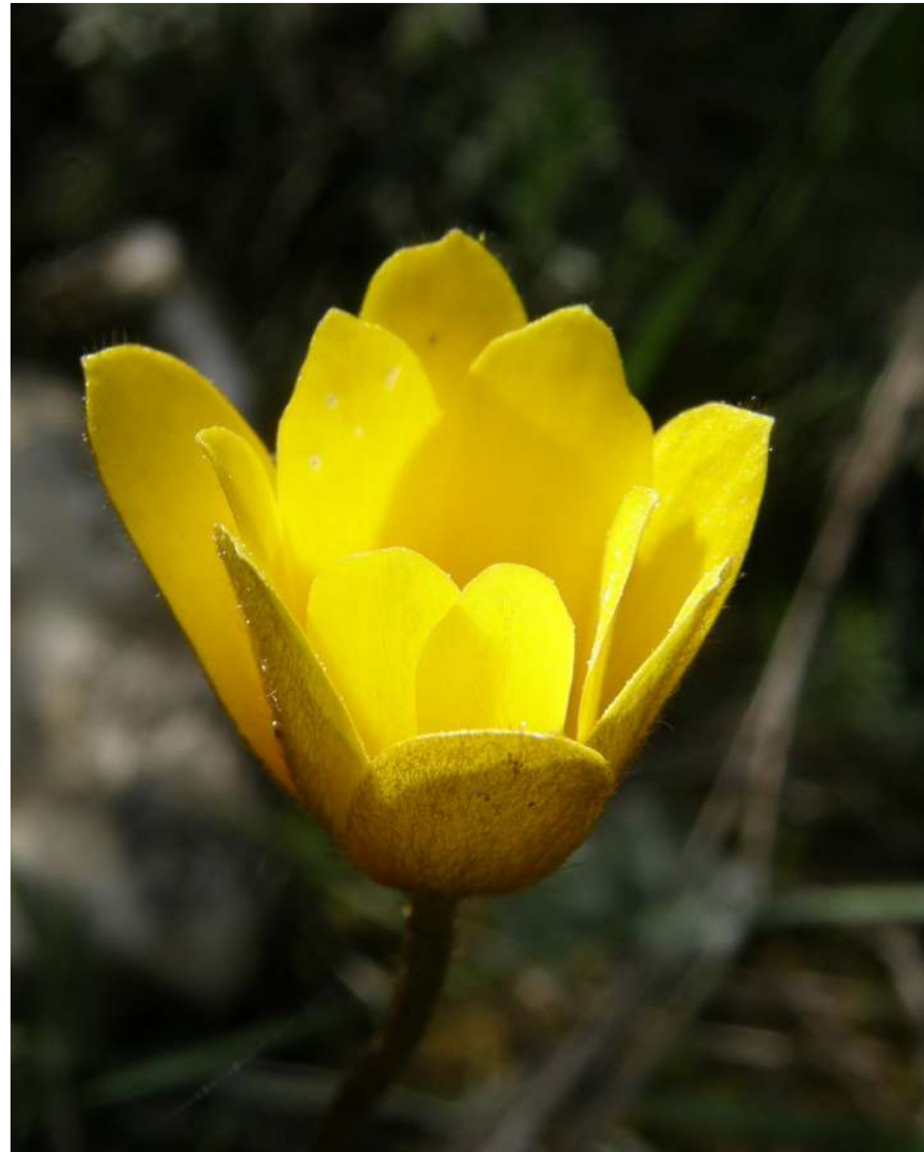
Hepatica is a small genus of flowering plants comprising ten species found in temperate regions of Europe, Asia and North America. The name "Hepatica" refers to these plants' **three-lobed leaves**, which to the imaginative eye resemble a human liver. This resemblance inspired early herbalists to prescribe their use in treating ailments of the liver – a good example of the principle of the 'Doctrine of Signatures', whereby God (or Nature) reveals a plant's use to humans through its appearance. Now known not to be useless in treating liver disorders, these poisonous plants have been used as diuretics and astringents and to relieve mild pain and inflammation (https://herbaria.plants.ox.ac.uk).

Photograph: Isaac Garrido

Basal Eudicots: order *Ranunculales*, family *Ranunculaceae*

Clematis flammula

Anemone palmata



Photos: Isaac Garrido

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Lecture 15 Eudicots-Rosids

Geranium purpureum

Euphorbia helioscopia

Ecballium elaterium

Hedysarum boveanum subsp. *europaeum*

Rosa sempervirens

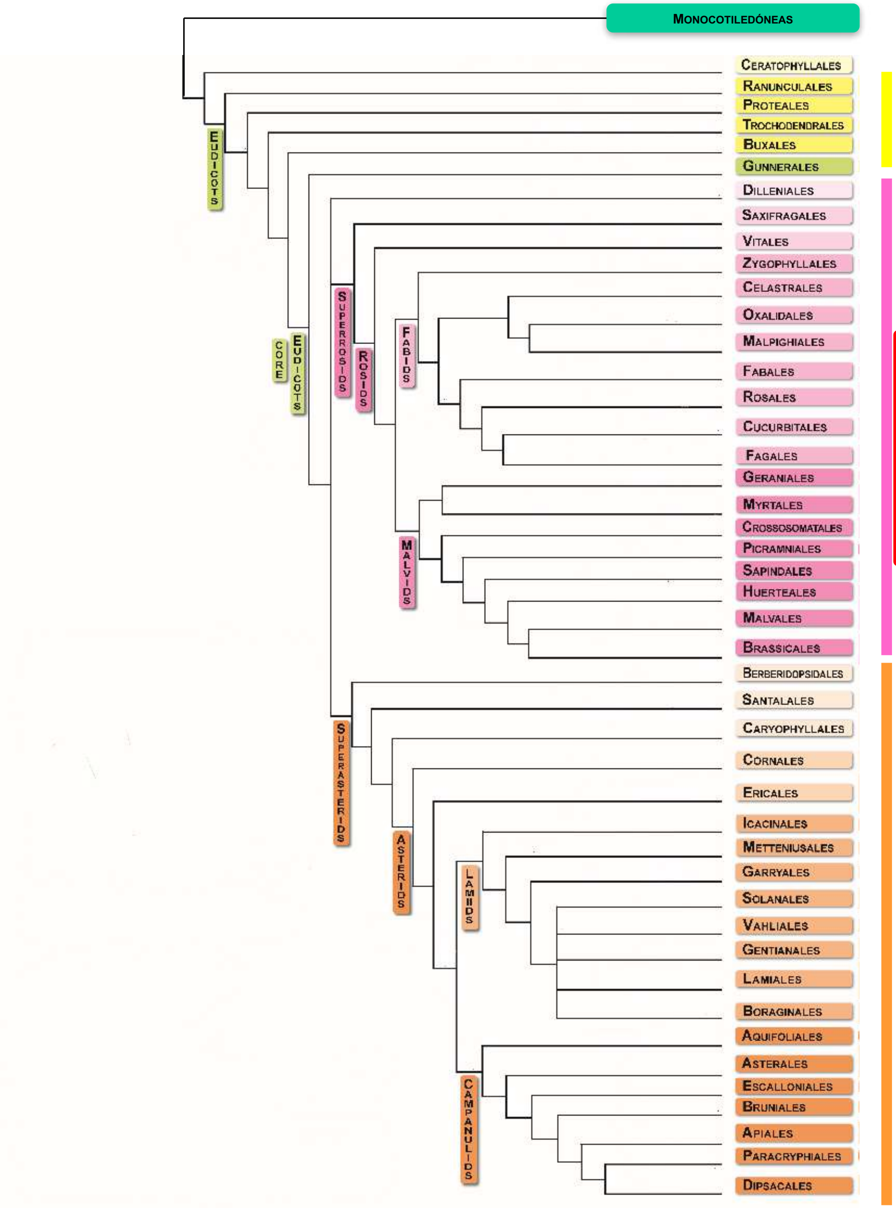
Photographs: Isaac Garrido

Topics

Main traits of Rosids

Diversity of Rosids and their uses for humans

Phylogenetic position of Rosids within *Magnoliophyta*

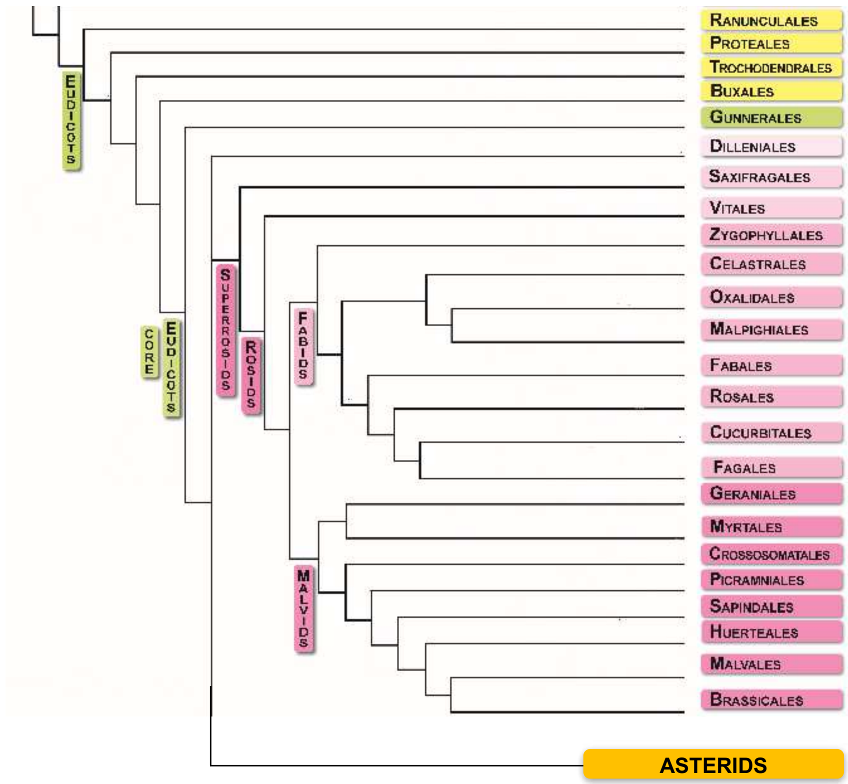


Basal Eudicots

Subclass *Rosidae* (Rosids)

Subclass *Asteridae* (Asterids)

The nucleus of Eudicots: Rosids (subclass *Rosidae*)



- Herbaceous or woody plants.
- (Penta-)cyclic flowers, often pentamerous; double perianth; free petals; sepals with three or more veins (nerves).
- Polystemonous or diplostemonous androecium.
- Tendency to develop a **hypanthium**.
- 17 orders and some 70,000 species.

Zygophyllales

Oxalidales

Fabales

Rosales

Cucurbitales

Fagales

Geraniales

Myrtales

Sapindales

Malvales

Brassicales

Topics

Main traits of Rosids

Diversity of Rosids and their uses for humans

Rosids: order *Malpighiales*

Hypericum perforatum (photo: Isaac Garrido)

Erythroxylaceae: trees or shrubs with tropane alkaloids.

Erythroxylum coca (the coca plant):

- a shrub from the Andes.
- widely recognised for its action (**cocaine alkaloid**) in enhancing work capacity, reducing fatigue, and mitigating thirst and hunger.

Hypericaceae: native to Europe but later introduced into North America. It has been used since the Middle Ages for its anti-inflammatory, analgesic, diuretic, and wound-healing properties. In more recent times it has gained favour as a treatment for anxiety and depression. **Hyperforin**, a phloroglucinoid, is now believed to be responsible for the plant's action due to its ability to inhibit serotonin, noradrenaline, and dopamine reuptake by increasing their concentration in the synaptic cleft.

Rosids: order *Malpighiales*

Euphorbia helioscopia

Euphorbia hirsuta latex

Euphorbia nicaaensis inflorescences

Euphorbiaceae: The *Euphorbia* (spurges) is the third largest genus of flowering plants, with almost 2,000 species. Its exceptional diversity of growth forms and near-cosmopolitan distribution have attracted human interest since ancient times. In Australia, for instance, the topical application of the latex of *Euphorbia peplus* is used as a home treatment for skin cancer and actinic keratosis.

The most-valued medicinal uses of *Euphorbia* species are in the treatment of digestive and respiratory complaints, inflammation and injuries, especially by members of *Euphorbia* subg. *Chamaesyce* (Ernst et al. 2015).

Photographs: Isaac Garrido

Rosids: order *Malpighiales*

Salix capraea (photograph: Isaac Garrido)

Family ***Salicaceae***. With over 330–500 species and 200 hybrids, willows (genus ***Salix***) are trees, shrubs or prostrate plants that are widely distributed in Africa, North America, Europe, and Asia. The genus is traditionally used in folk medicine and is a valuable source of biologically active compounds, including **salicin**, a prodrug for salicylic acid. Willows exert analgesic, anti-inflammatory, antioxidant, anticancer, cytotoxic, antidiabetic, antimicrobial, antiobesity, neuroprotective and hepatoprotective activities (Tawfeek et al. 2021).

Other members of this family include the genus *Populus* (poplar, “chopos”).

Rosids: order *Rosales*

- Mostly woody plants, with stipulate leaves.
- Flowers often develop an hypanthium.
- Reduced endosperm.

Ulmaceae ("olmos")

Urticaceae ("ortigas")

Rhamnaceae

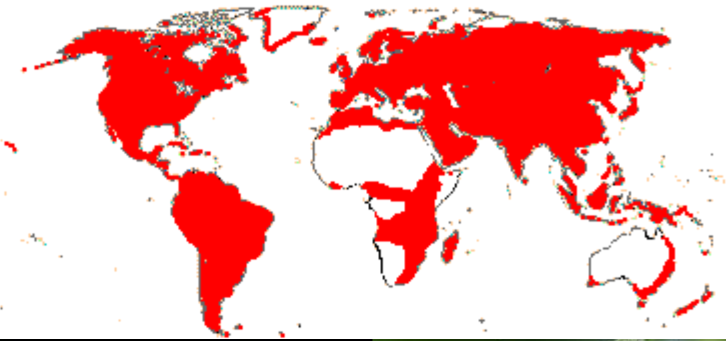
Cannabaceae ("cannabis")

Rosaceae ("rosas", "almendros", "albaricoqueros", "ciruelos")

Moraceae ("higos" and "moras")

Rosids: order *Rosales*, family *Rosaceae*

- Herbaceous to woody plants, also lianas.
- Alternate leaves, simple to compound.
- **Actinomorphic** flowers, usually **pentamerous**; free petals and ovary (gynoecium) located at different positions: superior in *Fragaria* or *Spiraea;* inferior in *Pyrus* or *Malus*; mid or central in *Rosa* or *Prunus.*
- Great fruit variability: polyfollicle, polyachene, polydrupe, pome, achene, drupe, cynarrhodium, etaerio, etc.



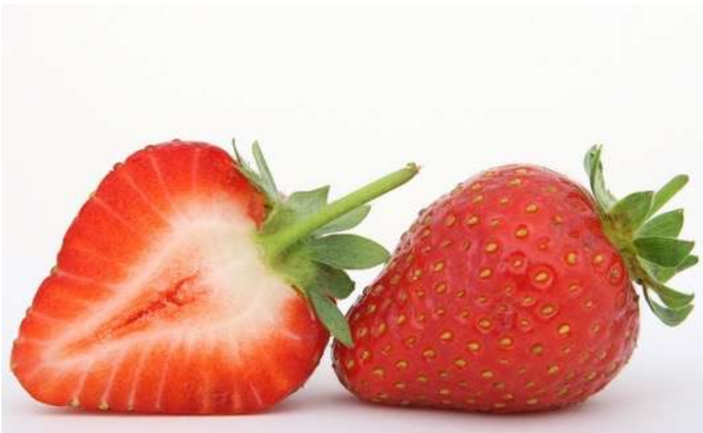
***Fragaria* sp.**

***Prunus* sp.**

***Pyrus* sp.**

Rosids: order *Rosales*, family *Rosaceae*

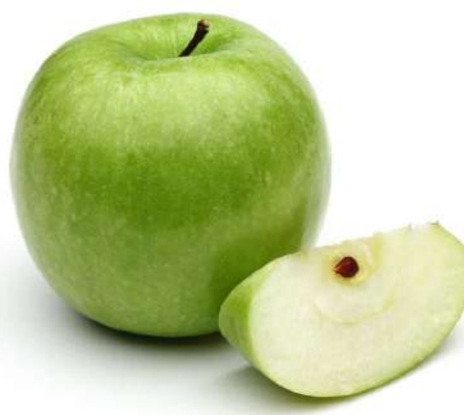
- Great fruit variability: polyfollicle, polyachene, polydrupe, pome, achene, drupe, cynarrhodium, etaerio, etc.



Etaerio (*Fragaria* sp.)

Cynarrhodium (*Rosa* sp.)

Pome (*Eriobotrya japonica*)

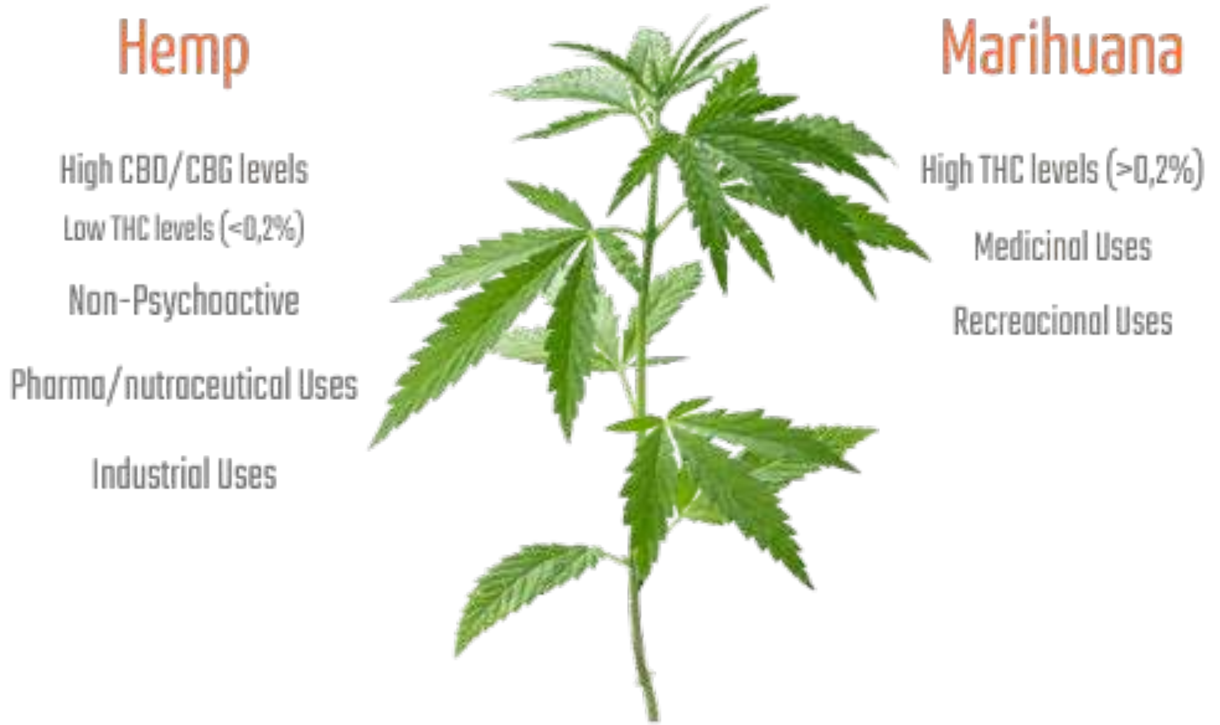


Pome (*Malus* sp.)

Drupe (*Prunus persica*)

Polydrupe (*Rubus ulmifolius*)

Rosids: order *Rosales*, family *Cannabaceae*



Probably the "best known" ingredient of *Cannabis*, trichomes is the psychoactive molecule **Δ-9-tetrahydrocannabinol (THC)**. However, over 480 compounds have been identified in the *Cannabis* genus, some of which have important therapeutic properties (Elsohly 2005). Indeed, several *Cannabis sativa* varieties have a minimum and legally permitted content of this THC molecule as well as a high content of other molecules such as **cannabidiol (CBD)** and **cannabigerol (CBG)**, which have an important therapeutic value.

https://www.tricopharming.com

Rosids: order *Rosales*, family *Cannabaceae*

Humulus lupulus (hop, "lúpulo") contains a variety of sesquiterpenoids, diterpenoids, triterpenoids, phytoestrogens, and the flavonoid xanthohumol, which has some in vitro anti-HIV activity. In addition to their use in **brewing beer** (where the bitter phytochemicals found in inflorescences are used), hops have been used for **sedative purposes**, though evidence of their efficacy is poor (Arranz et al. 2015).

Rosids: order *Fabales*, family *Fabaceae* (= *Leguminosae*)

- Herbaceous to woody, sometimes climbing, plants.

- Alternate leaves, which are often compound and with stipules.

- **Pentacyclic** flowers, usually **pentamerous** and often **zygomorphic**.

- Heteropetalous (**papilionaceous**) corolla; the fruit is a **legume** or a variation of a legume.

- ***Ulex***, ***Genista***, ***Cytisus***, ***Retama***, ***Trifolium***; this family of plants includes species that are important foods (legumes) for humans.

Root nodules-*Rhizobium* bacteria, atmospheric nitrogen fixers.

Rosids: order *Fabales*, family *Fabaceae*

Rosids: order *Fabales*, family *Fabaceae*

Ceratonia siliqua (carob tree). A Mediterranean species with fleshy, indehiscent fruits.

Some species of ***Acacia*** have flattened petioles (**phyllodes**) that serve as leaves.

Mimosa pudica is sensitive to heat or friction and moves its leaves rapidly.

Erythrina crista-galli (cockscomb) and ***Cercis siliquastrum*** (Judas tree/love tree) are widely used in gardening.

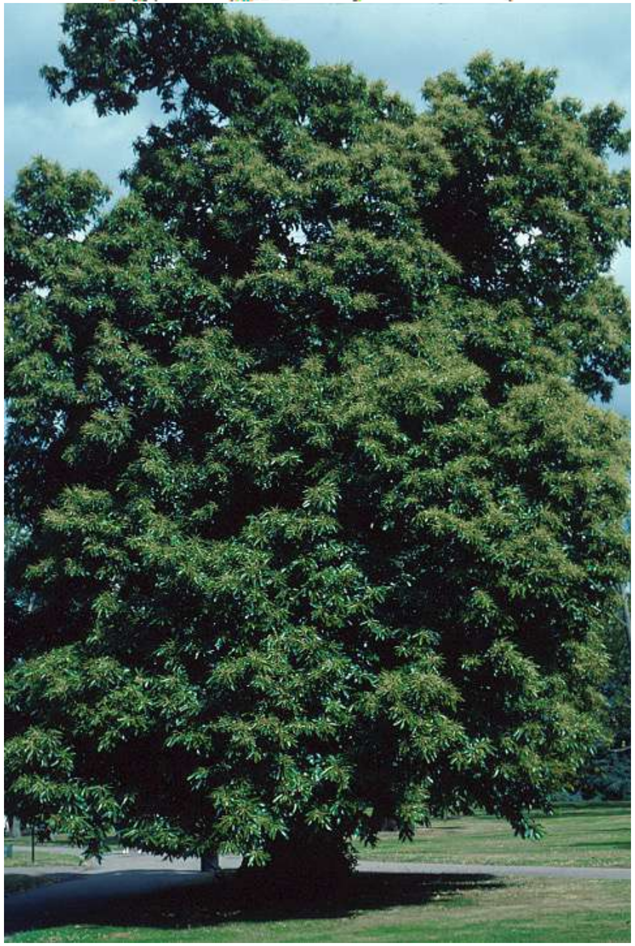
Rosids: order *Fabales*, family *Fabaceae*

Glycine max, commonly called **soybean** ("soja"), is an erect, bushy, hairy, annual legume. It features white to purple-pink flowers and trifoliate leaves. The flowers are small and ornamentally insignificant, somewhat resembling those of peas. The flowers bloom from mid- to late summer. The fruit is a hairy pod that grows in clusters of 3-5. Each pod contains 2-4 seeds. Soybeans are a major global food crop nowadays. They are grown mostly for their protein- and oil-rich seeds but also for forage, cover and green manure. Additional non-food uses such as biodiesel fuel are becoming increasingly significant. The genus name comes from Greek *glykys,* meaning sweet. This species is native to eastern Asia, where it was first cultivated in China around 3000 BC. (https://www.missouribotanicalgarden.org).

Rosids: order *Fagales*, family *Fagaceae*

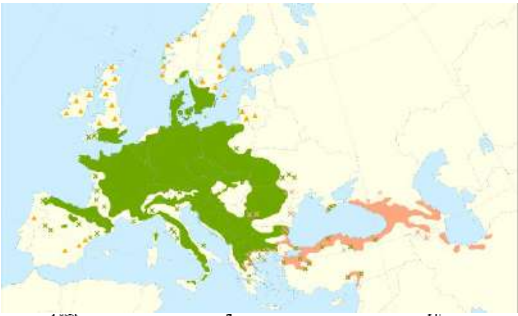
- Monoecious trees and shrubs.
- Alternate leaves.
- Unisexual flowers.
- Catkins inflorescences.
- Female flowers lack petals and can be clustered in groups of up to 3 flowers; in addition, they are included in an acrescent involucre made of scales (cupule or dome).
- The species includes tree genera that are components of forests that provide potential vegetation in large areas of temperate zones.
- The bark has a high concentration of tannins (astringents).

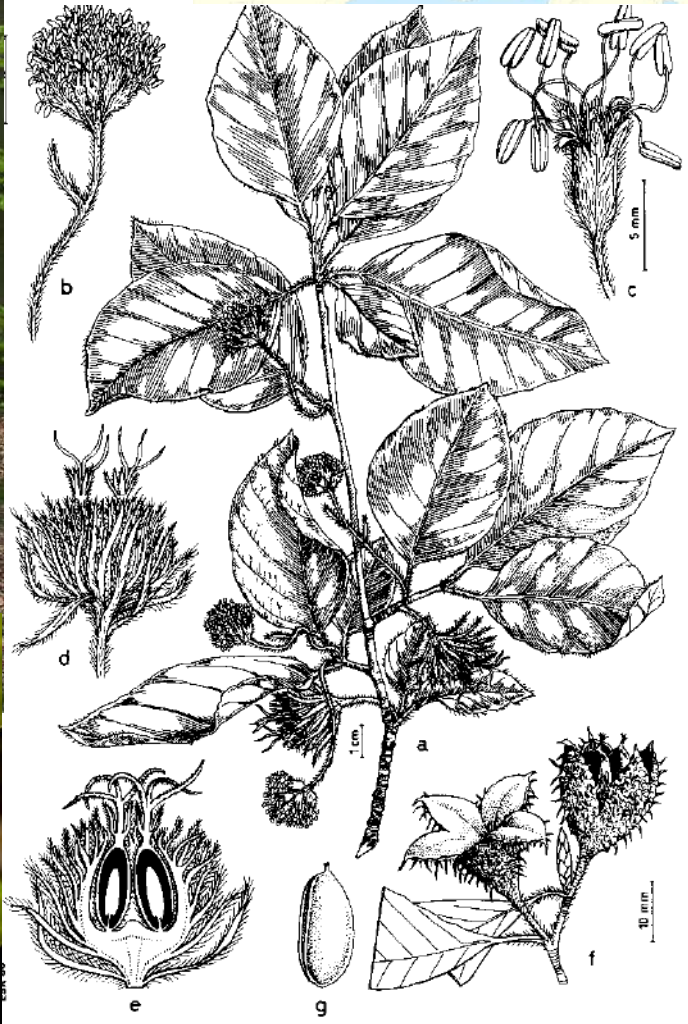
Castanea sativa



Rosids: order *Fagales*, family *Fagaceae*

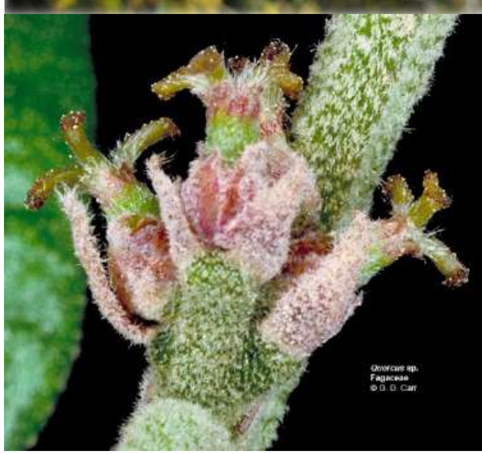
Fagus sylvatica **(beech, “haya”, “faig”)**





Rosids: order *Fagales*, family *Fagaceae*

The genus *Quercus*



Rosids: order *Fagales*, family *Fagaceae*, the genus *Quercus*

Main native species of *Quercus* in the Iberian Peninsula:

With perennial sclerophyllous leaves:

- *Quercus coccifera* ("coscoja")
- *Q. ilex* subsp. *ilex* ("encina", northern Mediterranean)
- *Q. ilex* subsp. *rotundifolia* (= subsp. *ballota*) ("carrasca" or "encina," south-western Mediterranean)
- *Q. suber* ("alcornoque")

With marcescent leaves:

- *Q. faginea* ("roble quejigo" or "rebollo")
- *Q. pyrenaica* ("roble melojo")

With deciduous leaves:

- *Q. robur* ("roble común" or "carballo")
- *Q. petraea* ("roble albar")

The English term for "encinas" and "robles" is oak.

Rosids: order *Fagales*, family *Fagaceae*, the genus *Quercus*

Quercus coccifera

"Coscoja, *coscoll*"

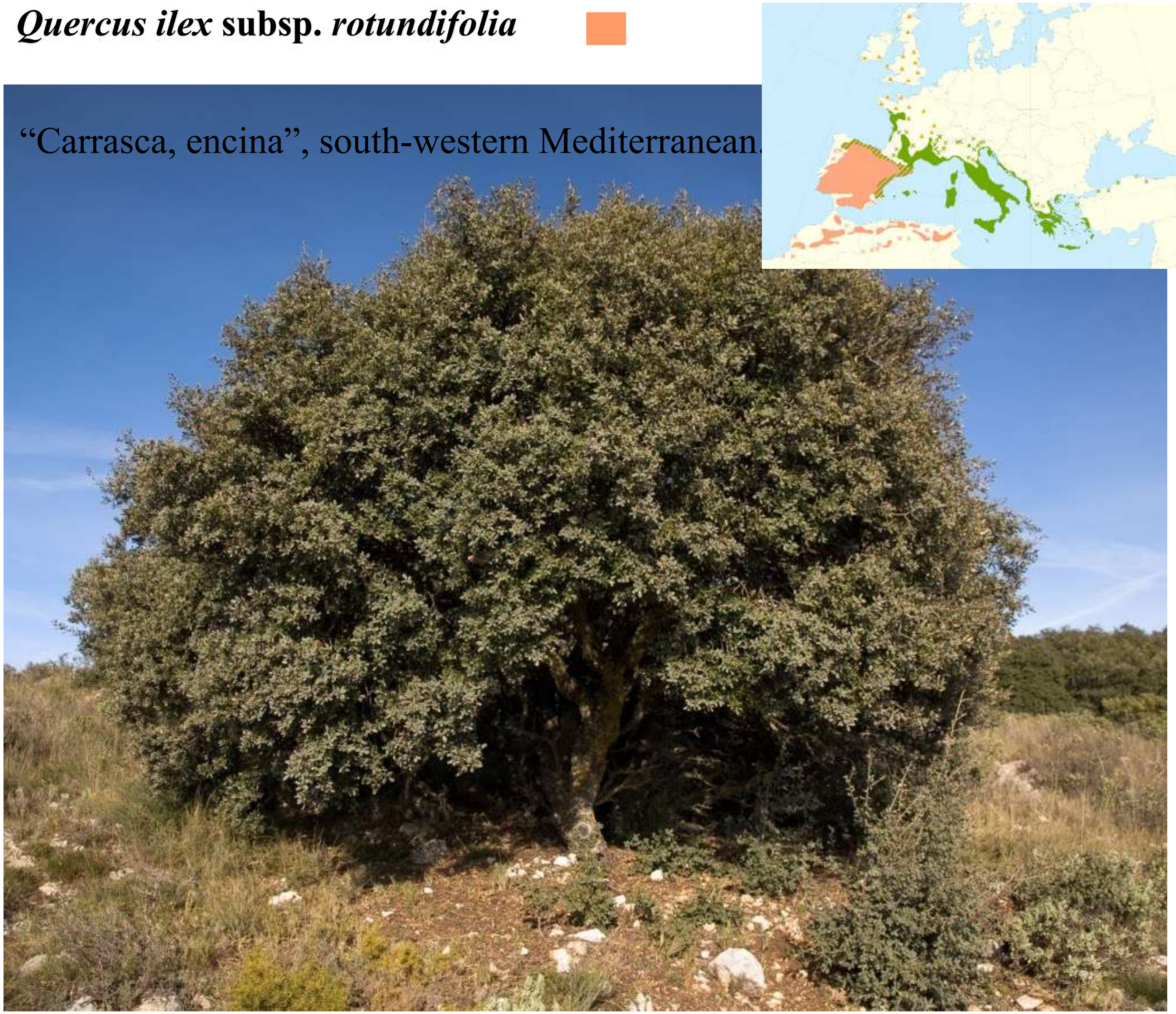
This species forms dense thickets in the Mediterranean region.

Acorn dome with spinescent scales.

Rosids: order *Fagales*, family *Fagaceae*, the genus *Quercus*

Quercus ilex* subsp. *rotundifolia

“Carrasca, encina”, south-western Mediterranean.



Carrascal (*holm-oak tree forest*) in Font Roja (Alicante)

Rosids: order *Fagales*, family *Fagaceae*, the genus *Quercus*

Quercus suber

Quercus suber in a pasture in Extremadura

Rosids: order *Geraniales*


- Herbaceous plants without secretory cavities
- Divided leaves
- Actinomorphic pentacyclic, pentamerous, hypogynous flowers that tend towards zygomorphy
- Superior syncarpous gynoecium
- Dry and polysperm fruit
- Two native genera from our region are ***Geranium*** and ***Erodium***.

Rosids: order *Myrtales*

- Mostly woody plants
- Leaves with essential oils in lysogenic cavities
- Actinomorphic, tetra/pentamerous flowers with a double perianth; inferior gynoecium with fused carpels
- Important families:

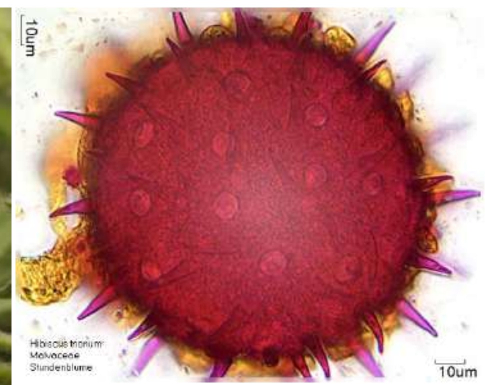
***Punicaceae* (e.g. *Punica granatum*)**

***Myrtaceae* (e.g. *Myrtus communis*, *Eucalyptus* spp.)**

Rosids: order *Malvales*, family *Malvaceae*

These include trees (*Tilia*), shrubs (*Hibiscus*) and herbaceous plants (*Malva*, *Lavatera*). The flowers are pentamerous, in many genera with epicalyx; stamens with filaments fused to the style; ovary superior, syncarpous. Pollen usually pantoporate.

Lavatera cretica

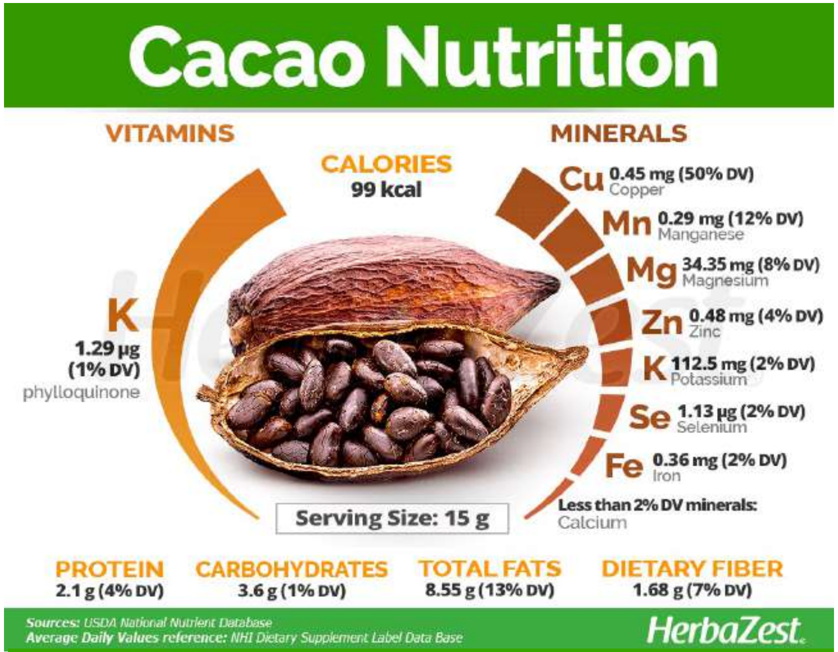


Hibiscus rosa-sinensis

***Gossypium hirsutum* (cotton plant)**

Rosids: order *Malvales*, family *Malvaceae*

Theobroma cacao



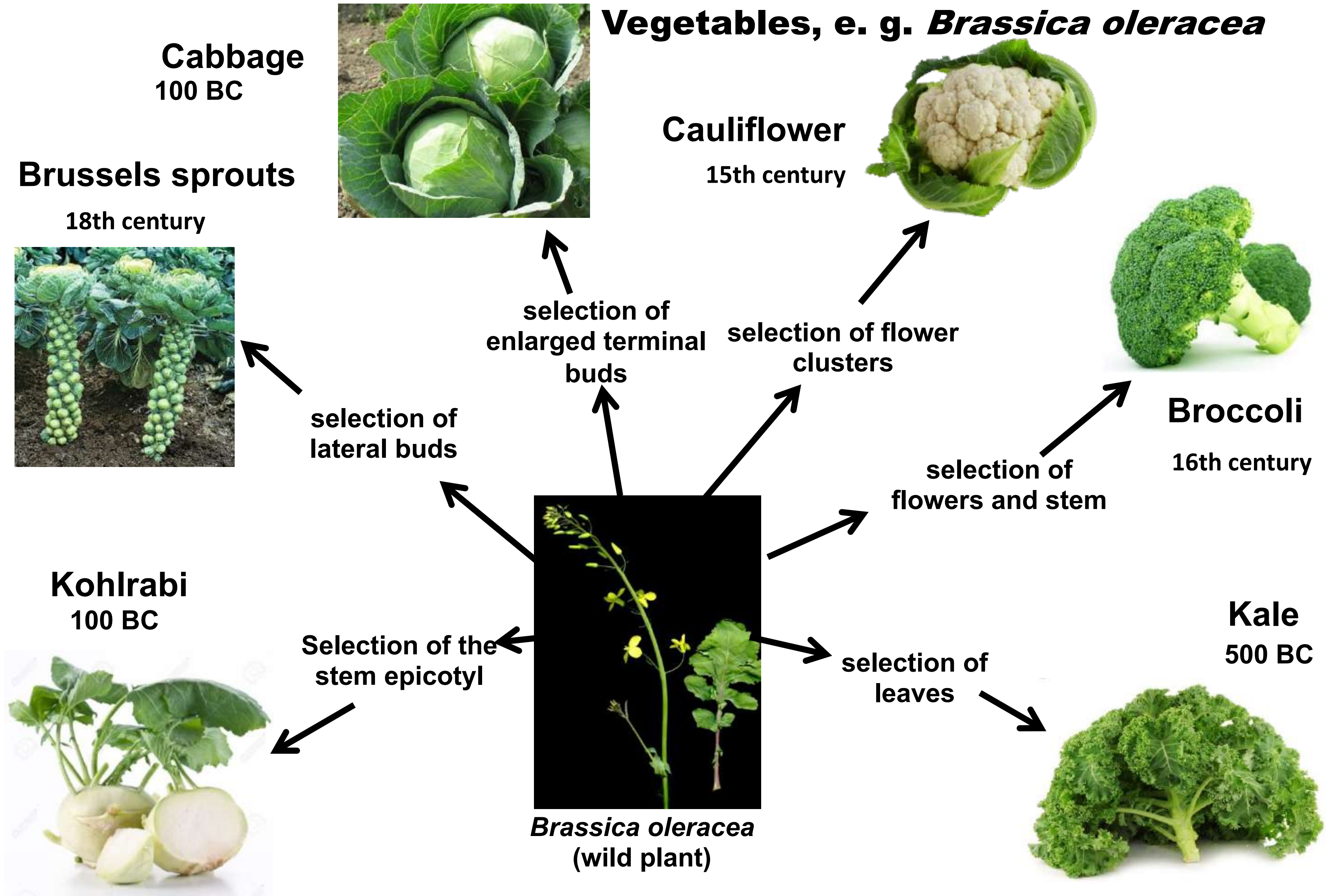
Rosids: order *Malvales*, family *Cistaceae*

These include rockroses ("jaras", *Cistus*; *Helianthemum* and *Fumana*), which are typical of Mediterranean dry scrublands.

Rosids: order *Brassicales*, family *Brassicaceae* (= *Cruciferae*)

- These include some 3,600 species of herbaceous or shrubby plants with a subcosmopolitan distribution.
- Alternate or basal leaves.
- Dissymmetric flowers with 4 sepals, 4 petals, 4+2 stamens, and 2 fused carpels.
- Dehiscent, dry fruits; often silique or silicule.

Rosids: order *Brassicales*, family *Brassicaceae* (= *Cruciferae*) - Artificial selection



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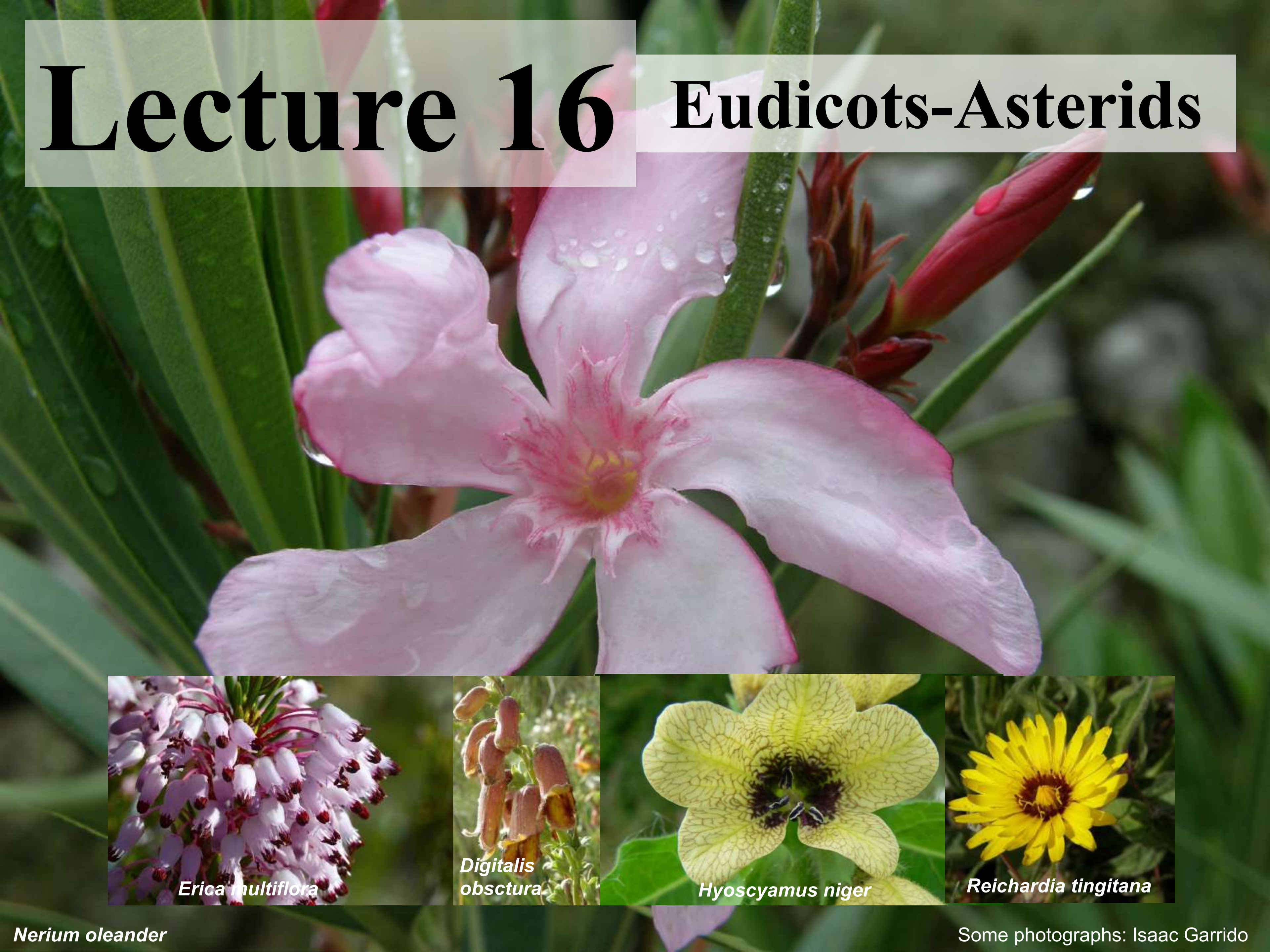
Lecture 16 Eudicots-Asterids



Erica multiflora

Digitalis obsctura

Hyoscyamus niger

Reichardia tingitana

Nerium oleander

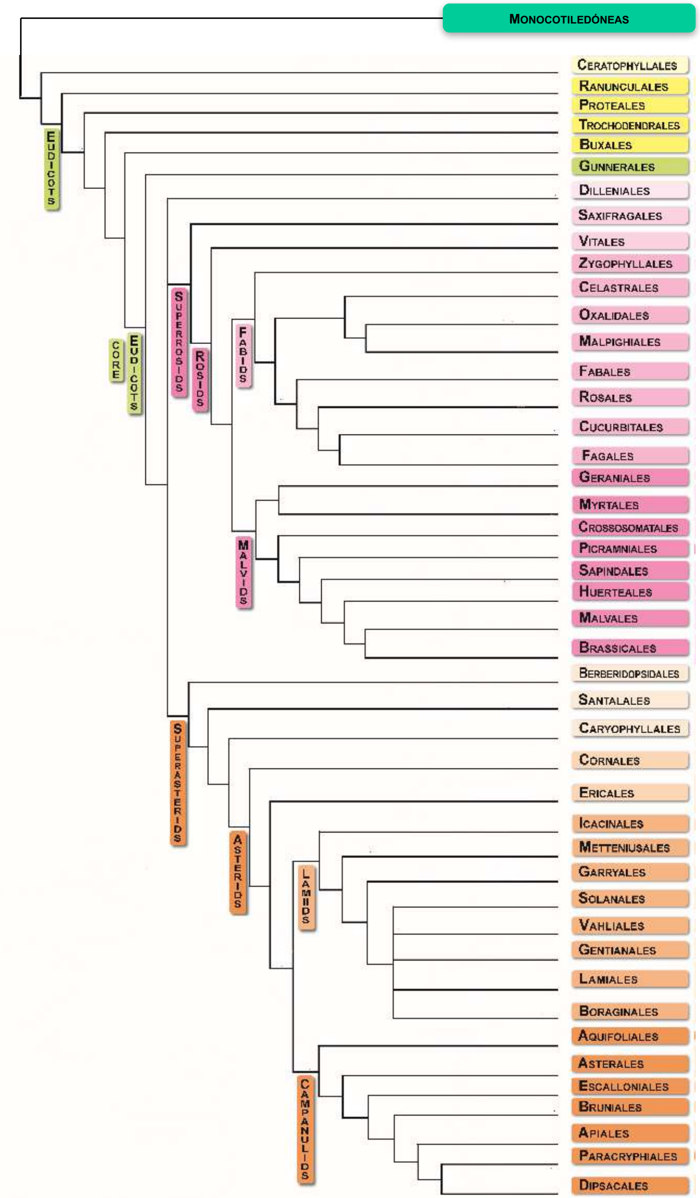
Some photographs: Isaac Garrido

Topics

Main traits of Asterids

Diversity of Asterids and their uses for humans

Phylogenetic position of Asterids within *Magnoliophyta*

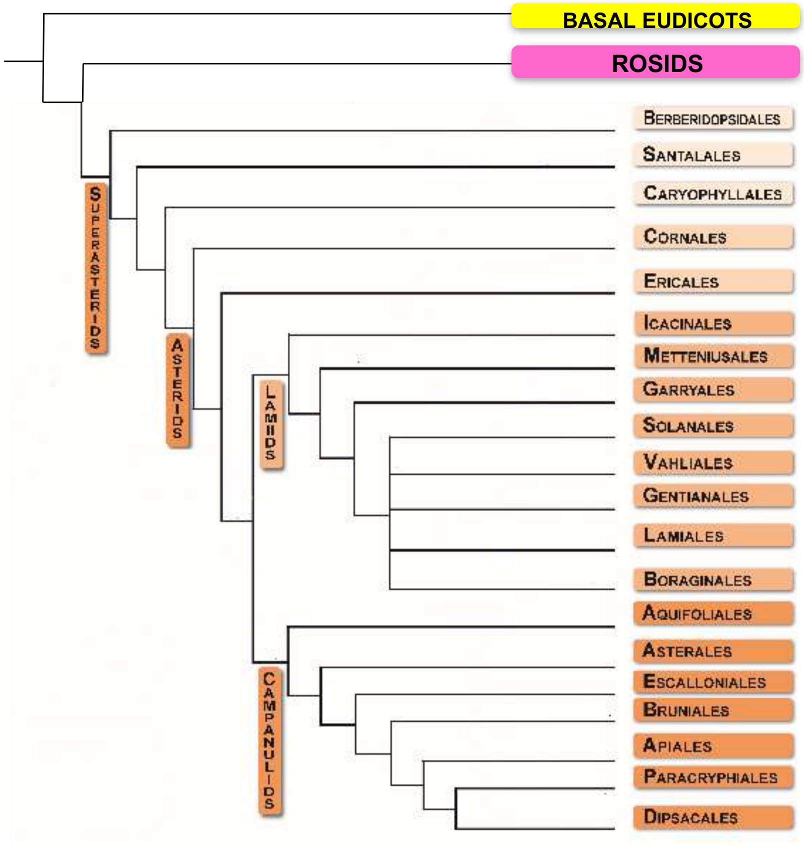


Basal Eudicots

Subclass *Rosidae* (Rosids)

Subclass *Asteridae* (Asterids)

The nucleus of Eudicots: Asterids (subclass *Asteridae*)



Herbaceous to woody plants.
Often produce iridoid monoterpens.
Tetracyclic, actinomorphic or zygomorphic flowers.
Adaptations to entomophilic pollination.
Pentamerous perianth.
Synpetalous, with **epipetalous stamens**.
Fused carpels.
Superior or inferior ovary.
Seed primordia with one tegument.
17 orders and 80,000 species.


Caryophyllales


Ericales


Solanales


Lamiales


Boraginales


Asterales


Apiales


Dipsacales

Topics

Main traits of Asterids

Diversity of Asterids and their uses for humans

Asterids: order *Caryophyllales*

These include plants that are nitrophilic, halophilic or xerophilic; many others inhabit extreme habitats (**extremophilic**).

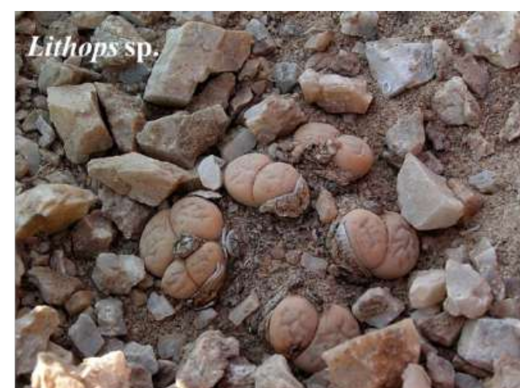
This group of plants is characterised by their **actinomorphic** and **pentamerous flowers**; the pigments present in floral pieces contain nitrogen (**betalaine**). Most belong to the families ***Aizoaceae***, ***Cactaceae***, ***Amaranthaceae*** or to ***Caryophyllaceae***.

Fam. *Caryophyllaceae*

Fam. *Cactaceae*

Fam. *Amaranthaceae*

Fam. *Aizoaceae*



Asterids: order *Ericales*, family *Ericaceae*

Woody plants; flowers with an urceolate corolla: ***Erica***, ***Arbutus***, ***Calluna*** and ***Arctostaphyllos***. The pollen grains are often dispersed in tetrads.

Vaccinium myrtillus *Erica arborea*

Erica multiflora

Asterids: order *Ericales*, family *Ericaceae*

Arbutus unedo, Strawberry tree

"Madroño" or "arbocer"

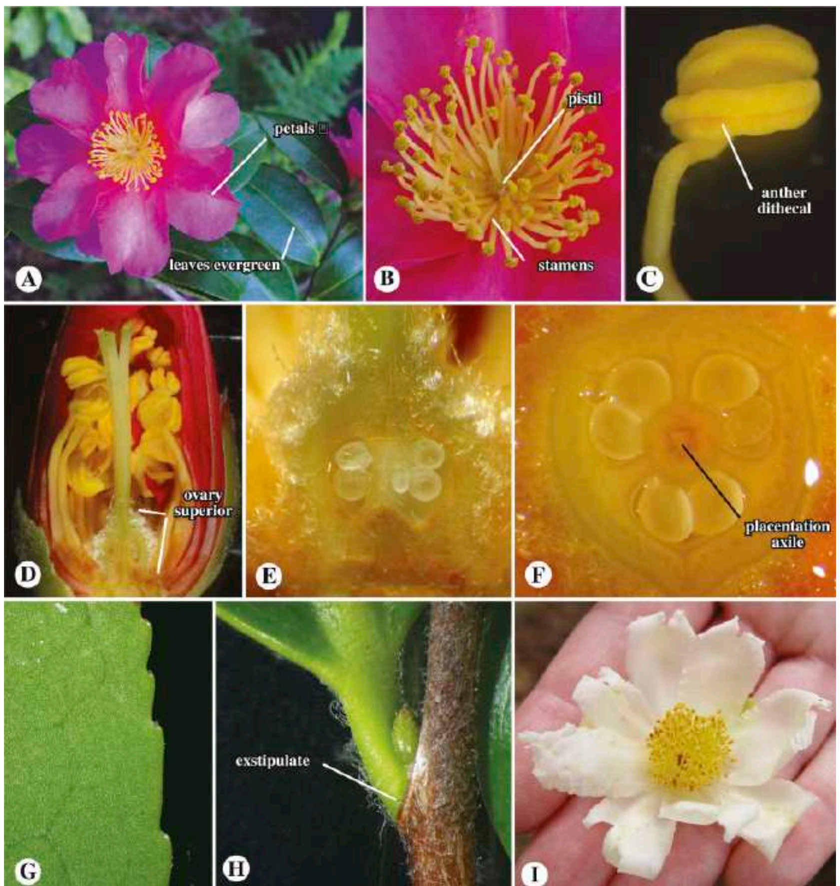
Ravines and thickets in temperate-to-warm, somewhat humid environments (laurel forest remains).

Asterids: order *Ericales*, family *Theaceae*

This small, essentially tropical family is especially diverse in southeast Asia and China, where its best-known genus is *Camellia*. The plants are generally perennial shrubs.

- They have an ornamental interest: ***Camellia japonica***.
- Their leaves are collected for producing different types of teas: ***Camellia sinensis***.

The leaves are rich in essential oils, polyphenols, vitamin C and **alkaloids** such as **caffeine** and **theine**.



***Camellia sinensis*, tea**

Adapted from Simpson (2010)

Asterids: order *Gentianales*

The angiosperm order *Gentianales* comprises five plant families: ***Apocynaceae*** (dogbanes and milkweeds, including *Asclepiadaceae*), *Gelsemiaceae*, ***Gentianaceae*** (gentians), *Loganiaceae* (strychnine plants), and ***Rubiaceae*** (**coffee** and madder plants). The families are distributed worldwide in most climates but are most abundant in the tropics. They can be large trees, shrubs, herbs or small saprophytes. They are characterised by their opposite, simple leaves usually with interpetiolar structures (stipules, lines or ridges). They have showy flowers, usually with 4–5 calyx and corolla lobes and 4–5 stamens attached inside the corolla. **Some typical phytochemicals are caffeine, toxic indole alkaloids and cardiac glycosides (e.g. strychnine, vincristine), and bitter tasting secoiridoids** (Struwe 2002).

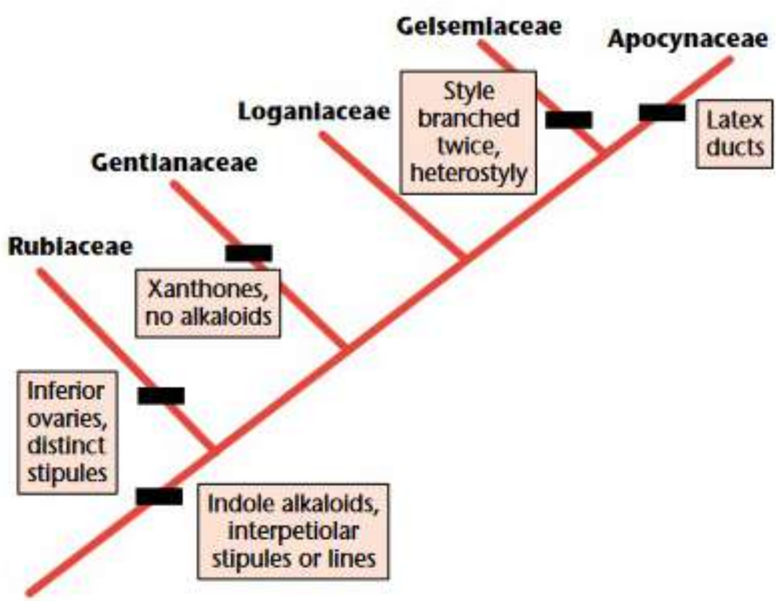
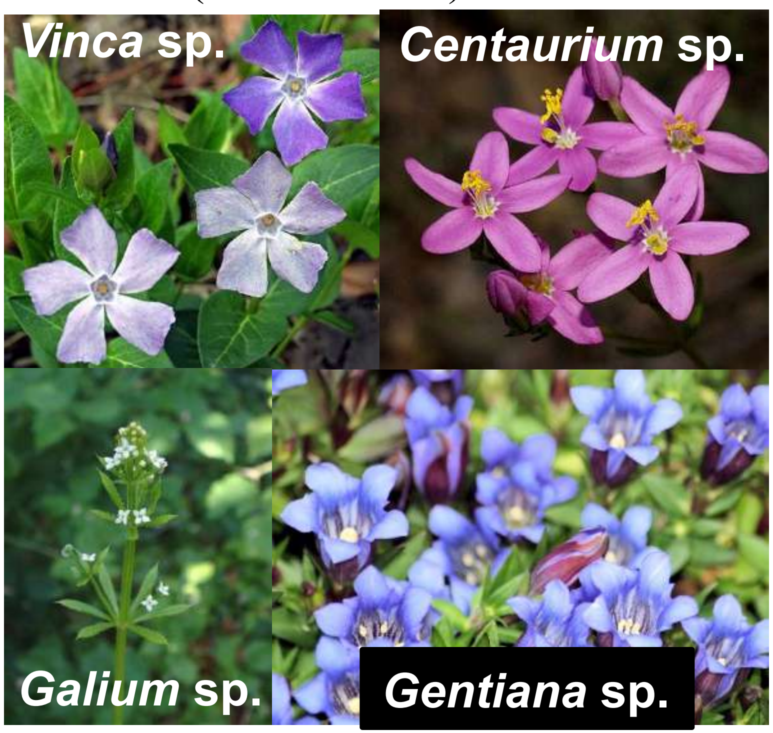


Figure 7 Synopsis of phylogenetic relationships in Gentianales. Characteristics for families and groups of families are noted.



Asteridsː order *Gentianales*, family *Apocynaceae*

Nerium oleander (oleander; "adelfa, baladre"). Oleander has traditionally been used to treat cardiac illness, asthma, diabetes mellitus, corns, scabies, cancer and epilepsy, and as an antibacterial/antimicrobial to heal wounds. However, quality clinical trials to support these uses are limited. Extreme caution should be taken because of its acute cardiotoxicity, hepatotoxicity and nephrotoxicity (https://www.drugs.com).

Photographs: Isaac Garrido

Asterids: order *Gentianales*, family *Rubiaceae*

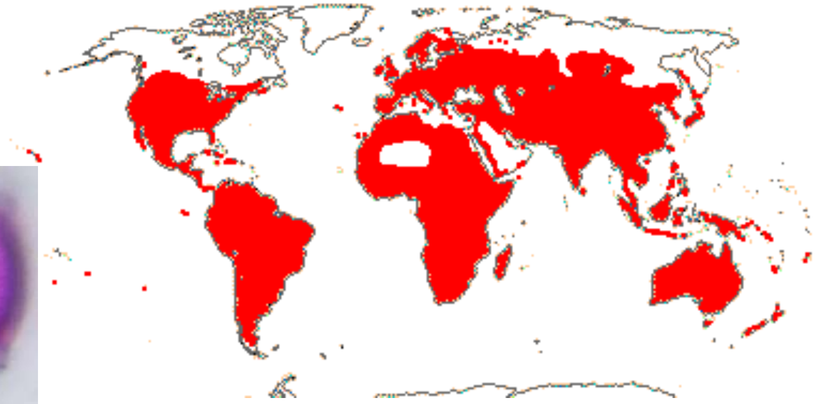
***Coffea arabica*, coffee**. Dried seeds "beans“ (drupes) are ground, roasted and brewed to make one of the two most important beverages in the western world. In its native Ethiopia, where it has been used as a masticatory since ancient times, it is also cooked in butter to make rich flat cakes. In Arabia a fermented drink from the pulp is consumed. Coffee is widely used as a flavoring in ice creams, pastries, candies and liqueurs. A source of **caffeine** (alkaloid), its dried ripe seeds are used as a stimulant, nervine, and diuretic acting on the central nervous system, kidneys, heart and muscles (https://hort.purdue.edu).

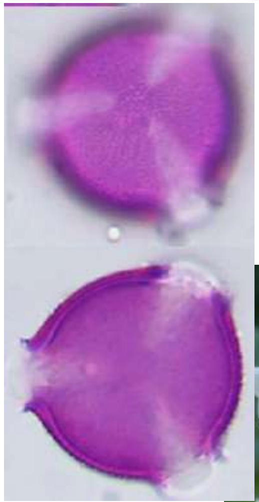
Asterids: order *Gentianales*, family *Rubiaceae*

***Cinchona officinalis*, quinine**. This South American tree is one of several *Cinchona* species used for the production of **quinine**, an **anti-fever agent**. It is especially useful in the prevention and treatment of **malaria**. Other alkaloids extracted from this tree include cinchonine, cinchonidine and quinidine.

Asterids: order *Solanales*, family *Solanaceae*

- Herbaceous or perennial plants.
- Alternate leaves.
- Flowers tetracyclic, pentamerous; sepals and petals fused.
- Pollen usually tricolporate.
- Gynoecium bicarpellar, superior.
- Fruit in berry or capsule.
- Some species produce toxic alkaloids (e.g. solanine, steroids with pharmaceutical interest, such as hyoscyamine, atropine, belladonine, scopolamine, and nicotine).
- Some species of agricultural interest are potatoes, eggplants, tomatoes, peppers. ***Solanum, Atropa, Hyoscyamus*.**





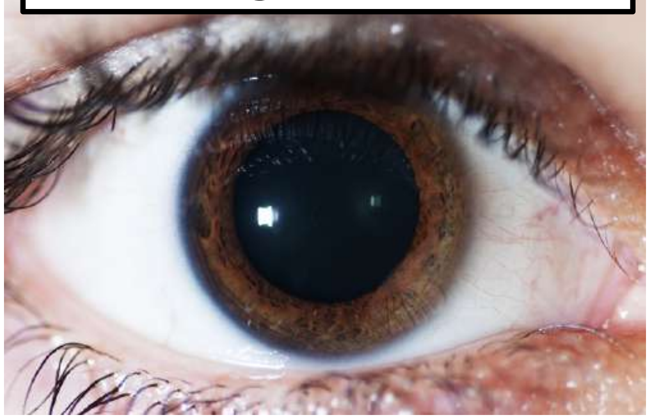
Solanum tuberosum
(potato)

Lycopersicum esculentum (tomato)

Asterids: order *Solanales*, family *Solanaceae*

Atropine is a tropane alkaloid and anticholinergic medication used to treat certain types of nerve agents and pesticide poisonings as well as some types of slow heart rate, and to decrease saliva production during surgery.

Atropa belladonna
(Belladonna, or deadly nightshade)



Hyoscyamus niger
(Henbane, "beleño")

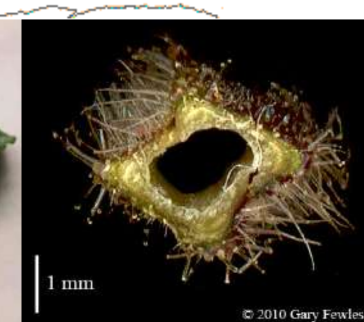
Henbane is used in traditional herbal medicine for ailments of the bones, rheumatism, toothache, asthma, coughs, nervous diseases, and stomach pain. In some cultures it may also be used as an analgesic, sedative, and narcotic.

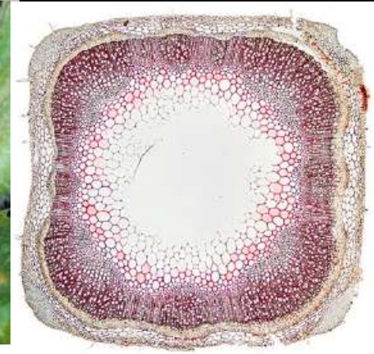
Asteroids: order *Solanales,* family *Solanaceae*

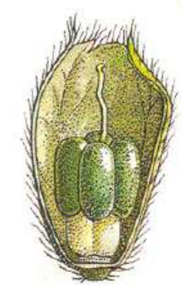
***Mandragora autumnalis*, mandrake,** is a highly valued wild medicinal herb. It is a perennial herbaceous plant with purple or violet blooms and orange or yellow mature fruits (berries). It is widely distributed throughout the Mediterranean Basin, including Palestine. It is still used in traditional Arabian medicine, especially Palestinian herbal medicine, to treat pains, insomnia, coughs, throat pain, bronchitis and various diseases of the genital organs. *Mandragora autumnalis* has antitumour, antioxidant and antimicrobial properties as well as free radical, cholinesterase, tyrosinase, α-amylase and α-glucosidase inhibitory activities (adapted from Al-Maharik et al. 2022).

Asterids: order *Lamiales,* family *Lamiaceae* (= *Labiatae*)

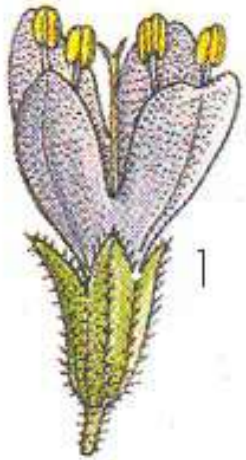
- Plants with **opposite** (and decussate) **leaves**.
- **Quadrangular** (square) **stem** (best seen in cross-section).
- **Aromatic plants** with glands and hairs with **essential oils**.
- Flowers are often **zygomorphic** with fused pieces.
- 5 fused sepals and 5 fused petals, often uneven.
- 2 stamens, or 4 didynamous.
- Pollen tricolpate/hexacolpate.
- Superior ovary is made up of two fused carpels that host two seed primordia; after fertilisation, they will give rise to a **schizocarp** divided into four monospermous fragments.
- Numerous important genera in Mediterranean scrublands are used as medicinal and flavouring agents, including ***Thymus*** (thyme, “tomillos”), ***Sideritis*** (ironwort, “rabos de gato”), ***Lavandula*** (lavender, “lavandas”), ***Salvia*** (sage, rosemary, “salvias”, “romero”), ***Mentha*** (mint, “mentas”), ***Satureja*** (savory, “ajedreas”), and ***Origanum*** (oregano, “orégano”), etc.



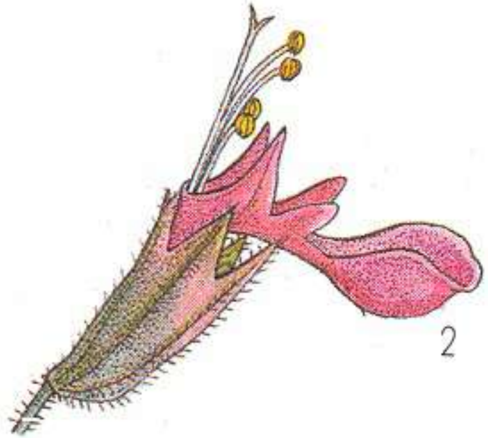




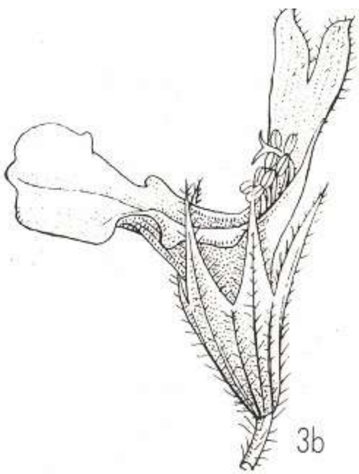
Asterids: order *Lamiales*, family *Lamiaceae* (= *Labiatae*)



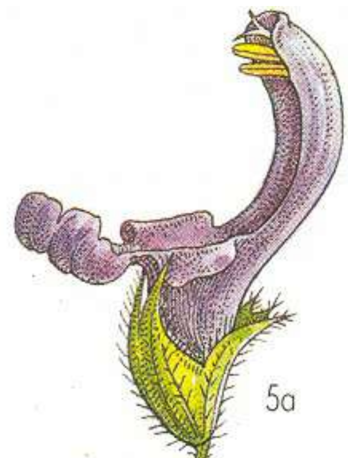
Actinomorphic calyx and corolla ***Mentha***



Unilabiate corolla of ***Teucrium***



Actinomorphic calyx and bilabiate corolla of ***Stachys***

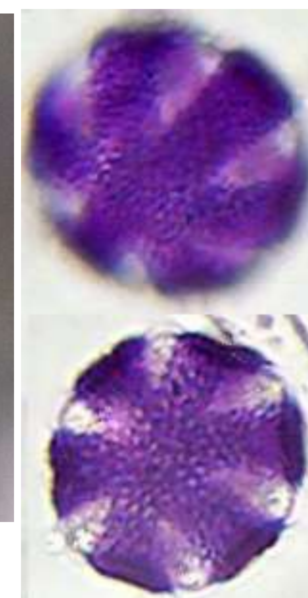


Bilabiate calyx and corolla of ***Salvia***

Asterids: order *Lamiales*, family *Lamiaceae* (= *Labiatae*)

***Lavandula latifolia*, lavender**

"Espliego" or "espígol comú"

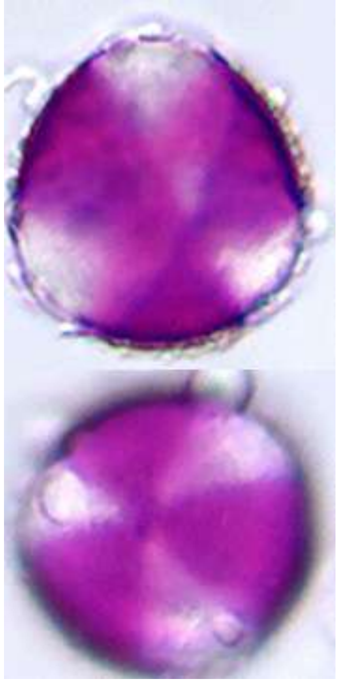


Western Mediterranean.
Dry scrubland on calcareous substrates.

Asterids: order *Lamiales*, family *Lamiaceae* (= *Labiatae*)

Phlomis lychnitis

"Oreja de liebre" or "orella de llebre"

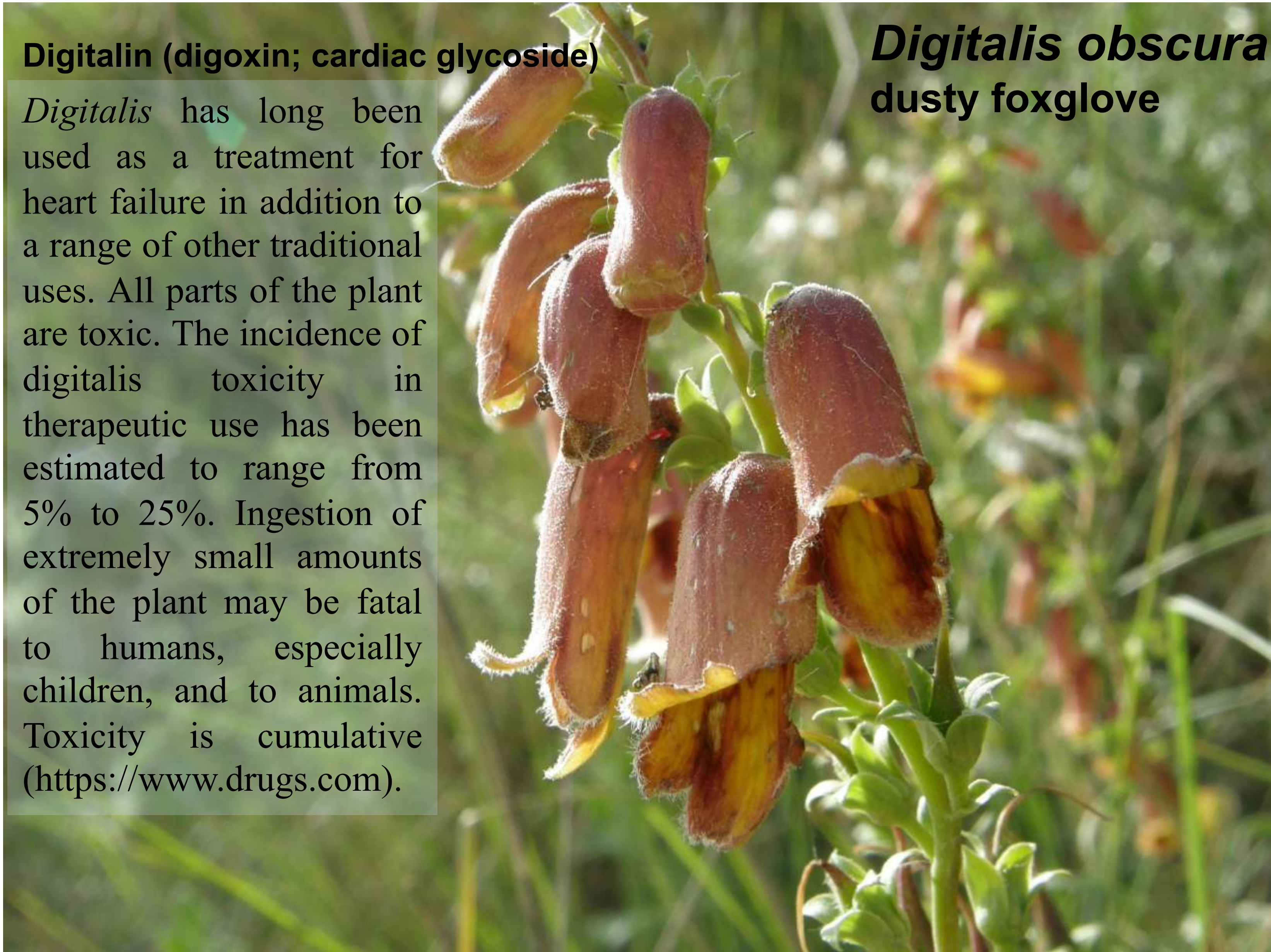


Asterids: order *Lamiales*, family *Lamiaceae* (= *Labiatae*)

Salvia rosmarinus, rosemary

"Romero" or "romer"

Asterids: order *Lamiales*, family *Scrophulariaceae*



Digitalin (digoxin; cardiac glycoside)

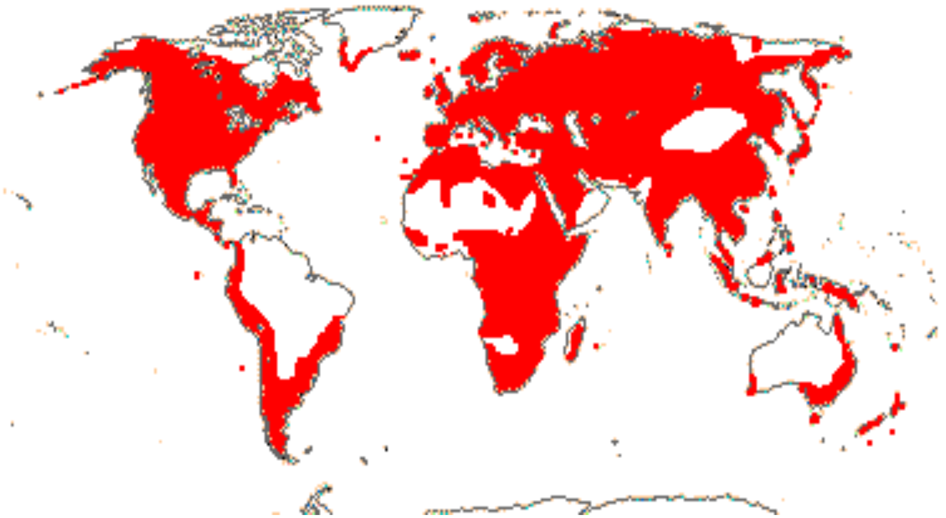
Digitalis has long been used as a treatment for heart failure in addition to a range of other traditional uses. All parts of the plant are toxic. The incidence of digitalis toxicity in therapeutic use has been estimated to range from 5% to 25%. Ingestion of extremely small amounts of the plant may be fatal to humans, especially children, and to animals. Toxicity is cumulative (https://www.drugs.com).

***Digitalis obscura*, dusty foxglove**

Photographs: Isaac Garrido

Asterids: order *Lamiales*, family *Apiaceae* (= *Umbelliferae*)

- Plants often herbaceous.
- Often compound and alternate leaves.
- **Small flowers**, **pentamerous**, 5 sepals (sometimes stunted), 5 free petals, 5 stamens, clustered in umbrellas.
- Syncarpellar, bicarpellar **inferior ovary**. **Dry fruit** in **dischizocarp**.
- Many are edible (e.g. carrot, parsnip, celery, parsley) or used as a medicine or condiment (e.g. fennel, coriander, cumin).
- Some contain essential oils or alkaloids.



Foeniculum vulgare
(fennel, "hinojo")

Asterids: order *Lamiales*, family *Apiaceae* (= *Umbelliferae*)

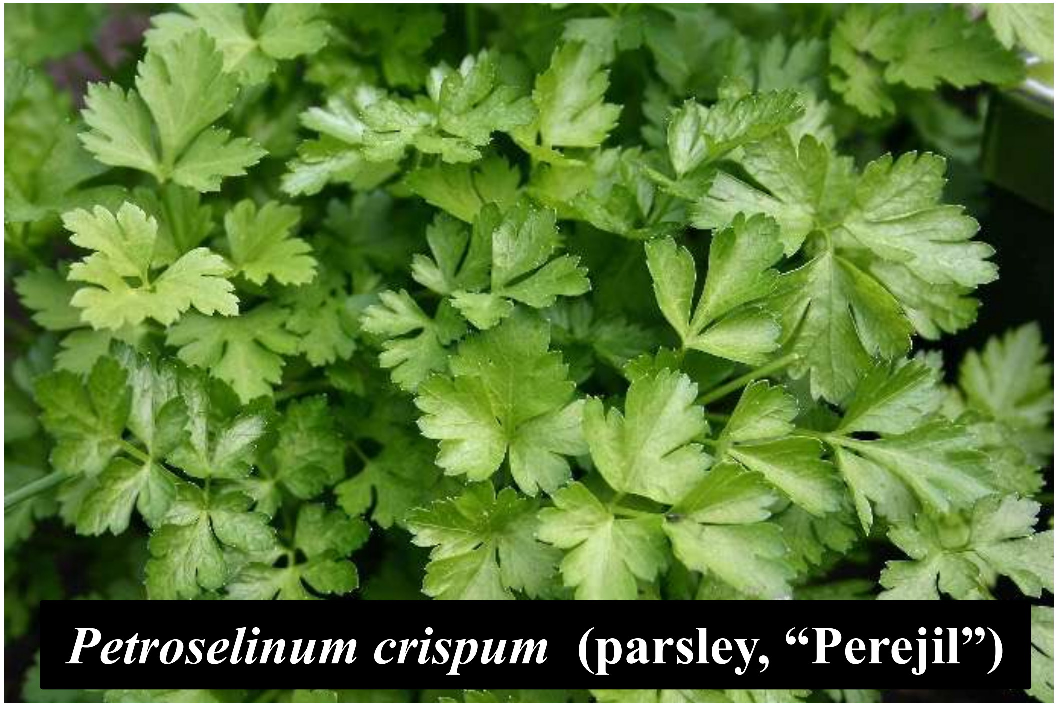
Conium maculatum **(hemlock, "Cicuta", neurotoxin)**

These contain alkaloids such as **coniine** (or **cycutin**, an alpha-propylpiperidine - piperidine), gamma-conycine, N-methylconiine, conhydrin and pseudoconhydrin, mainly in the unripe fruits. Coniine is a volatile, colourless, extremely toxic liquid at a concentration of up to 1% in fresh fruit. The first symptoms of poisoning are vomiting, dilated pupils, loss of coordination and cooling of the limbs, followed by paralysis, convulsions and death by respiratory paralysis. Poisoning is treated by administering medicinal charcoal to absorb the alkaloids, assisted respiration, and diazepam to control convulsions. Drastic vomiting measures such as syrup of ipecac and stomach pumping may also be used. The whole plant contains alkaloids, the concentration of which is lowest in roots and highest in green fruits. High temperatures increase the concentration of alkaloids. Coniine was used in ancient times for carrying out executions. **Poisoning can be caused simply by approaching the plant in circumstances where the alkaloids are more easily volatilised, such as high temperatures**. Adapted from https://www.plantasyhongos.es

Asterids: order *Lamiales*, family *Apiaceae* (= *Umbelliferae*)

Daucus carota (carrot, "zanahoria")

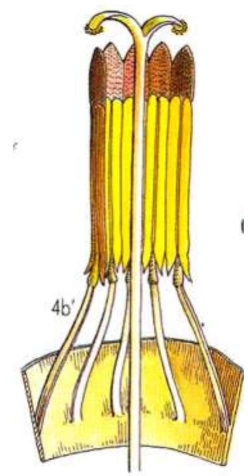
In addition to their nutritional properties, carrots are a rich source of antioxidants.

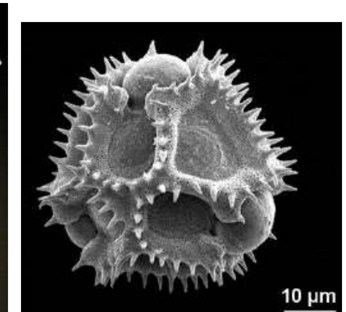


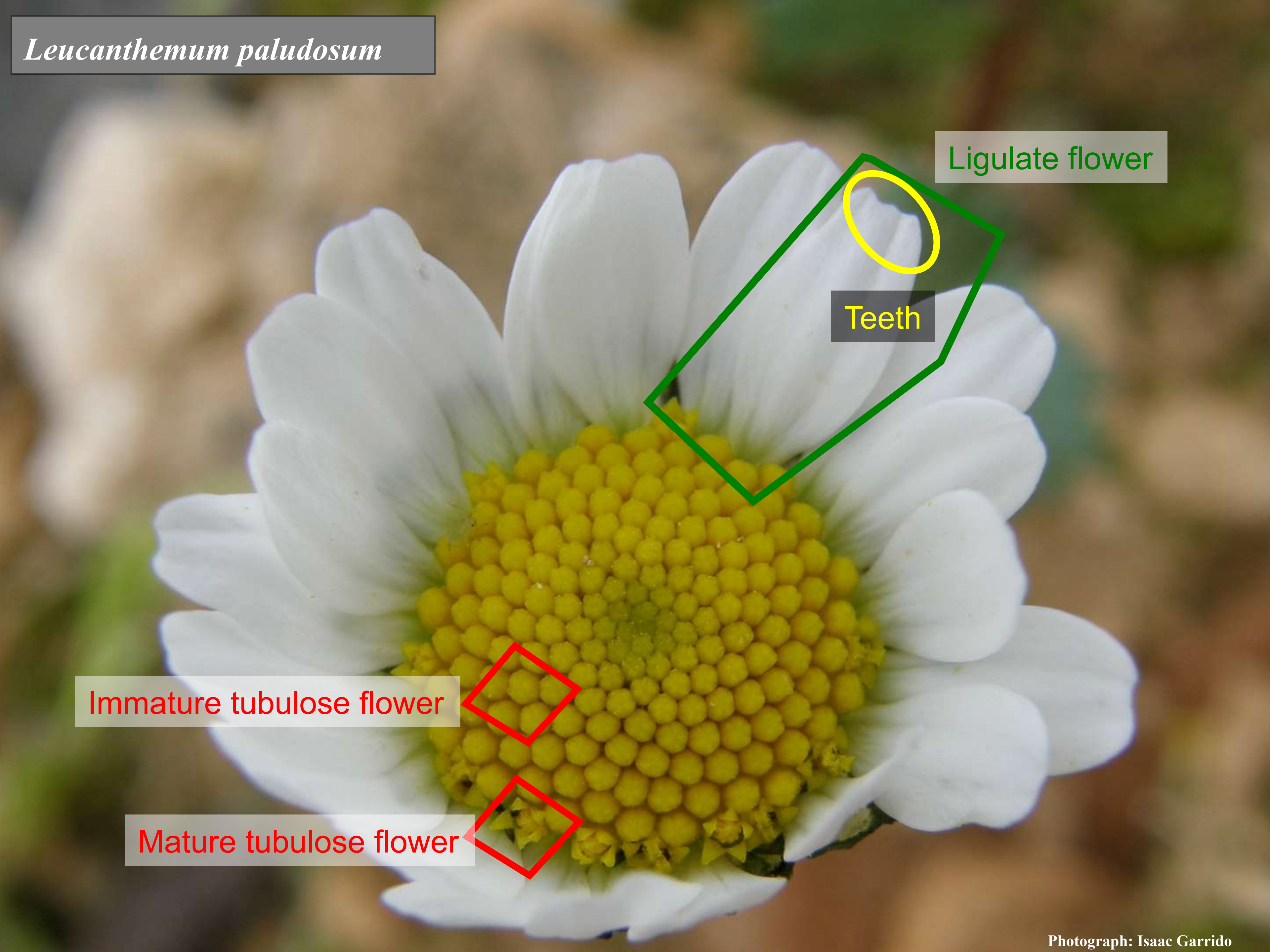
Petroselinum crispum **(parsley, "Perejil")**

Asterids: order *Asteraceae*, family *Asteraceae* (= *Compositae*)

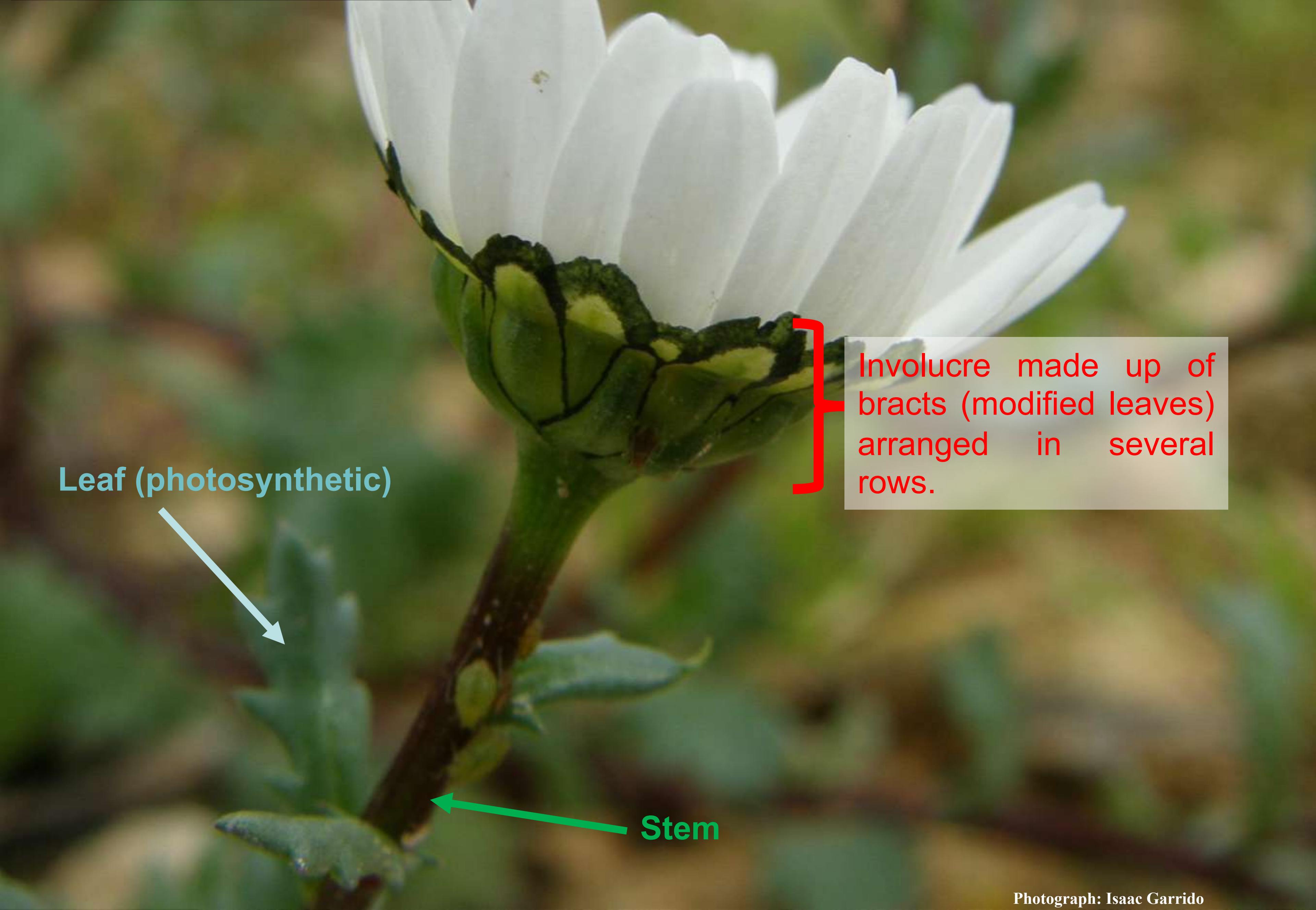
- Herbaceous to tree-forming plants.
- With polyacetylenes. **Inulin** as a reserve product instead of starch.
- **Actinomorphic or zygomorphic flowers** clustered in inflorescences called **capitula** (sing. capitulum).
- **Calyx stunted or reduced to a whorl of hairs**. Corolla with five fused petals (tubulose or ligulate).
- Five fused stamens (**synanthery**).
- Tricolporate pollen, often echinulate.
- Inferior ovary with one cavity, two fused carpels, and one seed primordium.
- **Dry fruit**, non-dehiscent, monospermous and complex: **cypsela**. Often carries a **pappus** of dispersing hairs.
- Many are edible vegetables (lettuce, endives, artichokes) or used for their seeds and oils (sunflower). Others have medicinal or cosmetic value (chamomile, southernwood) and yet others are ornamental (daisies, dalias, chrysanthemums).






Leucanthemum paludosum
Ligulate flower
Teeth
Immature tubulose flower
Mature tubulose flower
Photograph: Isaac Garrido

Leucanthemum paludosum



Asterids: order *Asteraceae*, family *Asteraceae* (= *Compositae*)

Basic types of capitula of *Asteraceae*

All tubulose flowers (the outer ones are longer).

Tubulose flowers in the central discs and ligulate ones in the periphery.

All ligulate flowers

Asterids: order *Asteraceae*, family *Asteraceae* (= *Compositae*)

Santolina chamaecyparissus
(“Manzanilla amarga”)

Helichrysum stoechas
(“Siempreviva”)

Asterids: order *Asteraceae*, family *Asteraceae* (= *Compositae*)

Achillea ageratum

Anacyclus clavatus

Andryala integrifolia

Galatella sedifolia

Bellis annua

Fotos: I. Garrido

Asterids: order *Asteraceae*, family *Asteraceae* (= *Compositae*)

Carthamus lanatus subsp. *lanatus*

Catananche caerulea

Centaurea pullata

Echinops ritro

Leuzea conifera

Reichardia tingitana

Fotos: I. Garrido

Helianthus annuus

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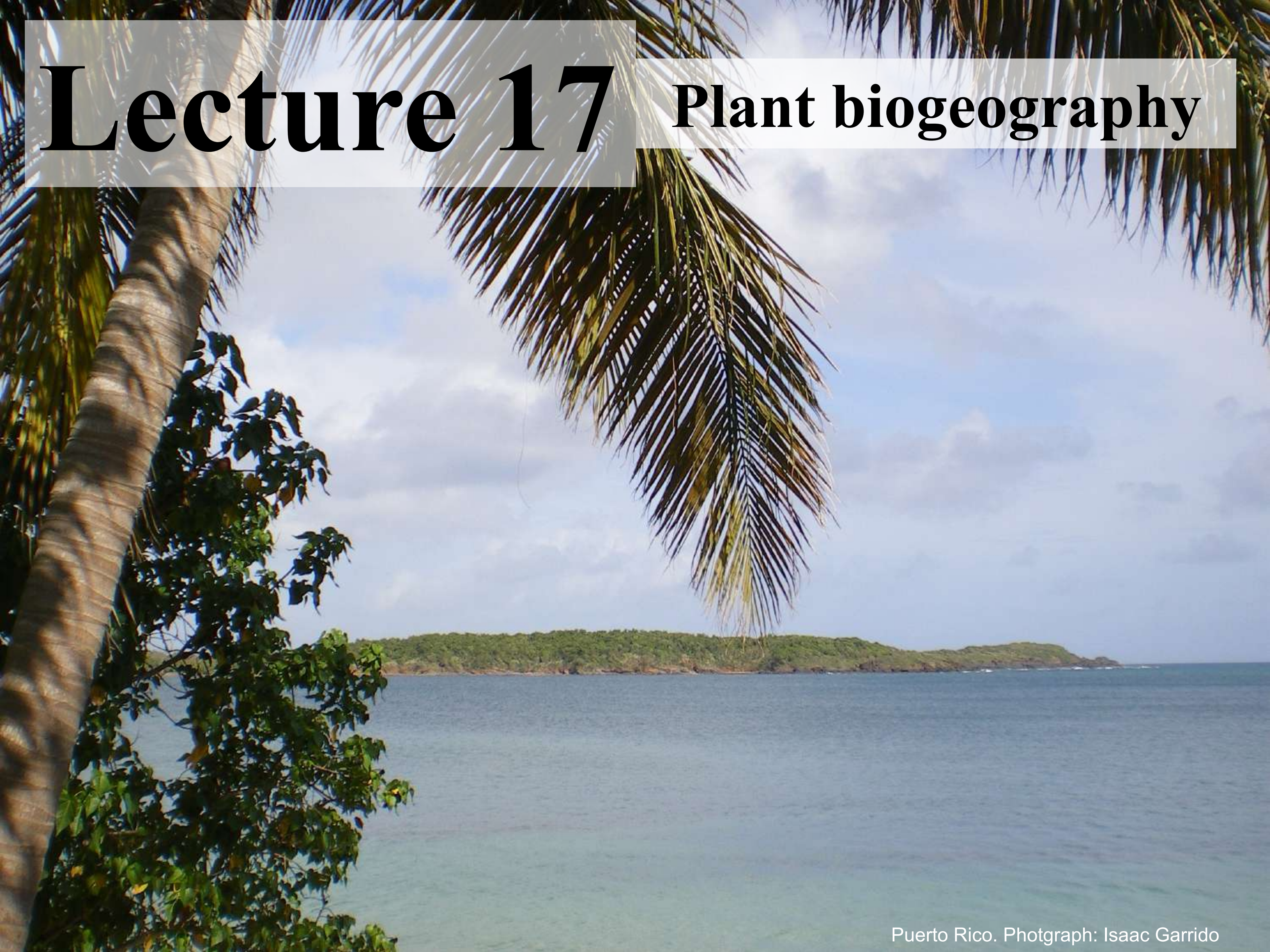
Lecture 17

Plant biogeography



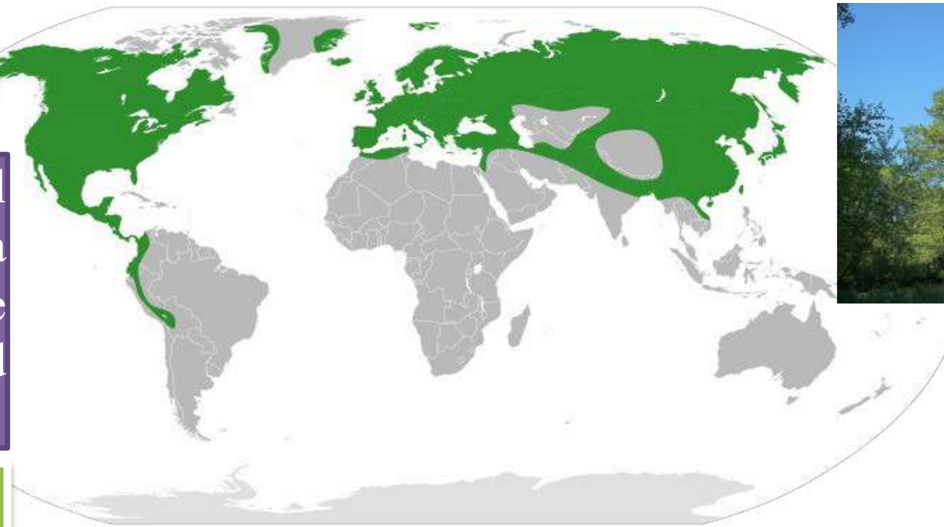
Puerto Rico. Photgraph: Isaac Garrido

Topics

Plant biogeography

Floristic kingdoms

Plant biogeography: phytogeography



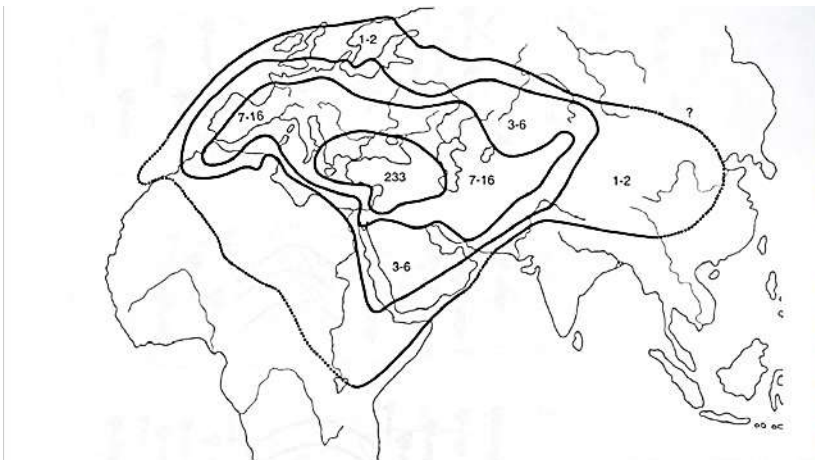
https://es.wikipedia.org/wiki/Alnus_glutinosa

<u>Biogeography</u> studies the spatial distribution of different taxa (species, genera, families) and the causal processes (historical and ecological) that determine it.

<u>Phytogeography</u> can be considered as biogeography applied to plants.

Distribution map of the genus *Alnus*

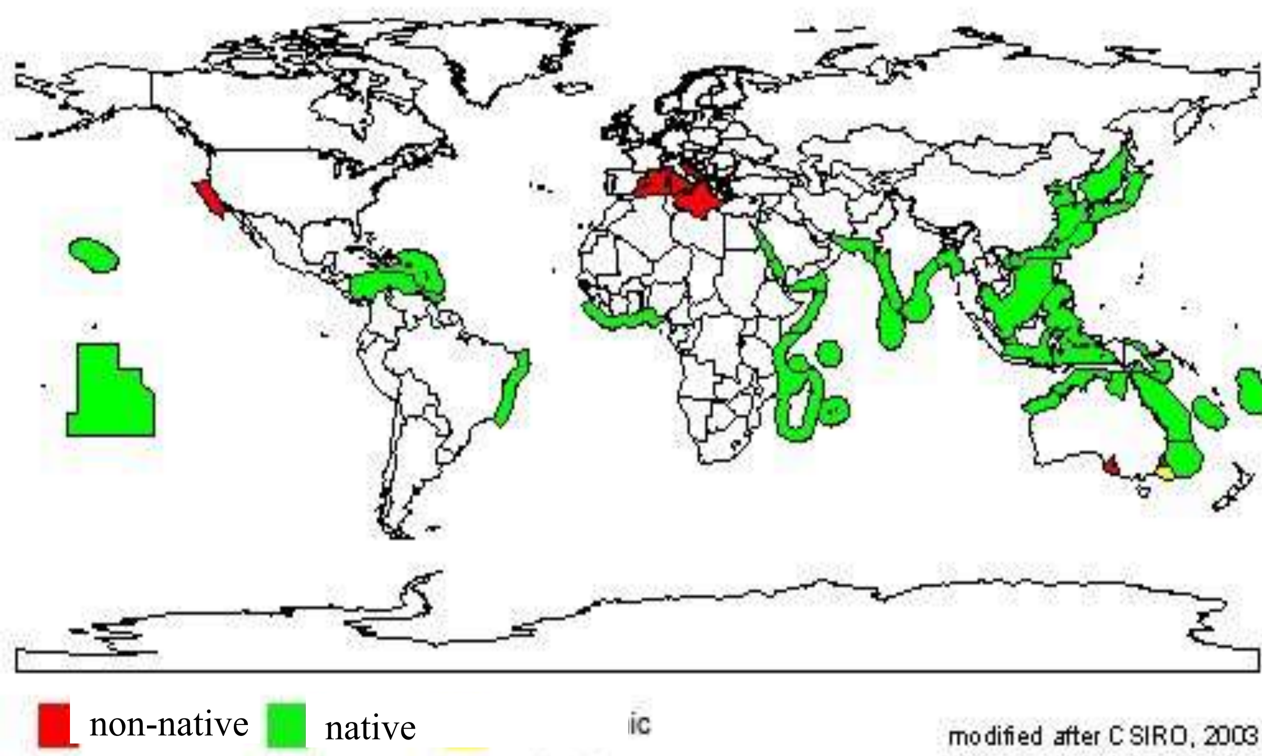
<u>Area</u> of a taxon: the sum of the geographical areas in which populations of a given taxon occur. Each plant species has a characteristic range, which is conditioned by historical and ecological factors and the dispersal of diaspores and may vary over time.



Area of *Verbascum* , Ozenda, 1992

Areas of distribution of plants: naturality

- **Native (indigenous, “autóctona”)**: a species that originated and developed in its surrounding habitat and has adapted to living in that particular environment.
- **Invasive (“invasora”)**: a species that out-competes other species, causing damage to an ecosystem.
- **Non-native (“alóctona”)**: a species that originated somewhere other than its current location and has been introduced to the area where it now lives (also called **exotic** species).

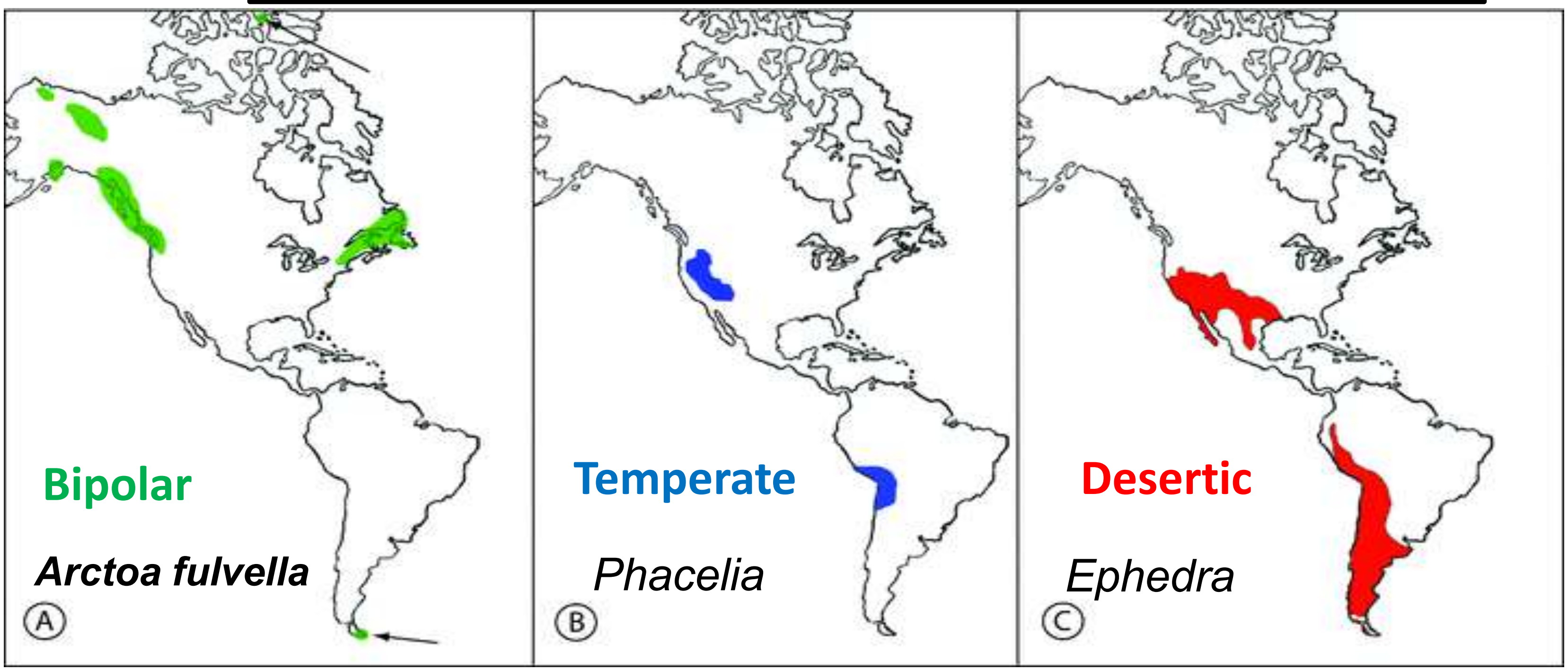


Caulerpa taxifolia

Areas of distribution of plants: continuity

Discontinuous or **disjunct ranges**: a spatially discontinuous distribution separated by geographical or climatic barriers, usually resulting from some kind of **regression** or **long-distance dispersal**.

Disjunctions at latitudes at comparable distance from the equator:



Journal of Systematics and Evolution
Volume 47, Issue 5, pages 331-348, 24 SEP 2009 DOI: 10.1111/j.1759-6831.2009.00054.x
http://onlinelibrary.wiley.com/doi/10.1111/j.1759-6831.2009.00054.x/full#f4

Three types of amphitropical disjunctions between North America and South America. **A,** The bipolar pattern, exemplified by distribution of the bipolar moss disjunct *Arctoa fulvella* (Dicks.) Bruch & Schimp (adapted from Ochyra & Buck, 2003). **B,** Temperate disjunction, exemplified by the *Phacelia* Juss. distribution (adapted from Solbrig, 1972). **C,** Desert disjunction, as illustrated by distribution of *Ephedra* L. (adapted from Caveney et al., 2001).

Areas of distribution of plants: continuity

Dryas octopetala

Arctic-alpine disjunct area

Figura 17-13. Área disyunta ártico-alpina de *Dryas octopetala*. 1. Área principal de distribución en la actualidad. 2. Localidades aisladas. 3. Registros fósiles de la última glaciación (Würm). (Adaptado de H. Walter y H Straka, 1970.)

Arabis alpina

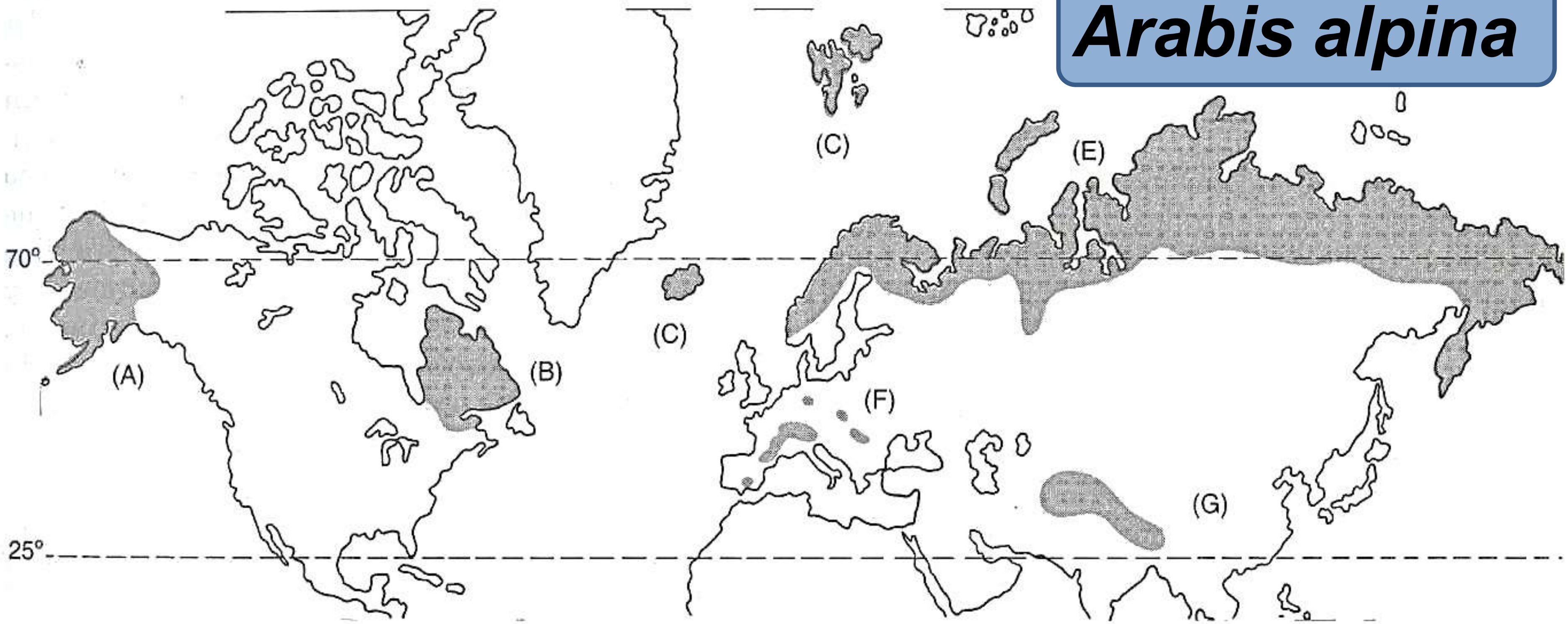


Figura 17-14. Disyunción holártica y bóreo-alpina de *Arabis alpina*, con distintas áreas: (A) alaskense, (B) labradoriana; (C) islas Spitzberg; (D) Islandia; (E) eurasiática septentrional; (F) alpídico-pirenaica-nevadense; (G) himaláyica. (Adaptado de P. Ozenda, 1982.)

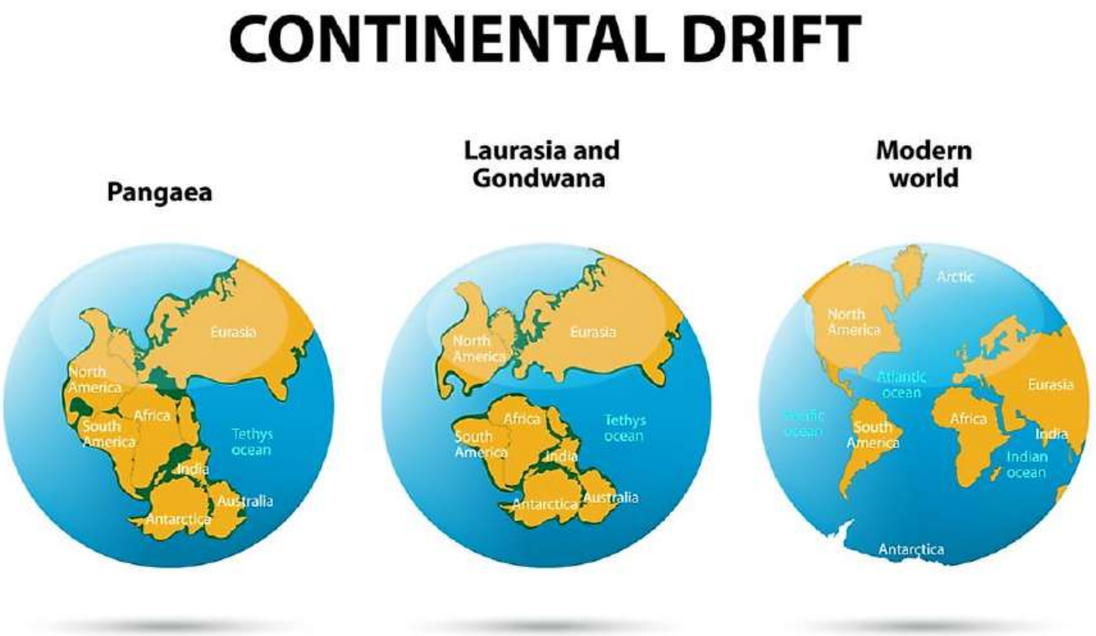
Areas of distribution of plants: continuity

How can the origin of these disjunct distributions spreading across different continents and ocean basins be explained? Two historical processes or mechanisms have traditionally been proposed.

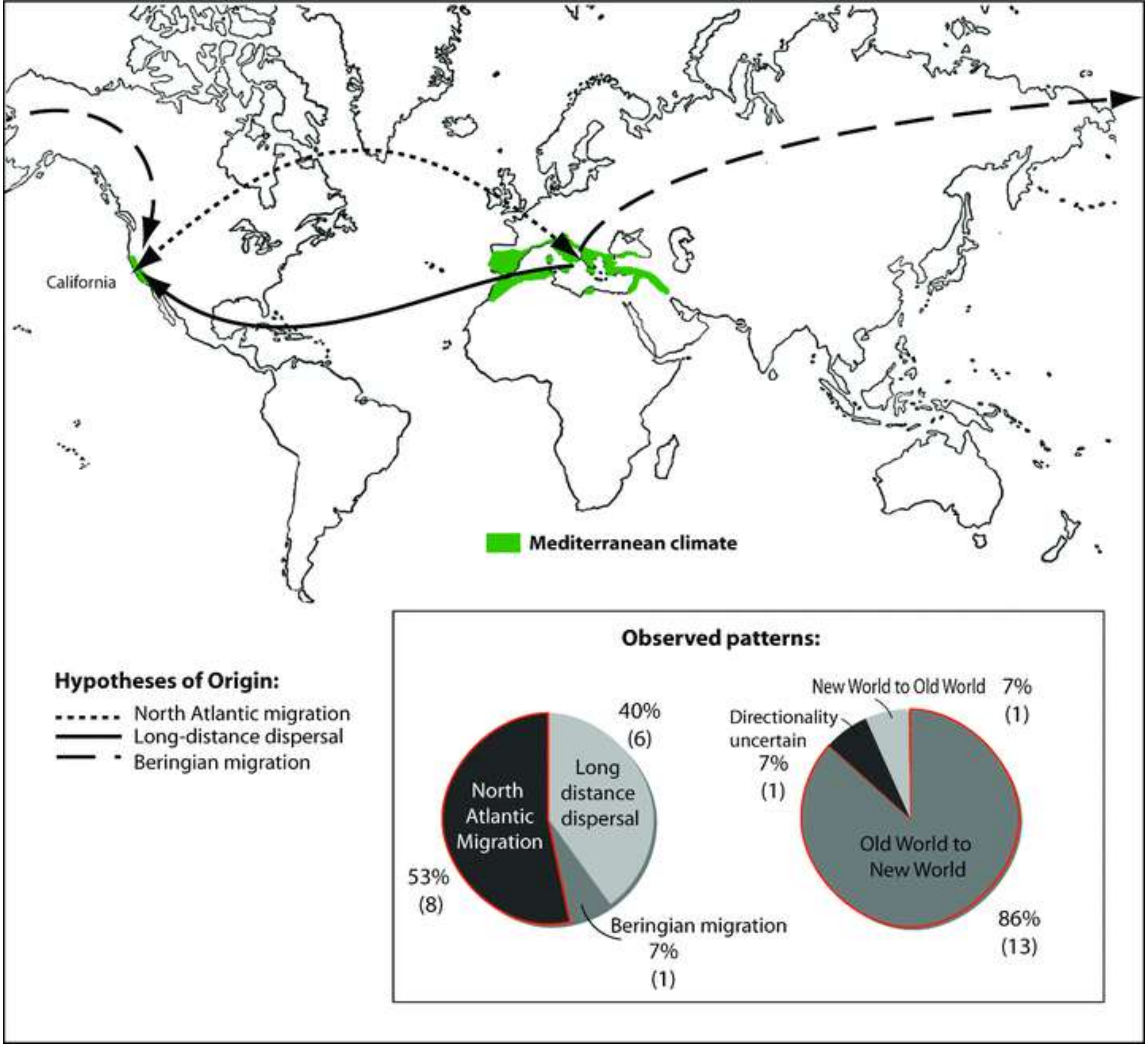
Dispersal: The taxon originated in an ancestral area (centre of origin) from where it dispersed to other areas across various geographical barriers.

Regression: The taxon occupied an ancestral area that was divided or reduced by the successive appearance of geographical barriers (the division of the supercontinent Gondwana and the appearance of new oceans).

These two processes are compatible and not necessarily mutually exclusive.



Evolution of the Madrean–Tethyan disjunctions and the North and South American amphitropical disjunctions in plants



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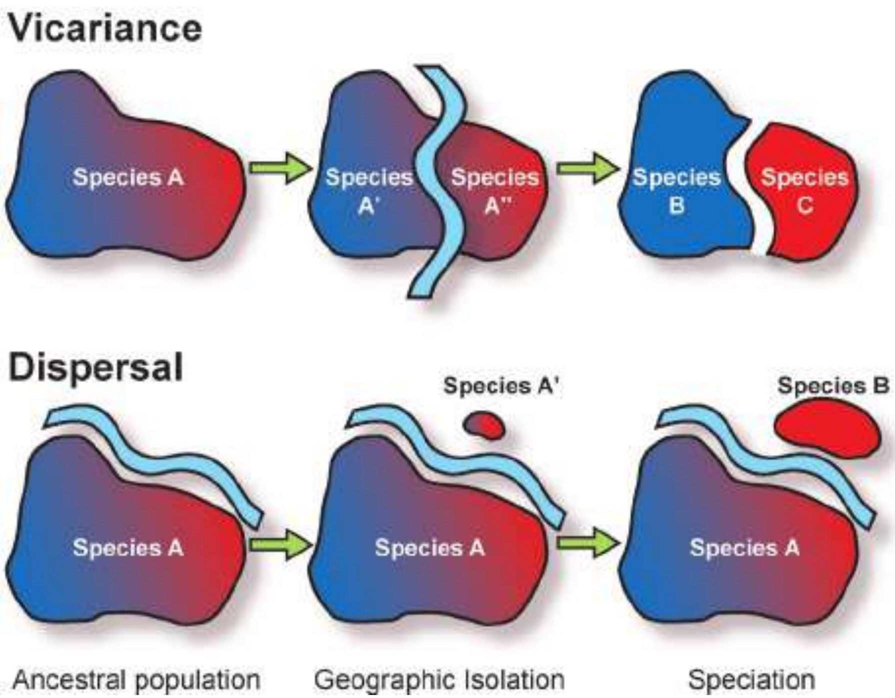
Areas of distribution of plants: vicariance

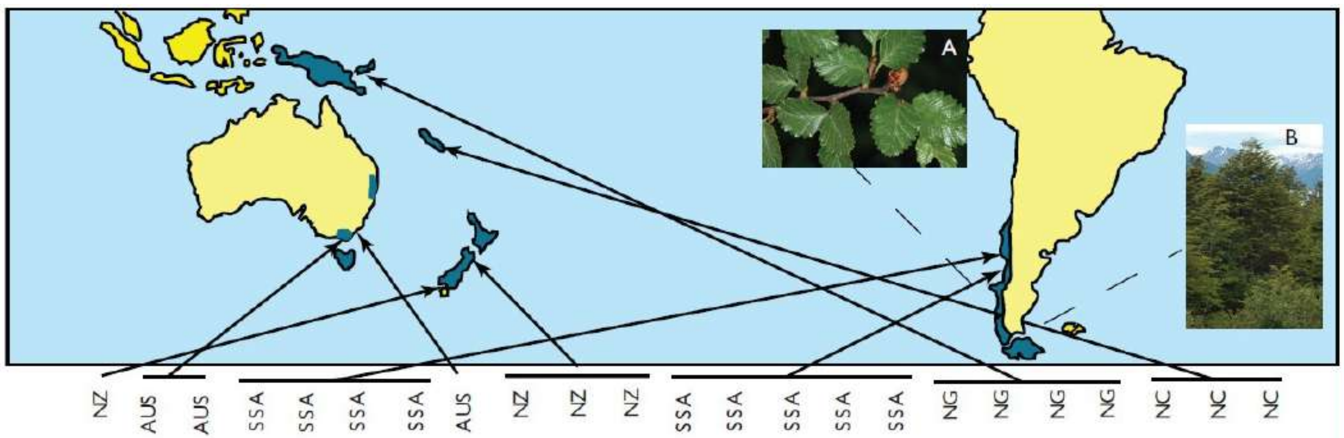
Vicariance or **vicariant species** refers to plants with a common evolutionary origin, which means that they are phylogenetically (and often morphologically) close. Also, since their primitive range has been divided, they now occupy separate territories. This situation can lead to **speciation**.

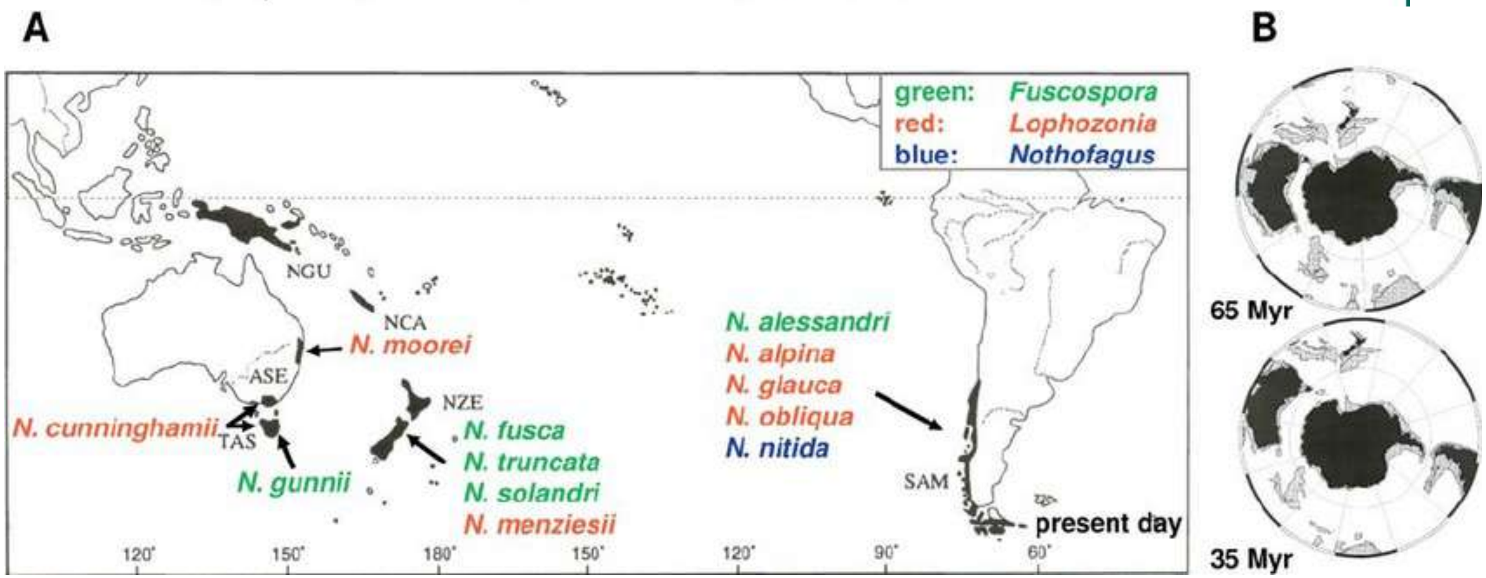
Vicariant species: close allopatric species resulting from the appearance of a barrier to dispersal. Such species tend to develop in similar habitats.



Geography of allopatric speciation modes. In **vicariance**, the ancestral population (Species A) is passively divided by a geographic barrier. Incipient species (Species A' and A") form during geographic isolation and later diverge to become new species (Species B and C). In **dispersal**, a subpopulation of the ancestral species (Species A) actively migrates across a geographic barrier to form an incipient species (Species A'), which later diverges to become a new species (Species B) (adapted from Stigall 2012).

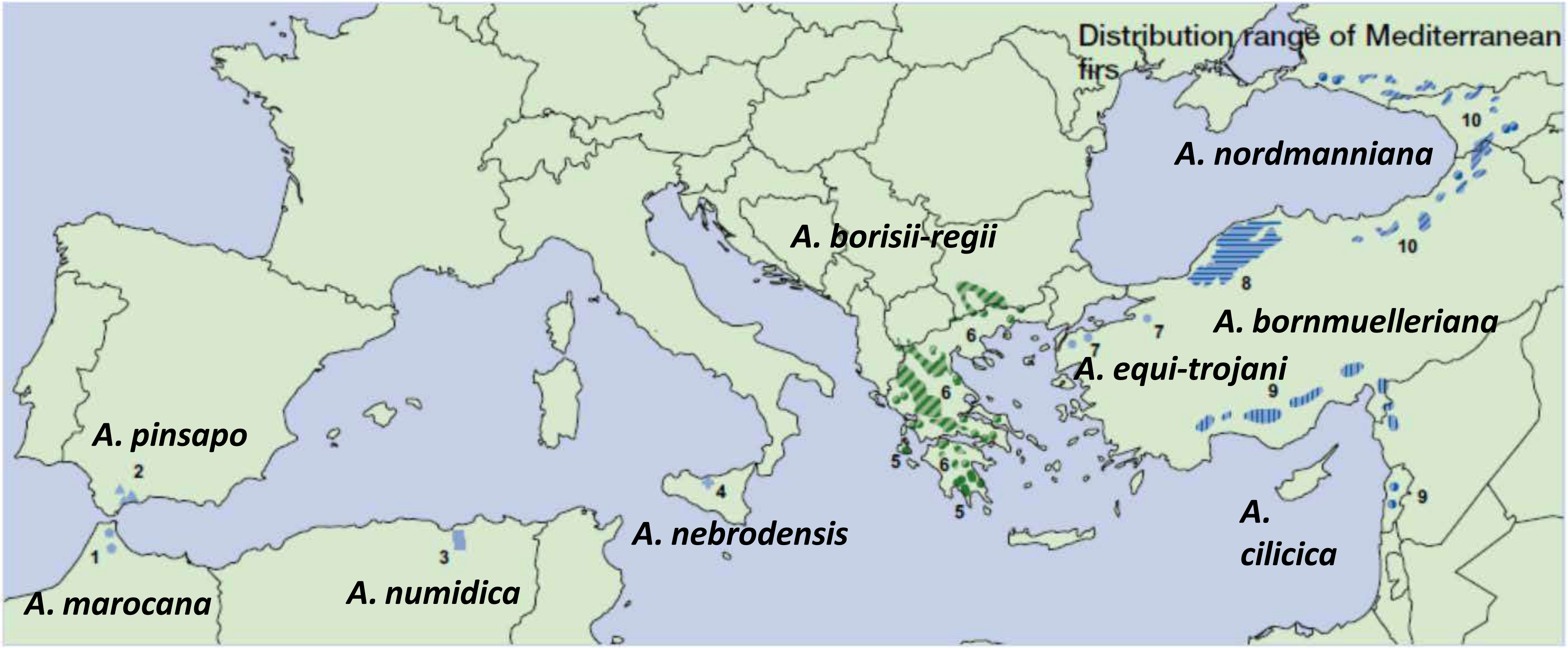
Areas of distribution of plants: dispersal and vicariance in *Nothofagus*





Nothofagus probably originated on the supercontinent Gondwana at the end of the Cretaceous (65 Ma) before the separation of South America and Australia (30 Ma).

Areas of distribution of plants: vicariance in Mediterranean firs (*Abies*)



- 1 *Abies marocana*
- 2 *Abies pinsapo*
- 3 *Abies numidica*
- 4 *Abies nebrodensis*
- 5 *Abies cephalonica*
- 6 *Abies borisii-regis*
- 7 *Abies equi-trojani*
- 8 *Abies bornmuelleriana*
- 9 *Abies cilicica*
- 10 *Abies nordmanniana*

Areas of distribution of plants: area extension

The extent of the ranges varies from cosmopolitan to more restricted endemics

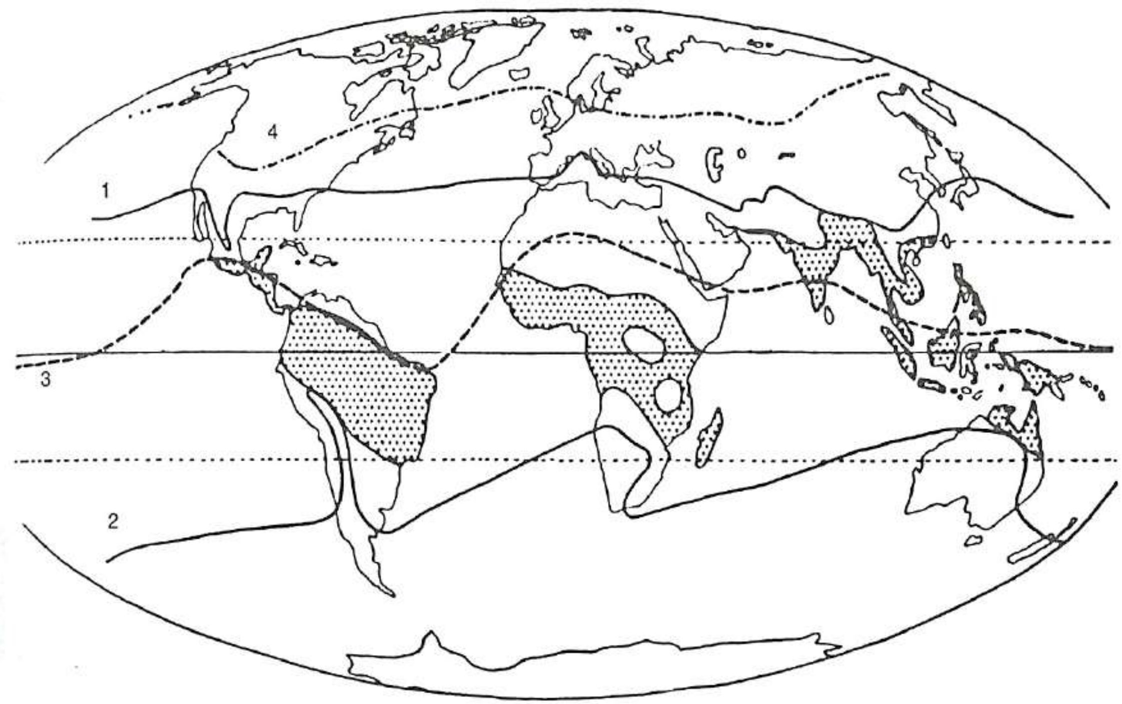


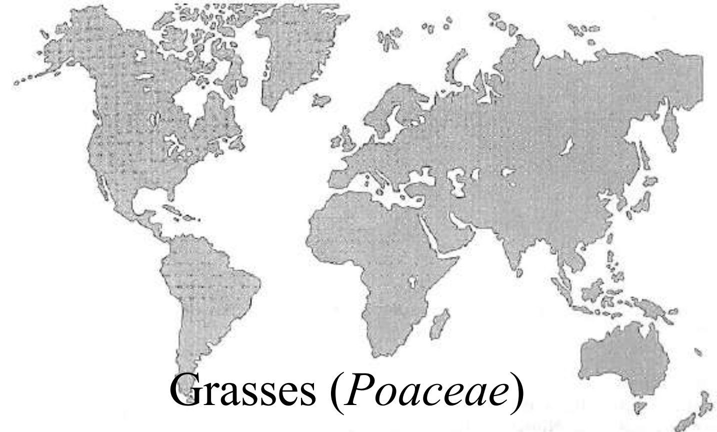
Figura 17-9. Distribución de la familia Palmáceas. 1. Límite septentrional actual. 2. Límite meridional actual. 3. Ecuador térmico, línea de máxima temperatura media anual. 4. Límite septentrional durante el mioceno. (Adaptado de P. Ozenda, 1982.)

Example of a **circumtropical distribution**: palms (*palmae*).

Areas of distribution of plants: cosmopolitan distribution

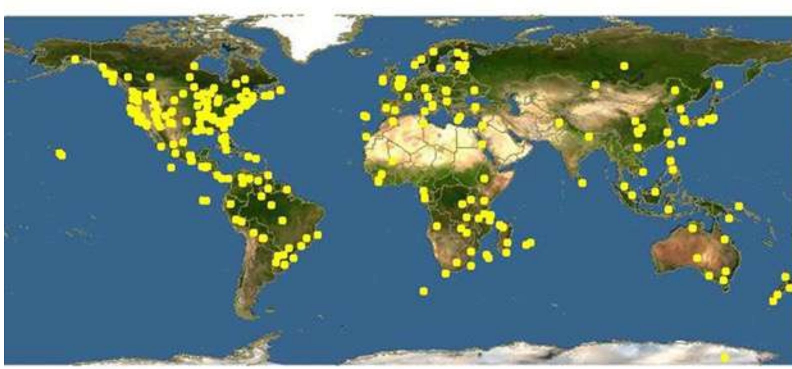
A taxon is **cosmopolitan** when its range is global or it is distributed over an exceptionally large area.

Many algae and microscopic fungi are cosmopolitan (likely causes: resistant stages and ease of dispersal).



Grasses (*Poaceae*)

- Many families and genera of aquatic plants are almost cosmopolitan (*Lemnaceae*, *Azolla*, *Myriophyllum*, *Ceratophyllum*, *Chara*).
- A few species are cosmopolitan.

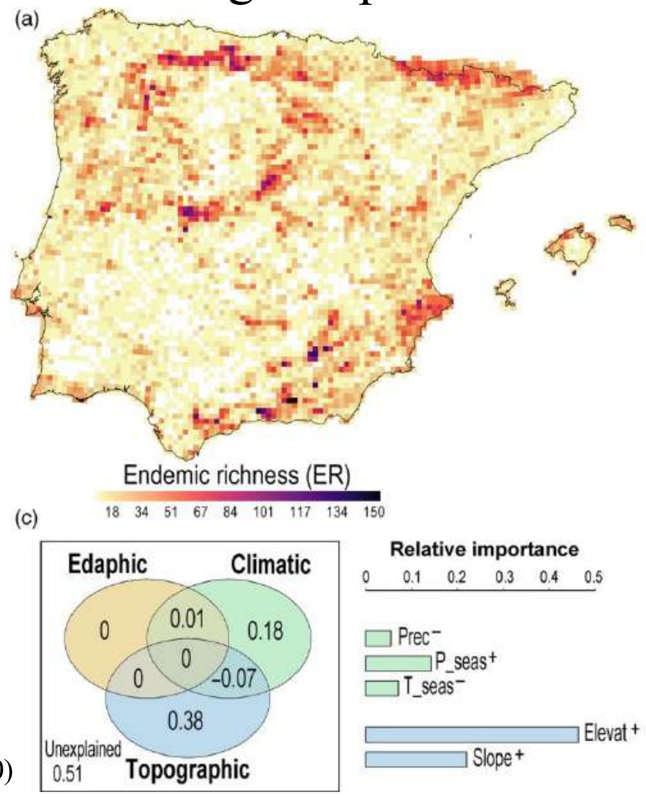


Pteridium aquilinum

The range is smaller in **subcosmopolitan** taxa than it is in cosmopolitan taxa.

Areas of distribution of plants: endemisms

- An **endemic taxon** is restricted to one or a few **localities**; use of the term "endemic" therefore depends on the geographical scale considered.
- Endemic species do not usually constitute a homogeneous group.
- Endemisms are **more frequent in lower taxonomic categories** (species and genera) than in higher ones. However, endemic families exist, e.g. *Bromeliaceae*, *Cactaceae* (except *Rhipsalis*) (neotropical endemisms).
- Endemisms are the result of complex historical and ecological processes. Types of endemisms:
  - i. **Topographic endemisms** **(mountains)**
  - ii. **Island endemisms**
  - iii. **Edaphic endemisms** **(e.g. acidic or calcareous soils)**
  - iv. **Desert endemisms**
  - v. **Palaeoendemisms and neoendemisms**

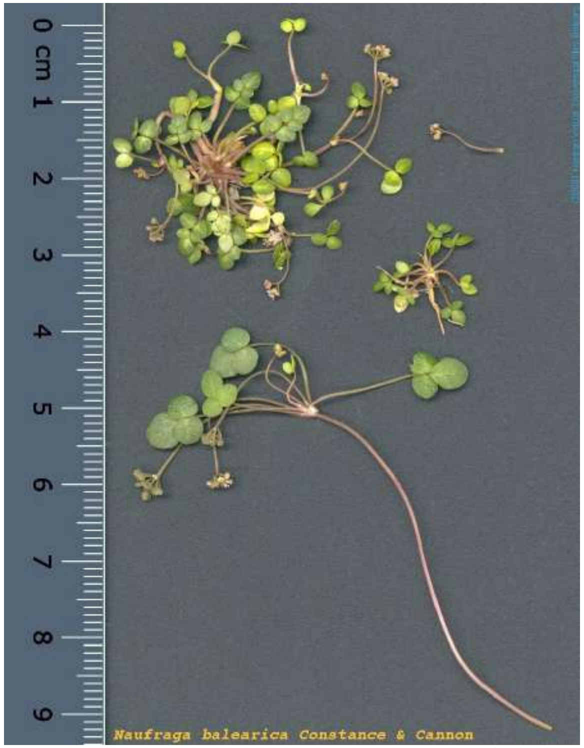


Adapted from Buira et al. (2020)

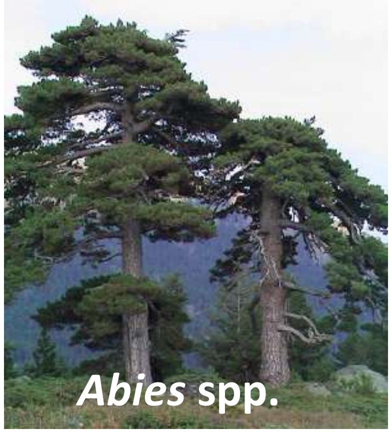
Areas of distribution of plants: endemisms

> A taxon is endemic to an area or region when all its populations are found within that territory.

- **Palaeoendemisms**: ancient or relict taxa (remnants of species that had a wider distribution in the past): *Ginkgo*, *Sequoia*, *Metasequoia*, *Araucaria*, *Welwitschia*, *Naufraga balearica*.
- **Neoendemisms**: more recent and often related species whose origin responds to contemporary selection pressures: 75% of Mediterranean endemics.



Naufraga balearica. Found in Sierra de Tramontana, Mallorca, and very rarely in Corsica, where it appears to be extinct.



Areas of distribution of plants: endemisms

Areas of highest diversity in the Mediterranean based on the rate of endemism (based on Blondel *et al*. 2010).

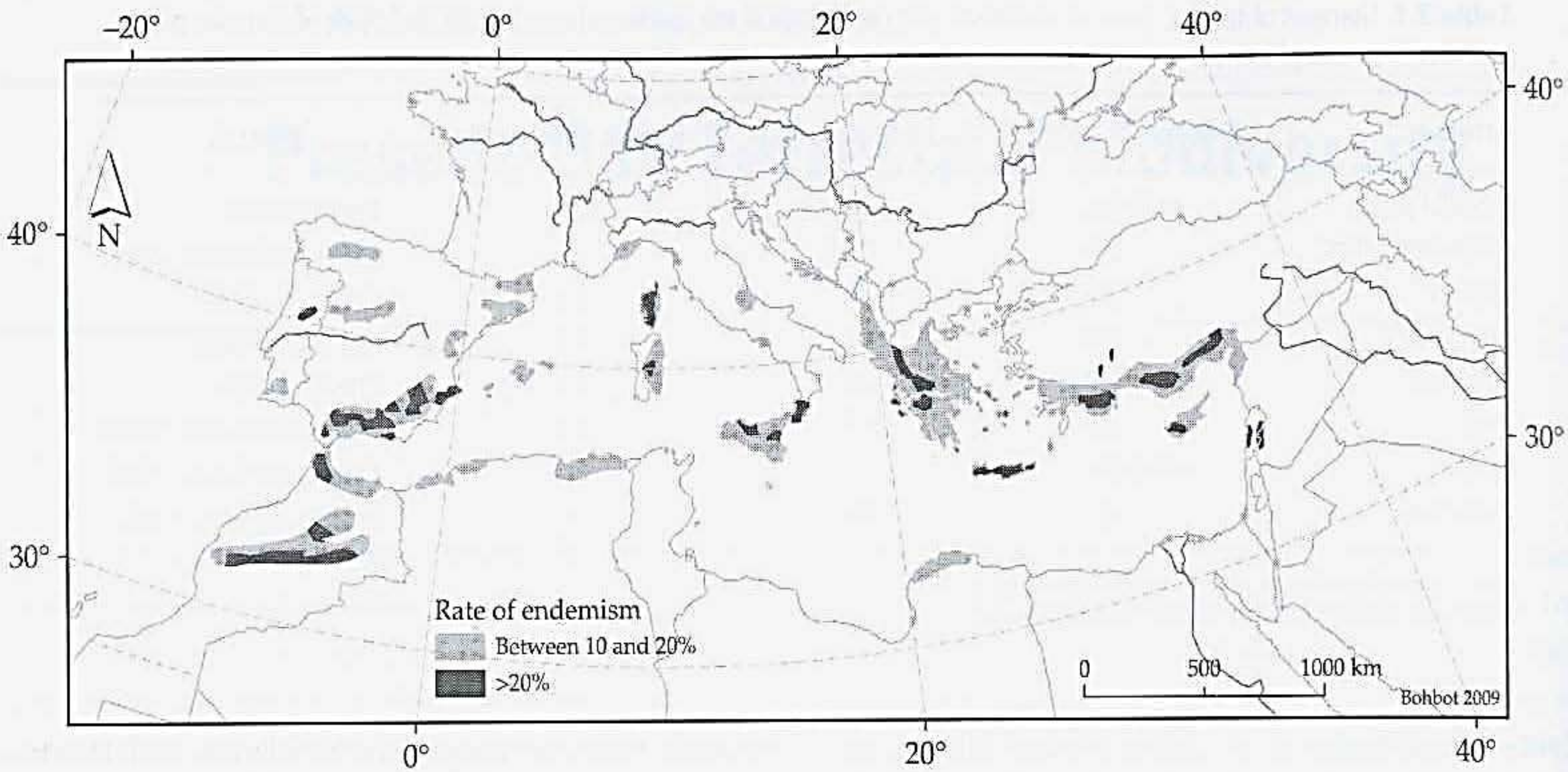


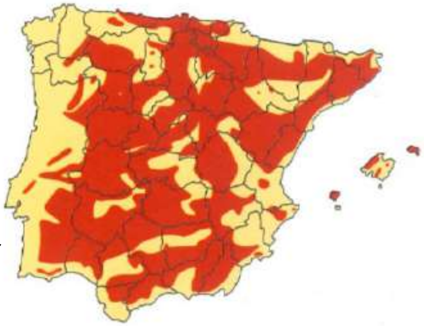
Figure 3.1 Hotspot areas for plant species diversity in the Mediterranean Basin, including the Canary Islands and Madeira. Modified from Médail and Quézel (1997) and Médail (2008b).

Areas of distribution of plants: potential vs real

Depending on the current area of distribution and possibilities for expansion, a distinction is made between:

- **potential range distribution**, which is the set of places where the environmental conditions for a species considered to thrive are present.
- **real range distribution**, which is the set of places where the taxon under study can be located.

Potential and real range distributions do not necessarily coincide; potential ranges are often larger than real ranges. For example, the real range of the holm oak (*Quercus ilex*) in Spain comprises the places where this plant still grows, but its potential range is much larger since almost 80% of the Iberian Peninsula is suitable for holm oak.



Potential range of *Quercus ilex* subsp. *ilex*

Topics

Plant biogeography

Floristic kingdoms

Floristic kingdoms of the world

In phytogeography, **phytochorion** is a geographical area with a relatively uniform composition of plant species. Adjacent phytochoria do not usually have a sharp boundary but a soft one, a transitional area in which many species from both regions overlap. The region of overlap is called a vegetation tension zone.

In traditional schemes, areas in phytogeography are classified hierarchically according to the presence of endemic families, genera or species, e.g. in **floral** (or **floristic**, **phytogeographic**) **zones** and **regions and** also in **kingdoms**, **regions** and **provinces**.

According to Good (1947), there are **six floristic kingdoms**: Holarctic, Paleotropical, Neotropical, Australian, Antarctic and South African (Capense).

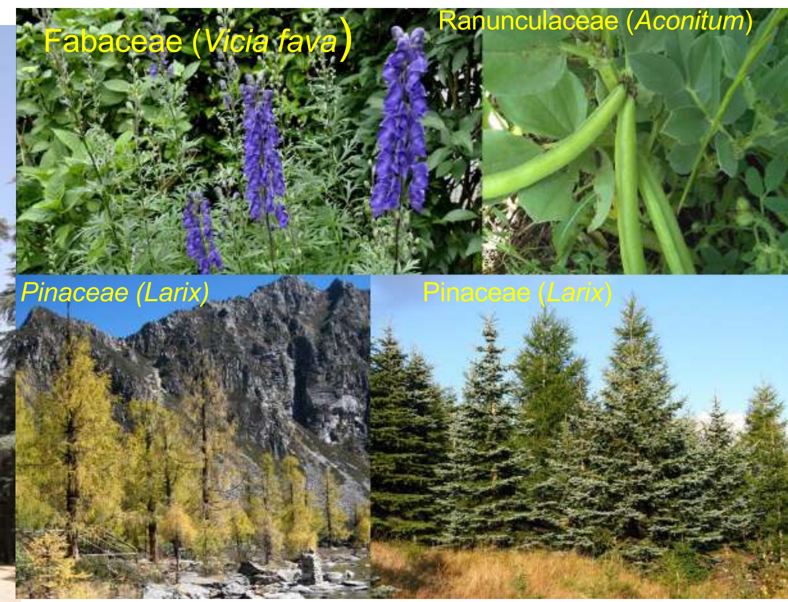
The **kingdom** is the unit of highest biogeographic rank. It comprises territories characterised by higher-ranking endemic taxonomic units and characteristic vegetation types.

Kingdoms are subdivided into **regions** characterised by their own species, genera and families.

Holarctic kingdom

- This is the most extensive kingdom, occupying the Northern Hemisphere north of the Tropic of Cancer.
- The Nearctic and Palearctic regions of the kingdom have maintained communication since the Cretaceous.
- The Holarctic kingdom has remarkable floristic uniformity, with 60 endemic families: *Pinaceae*, *Salicaceae*, *Ranunculaceae*, *Brassicaceae*, *Rosaceae*, *Fabaceae*, etc., are widely represented.
- Endemic coniferous genera: *Pinus*, *Abies*, *Cedrus*, *Larix*, *Picea*, etc.
- Vegetation types: tundra, coniferous forests, deciduous forests, Mediterranean sclerophyllous vegetation.
- This kingdom includes the Mediterranean, Eurosiberian, Saharo-Arabian, and Chinese-Japanese regions, etc.

Cedrus atlantica, Moyenne Atlas, Morocco



Paleotropical kingdom

- This kingdom comprises the African regions south of the Sahara, the southern and southeastern regions of Asia, and some Pacific islands.
- Very high biodiversity.
- Over 40 endemic families: *Dipteridaceae*, *Welwitschiaceae*, *Degeneriaceae*, *Salvadoraceae*.
- Rainforests, wooded and herbaceous savannas, monsoon forests, semi-deserts and deserts.
- There is a high level of endemism in the tropical islands (e.g. Hawaii and New Caledonia).

Baobabs (*Adansonia digitata*) in Madagascar


Welwitschiaceae (Welwitschia)


Dipteridaceae (Dipteris conjugata)


Degeneriaceae (Degeneria)


Salvadora persica
Salvadoraceae
Media code: as210
Vikhroli Creek, Mumbai City District,
Maharashtra, India. 2008/03/02.
© Paresh Churi

Neotropical kingdom

- This kingdom comprises the regions of Central and South America (except the Austro-American tip).
- It has been separated from the Paleotropics since the Cretaceous.
- Very high biodiversity.
- Endemic families: *Cactaceae*, *Tropeolaceae*, *Bromeliaceae*, *Cannaeaceae*, *Heliconaceae*.
- The vegetation includes rainforests; *cerrados* (savannah-type, Brazil); *caatingas* (desert and xerophytic shrub flora, Brazil); *páramos* (Speletia); *puna* (high Andean plateau); Mexican deserts (*Carnegiea*, *Opuntia*, *Agave*, *Yucca*); Pacific deserts (*Cactaceae* and *Bromeliaceae*); and the Chilean Mediterranean zone, etc.
- Biotic interactions: myrmecophily

Bromeliaceae

The South African (Capense) kingdom

- Important connections with the Paleotropics. Located in the extreme south of Africa.
- Mediterranean climate.
- Great floristic originality (8,500 spp.); > 200 endemic genera.
- High level of endemism (70%): *Erica* (600 spp., of which 450 are endemic), *Crassula*, *Protea* (100 spp.).
- Numerous ornamental plants originate here.
- Mediterranean scrub-like vegetation called "Fynbos", which consists of sclerophyllous and ericoid plants, generally without trees.


Protea sp.


Carpobrotus sp.

Australian kingdom

- This kingdom comprises Tasmania and Australia.
- It is of Gondwanian origin.
- Large number of endemic plants.
- Forests of *Eucaliptus* (700 spp.) and *Acacia*.
- Vegetation: Mediterranean scrub of *Proteaceae* (*Banksia*) and *Myrtaceae* (*Melaleuca*).
- Pyrophytism.

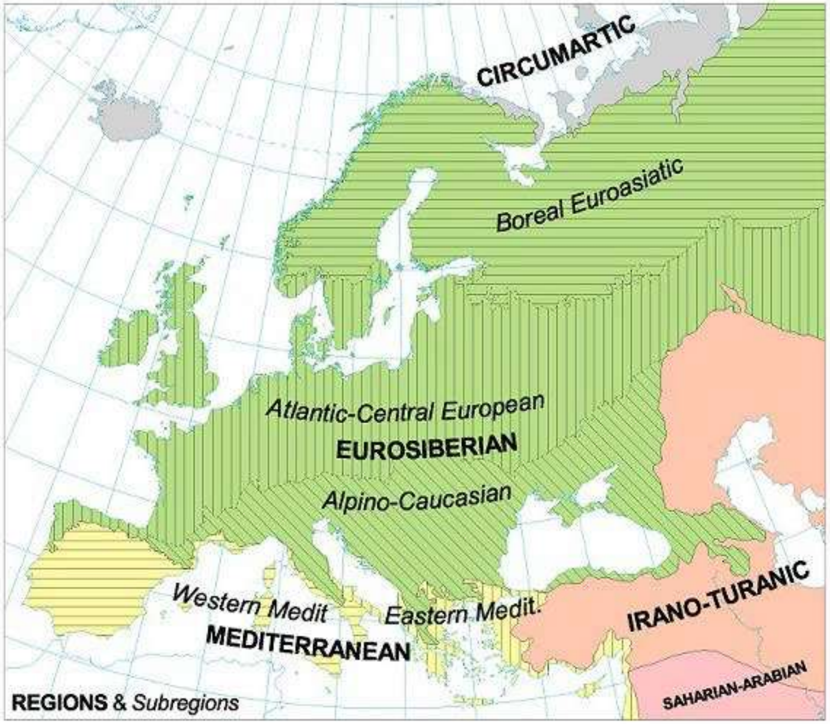
Acacia dealbata

Eucaliptus rostrata

Antarctic kingdom

- This kingdom includes the southern part of the Southern Cone of South America, southern New Zealand, the archipelagos north of Antarctica, and areas devoid of perpetual snow on this continent.
- The environment ranges from cool and humid (similar to the taiga in the Northern Hemisphere) to very cold (similar to the arctic tundra also in the Northern Hemisphere).
- It contains various genera of conifers (*Araucaria*, *Prumnopitys*, etc.), the southern genus vicariant of beeches (*Nothofagus*), etc.

European and Iberian Peninsula phytochoria



Según el sistema de Takhtajan las fitocorias se clasifican de manera jerárquica de acuerdo con la presencia de familias, géneros y especies endémicas en:

Reino

subreino

Región

subregión

Provincia

subprovíncia

Distritos

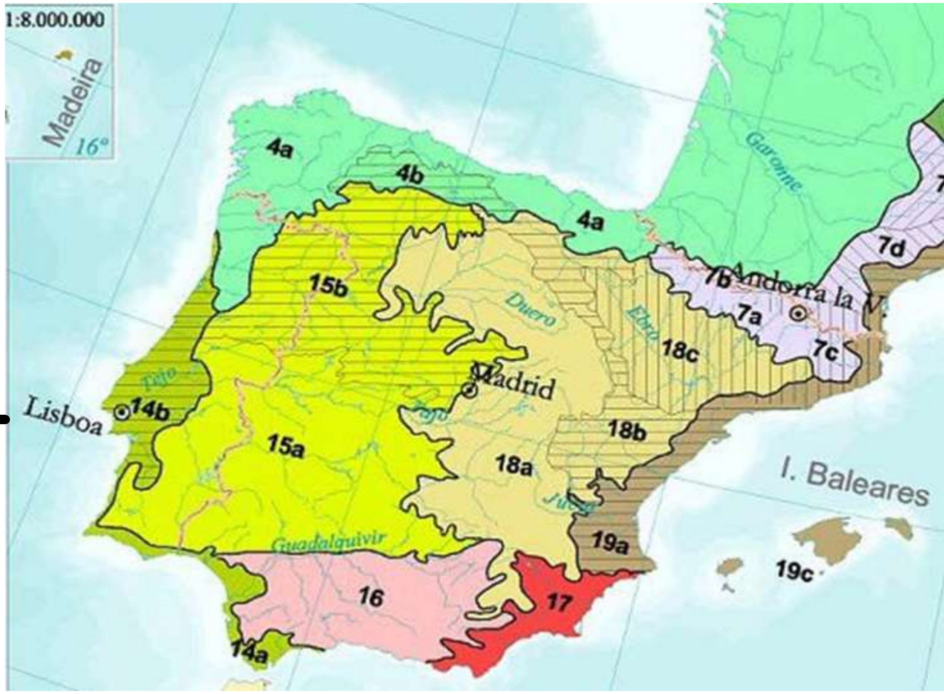
Regiones de la tierra

Eurosiberian region

4 «Atlántica Europea»
7 «Pirenenaica»

Mediterranean region

14 « Lusitano-Andaluza costera»
15 « Mediterráneo Ibérica Oriental»
16 « Bètica»
17 « Mediterraneo-Murciano-Almeriense»
18 « Mediterráneo Ibérica central»
19 « Catalano-Provençal-Balear»



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