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He is the author of « an investigation of the level of selected trace metals in plant species within the vicinity of tantalum mining area in Gatumba, Rwanda; l'Etude d'hygiène et assainissement à l'enseignement primaire et secondaire ; l'etude lymnologique et systématique algale des lacs Cohoha, Rweru et Gitamo ; and many Biology module in KIE».

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His other activities include:

Consultancies: various studies in the fields of the identification, the formulation and the evaluation of rural development projects, in the analysis of the of Currirula, in the definition of the strategy of environment management

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MODULE 2

Plant diversity, structure and function

Introduction

Plants are organisms characterized by the following traits:

- Despite their enormous variation from a tiny moss to a giant tree, all plants are multicellular and eukaryotic (i.e., each cell possesses a membrane-bound nucleus that contains the chromosomes).
- Plants are autotrophic organisms able to synthetize their own food by using photosynthesis process.
- Plants are fixed in the substratum and depend on the environmental conditions and adapt by the cellulosic cell wall, the protective tissues and some molecules such lignin which give a stiff form to plants.
- Plants have few differentiated tissues or organs and for that they have an indefinite growth and a high capacity of reproduction (sexual reproduction, vegetative propagation).
- Unlike to animals, plants have two alternating life generations: the diploid sporophyte which produces spores and the haploid gametophyte which produces gametes.

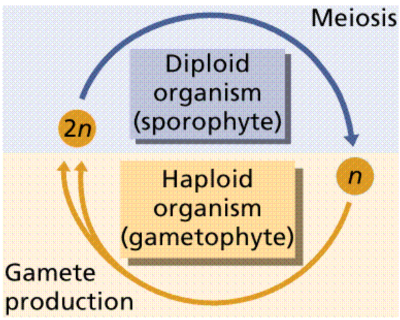

Figure 1: Typical alternation of generation in plant life cycle (Source: www2.estrella mountdin.edu/faculty/farabee/ bioBK

- Plants have an open structure i.e. all the organs are produced externally and are in contact with the external atmosphere.
- Plants are not sensitive except some which respond to external stimuli by closing the leaves for example.
- Plants sense changes in their surroundings and respond to them as they are able to detect and respond to light, gravity, changes in temperature, chemicals, and even touch. Unlike animals, plants do not have nerves or muscles, so they cannot move very fast. A plant usually responds to change by gradually altering its growth rate or its direction of growth.

Plant diversity refers to the variety of plants that exist in the world. Plants show differences in terms of classification, ecology, adaptation, etc. They grow in diversified habitats such as humid zones, deserts, rocks, water and contribute to form simple or complex ecosystems. Those differences contribute to explain their diversity.

Plants adapt to their habitats and adaptation is a genetic characteristic transmitted though their sexual or asexual reproduction.

Plants have been utilized to meet the human needs such as food, drinks, clothing, fibers and furniture production, medicine, etc.

Many substances produced by plants are used in industries such as spices, soap, oils, antibiotics, resins, rubber, etc. Plants are also used for ornamentation and scientific studies.

Plants absorb carbon dioxide released in the atmosphere through the respiration phenomenon and then contribute to alleviate the climate changes.

Plants are the foundation of the food chains so they are called primary producers: they produce biomass from inorganic compounds (autotrophs).

On the other hand, some plants cause allergy and others are toxic to humans and animals. Others do not have any known utilization but at least contribute to the ecosystem balance.

Many disciplines contribute to the knowledge of plants: systematics, ecology, plant sociology, plant geography, genetics, plant anatomy, plant physiology, etc.

The present module will deal with the diversity and classification of plants, the plant structure, physiology, growth and development.

What is in this module?

This module contains eight blocks:

Block 1: Principles of plant classification and nomenclature

Block 2: Algae

Block 3: Bryophytes or Non vascular plants

Block 4: Tracheophytes or Vascular plants

Block 5: Plant external structures

Block 6: Plant internal structures

Block 7: Plant growth and development

Block 8: Plant nutrition

General objectives of the module

At the end of the module, students will be able to:

- discuss the plants diversity and the role of each component in the ecosystem balance;
- differentiate groups of plants, explain their ecology and show their importance for human beings and for the ecosystem;
- explain the evolution of plants from the algae to the angiosperms;
- explain the evolution of the classification criteria and understand the modification occurred in the previous classification systems by using the new criteria;

- advocate for the endangered species of plants;
- describe the external and internal organization of higher plants;
- discuss the processes of development and growth in higher plants;
- explain fundamentals of mineral nutrition and photosynthesis in plants.

Icons used

☞ Indicates an important point in your study.

? Indicates a question which you need to think about and answer

Indicates an activity that you must complete before you proceed with your study

Indicates reading material that you must have and use in order to understand the module or the block.

☑ Indicates suggested answers to activities in the block

How will I assess my learning?

The module is subdivided into blocks, the blocks into sections and some sections into subsections.

Two kinds of assessment are proposed in this module. The first one tests your knowledge before you embark on the study of this module. You will answer the questions and will self – assess using the answers provided at the end of the introduction.

The second evaluation will be done at the end of each section. A series of questions will be provided on the contents of each section, the answer will be given at the end of the block. One advice: understand well the contents of the previous section before you move on to the questions.

How much do I know?

Before you really start studying the module, we first propose some general questions to test your current knowledge on plants and fungi.

Follow the following instructions:

- the work is strictly personal ;
- first, read attentively and understand the questions ;

- answer the questions to the best of your ability using your previous acquired knowledge ;
- do not refer to your notes or to the answers provided just after the activity ;
- mark your answers as objectively as possible by comparing them to the answers suggested at the end of the questions.

Activity1

1. What are the main subdivisions of non flowering plants (Cryptogams)?
2. What do you know about the sporophyte in ferns (Pteridophyte)?
3. Differentiate Bryophytes and Pteridophytes morphologically.
4. How do fungi feed?
5. What is a digenetic cycle?
6. Differentiate Gymnosperms and Angiosperms.
7. The following figure is a longitudinal section of a plant flower:

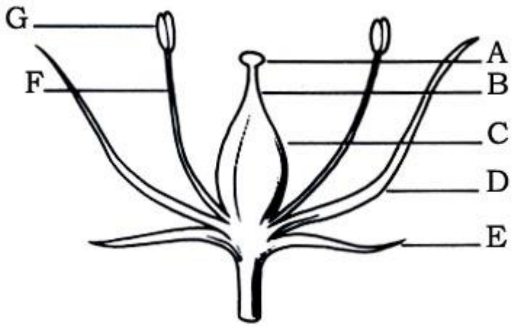

Figure 2. Longitudinal section of a plant flower.

a. Label the parts lebelled A, B, C, D, E, F,G on figure 2 above.
b. State the roles of parts labelled by D and E.
c. What are the parts forming the female reproductive organ?

Feedback

These exercices aim at reminding you the notions and principles you learnt in secondary school.

Mark yourself and appreciate your performance; if your performance is good, congratulation; if your performance is not good, you must work to improve it.

Answers to the activity 1

1. Thallophyta – Bryophyta – Pteridophytes
2. In ferns, sporophyte is made of a vegetative body : rhizome + leaves ; the lower side of the leaves bears sporangia forming sori; the sporangium contains spores, when the spores are mature; they are released and germinate and give a gametophyte (prothallus)

Bryophytes	Pteridophytes
Small leaves	Small and tall leaves
No roots but rhizoids	Roots developed
Stem present	Stem present
No vascular tissue	Vascular tissue present

4. Fungi are heterotrophic: saprophytes or parasites or simbiotic.
5. Digenetic cycle is a life cycle made of two generations: gametophyte and sporophyte.
6.

Gymnosperms	Angiosperms
Inflorescence: cone	Inflorescence diversified not a cone
Ovule and seeds naked	Ovule and seeds protected
Absence of bisexual flowers	Generally bisexual flowers
Absence of double fertilisation	Double fertilisation

7.

a)

A: Stigma	B: Style	C: Ovary
D. Petal	E: Sepal	F: Filament
G: Anther		

b) Protection of ovary

c) A (stigma) and B (style)

Activity 2

1. In your area, collect about ten different flowering plants making sure that you get all the parts of these plants. Observe all the parts carefully and answer the following questions:
   - Describe each plant part.
   - Explain the functions of each plant part.
   - Identify adaptations of each plant part to its function.
2. a) Define the following terms:
   - transpiration
   - respiration
   - glycolysis

   b) What is the role of chlorophyll in photosynthesis?

Feedback

Compare your answers to those suggested. The marks you get will inform you about your current knowledge of plant diversity, structure and function. If you are weak you will have to make much efforts to read the required standard to be able to complete this module, in case you encounter any particular problems, seek assistance from your tutor.

Answers to Activity 2

1.

- *The root:* generally underground, being ramified and carrying many root hairs, that would allow them to easily take up the duties of absorption of nutritive substances in the ground and fixing the plant in the ground.

- *The stem*: located between the roots and the leaves, it connects between these two organs allowing the circulation of the saps in the ascending and descending direction.

- *The leaf*: it is a flattened blade, green and crossed by veins, it easily ensures the exchanges between the plant and the external environment but also manufactures nutrients; the veins conduct the crude sap and the elaborate sap respectively in the leaf and towards the stem.

- *The flower*: it is like a short branch whose leaves are transformed to protect the reproductive parts of the plant.

- *The fruit*: it is made of an envelope protecting the seeds until when they are released to be able to ensure the perpetuation of the species.

2. a)

- Transpiration: water emission in the form of water vapour by a living body.

- Respiration: phenomenon by which the living organisms break up, by a series of metabolic oxidations, organic matter into simpler compounds with a release of energy.

- Glycolysis: phenomenon of degradation or decomposition of glucose (C_6) into two molecules of pyruvic acid (C_3).

b) The role of chlorophyll is to collect the light necessary for photosynthesis.

BLOCK 1

Principles of plant classification and nomenclature

Introduction

Classification enables establishing relationships among organisms, knowing the characteristics of groups of organisms and providing an organized way of studying them. While classifying, one will require using appropriate names at each level of classification. In this block, the general principles of classification are outlined but also the rules followed in naming organisms. The basic concepts developed in this block are very important to better understand the content of the next blocks of this module.

What is in this block?

This block is divided into four sections:

Section 1: Principles of plant classification

Section 2: Systems of classification

Section 3: Nomenclature of plants

Section 4: Evolution of plants

Estimated study time

We estimate that you will need 8 hours to study the content of this block and do all activities.

Learning objectives

At the end of this block, students will be able to:

- explain the principles followed in classifying and naming plants;
- discuss the heterogeneity and evolution of plants;
- discuss the significance of plant classification and nomenclature;
- P ropose reliable criteria to be used for a coherent classification system.

Keywords

Systematics
Taxonomy
Taxon
Species
Identification

Section 1: Principles of plant classification

Biologists divide up living organisms into groups, according to features which are thought to be of biological significance. Organisms sharing major features are grouped together, and separated from other different organisms. Each group is given a scientific name according to established rules in order to avoid ambiguity.

Plant **systematics** is the science which aims to identify, to classify and to study plant evolution. Plant systematics and plant taxonomy are synonymous. However, for some authors plant **taxonomy** deals only with classification while plants systematics deals with identification, classification and evolution.

Characterization, identification, classification (according to certain features) and nomenclature (giving names for recognition and differentiation from other organisms) are the basics of Systematic study.

The arrangement of organisms into groups is guided by international rules: similar species are grouped into a genus, similar genera are grouped into a family, similar families are grouped into an order, similar orders are grouped into a class and similar classes are grouped into a phylum. Each category or level of classification such as species, genus, family,... is called **taxon** (plural taxa).

The role of plant classification is to arrange the plants into a coherent, natural and universal system. Plant classification starts with the simplest group and goes towards the most complex one. The simplest group is the **species** which is the basic taxon. Plant individuals of the same species which reproduce sexually are interfertile.

Species are subdivided into subspecies and varieties. The latter show differential characteristics related to the environment. There are also supra species taxa (beyond the species): genus, family, order, class, phylum and kingdom.

Plant identification is the use of the main characteristics of parts (flowers, fruits, leaves and stem) to name a plant. Keys for identification are used for this exercise.

The description of a plant is the enumeration of its characteristics.

Activity 1

1. Give two reasons why classification of plants is very important.
2. Distinguish between classification and identification.
3. Define plant Systematics.
4. What is the basic taxon in plant classification?
5. In ascending order give the taxa names used in plant classification.

Feedback

All the living things including plants are classified into respective groups according to specific criteria. Any plant you see in your daily life belongs to a particular plant group. This section introduced you to the basic concepts and terminology used as far as plant classification is concerned.

Section 2: Systems of classification

Keywords
Artificial classification
Natural classification
Phylogenetics
Molecular classification

Classification of living organisms is probably as old as human civilization. Classification systems are systems with a distribution of classes created according to common relations or affinities among organisms.

1. Artificial classification

The traditional communities knew empirically the names of the plants. The earliest classification was probably on the basis of utility to man. Plants and animals were classified on different basis such as edible and non-edible ones, useful and harmful ones and so on. The first classifications were therefore artificial and had some drawbacks:

- The criteria used for classification are superficial and do not reflect the natural relationships.
- The system does not reflect the evolutionary relationship between the organisms.
- Many unrelated organisms are placed in the same group on the basis of their habitats (dwelling place) (For example, whales and fishes in the same group).
- Closely related organisms have been placed in different groups because of the differences in their habitat, feeding habits, etc.
- One or very few criteria were used to classify plants so the classification was not coherent.

2. Morphological classification

At the end of the 17th century, botanists discovered the existence of natural affinities among plants. They abandoned the use of one criterion or few criteria in classification and agreed on the use of multidisciplinary criteria: morphology, anatomy, paleontology, palynology, cytogenetics, biochemistry, ecology, cytology, plant geography,… The classifications obtained were natural because they could take into account all the similarities and differences between organisms.

3. Evolutive classification

In the 19th century, evolution was introduced in the plant classification under the influence of the theory of natural selection and evolution developed by Darwin (Darwinism). Since Darwin's time, biological classification has come to be understood as reflecting evolutionary distances and relationships between organisms.

The Darwinism introduced phylogeny in plant classification; phylogeny gives the information on the plant evolution, the relation between taxa within times. The evolution is related to adaptive and genetic characteristics, so the classification was called phylogenetic classification.

Phylogenetic systematics is the field of Biology that deals with identifying and understanding the evolutionary relationships among many different kinds of life on earth, both living and dead.

4. Modern classification

The Darwinism theory has introduced the cladistic and phenetic classifications taking into consideration the filiation of species according to the evolution. Phenetics utilises morphological criteria and other new criteria such as molecular biology, biochemistry (specific substances produced by plants). Cladistics uses the genealogy of plants aiming to group together all the descendants of the same ancestor.

5. Molecular classification

Molecular systematics is a branch of the traditional field of systematics that utilizes molecular biology techniques. The evolutionary relationships of organisms are studied using their DNA, RNA and protein sequences to establish their systematic positions. A tree is constructed using those sequences and the organism relationships are inferred from that tree. Before molecular biology, everything was described by what we can see and how we classify species' relationships. With the help of decoding DNA, scientists have been able to separate species based on their DNA sequence.

Activity 2

1. Differentiate the artificial classification and the natural classification.
2. What is the innovation brought into the classification system using molecular criteria?

Feedback

The way plants and other organisms are classified changed through times depending on investigation techniques in use. The best classification system is the one reflecting evolutionary relationships between different groups of living organisms. It is important for you to know criteria used for each classification system.

Section 3: Nomenclature of plants

1. Concept

Keywords

ICBN

Binomial nomenclature

Taxon

This box is in a wrong place!

Plants have been given local names for long time. These names were local, ambiguous and not precise. Nomenclature consists in scientifically naming organisms.

The current nomenclature system is **binomial** (or binominal), meaning that the name of a species is made of two words. It was introduced by Linnaeus in his book “Species plantarum”. The scientific names are italicized or underlined (Example: *Ipomoea batatas* or <u>Ipomoea batatas</u> for the sweet potato).

Principles and rules of nomenclature of plants have been prepared and adopted by International Code of Botanical Nomenclature (ICBN). The ICBN provides the set of rules and recommendations dealing with the formal botanical names that are given to plants. Its intent is that each taxonomic group, plural "taxa") of plants has only one correct name that is accepted worldwide.

The first word of the species is the name of the genus and the second is the specific epithet. The epithets generally refer to morphological characteristics, ecology or chemical content of the plants. Some epithets are related to the geographical location of the species (*Eragrostis kivuensis*)) or dedicated to the first collector (*Coelachne auquieri*) or to scientists who contributed the botanical knowledge progress.

The specific epithet is followed by the name(s) of the author(s) who described the species. The author names are written entirely or represented by the initials of their names (example: Linnaeus or L.).

Example: *Coelachne auquieri* Ndabaneze is a grass collected in the Nyungwe forest in Rwanda. The name of the genus is "Coelachne"; the specific epithet is ‘auquieri’, dedicated to Auquier who collected the plant in the Nyungwe forest. The author is Ndabaneze who described the species for the first time.

The International Code of Botanical Nomenclature decided on the existence of seven primary taxonomic ranks as shown in the following example:

Rank		Ending	Examples
1.	**Kingdom**	-ae	Plantae
2.	**Division** (Phylum)	-phyta	Pinophyta, Magnoliophyta
3.	**Class**	-opsida	Pinopsida, Liliopsida, Magnoliopsida
4.	**Order**	-ales	Pinales, Liliales, Magnoliales
5.	**Family**	-aceae	Pinaceae, Liliaceae, Magnoliaceae
	Tribe	-eae	Pineae, Lilieae, Magnolieae
6.	**Genus**	A noun	*Pinus*, *Lilium*, *Magnolia*
7.	**Species**	Depends	*Pinusflexilis*, *Liliumgrandiflorum,Magnolia grandiflora*
8.	**Variety**	Depends	*Pinusflexilis* var. *humilus*
9.	**Form**	Depends	

The name of the genus takes a capital letter and is italicized. The name of the families derives from the original genus of the family. Examples: Rosa (Rosaceae), Poa (Poaceae), Cyperus (Cyperaceae), Geranium (Geraniaceae), etc..However, eight families make exceptions to this rule: Compositae (Asteraceae), Cruciferae (Brassicaceae), Gramineae (Poaceae), Guttiferae (Clusiaceae), Labiatae (Lamiaceae), Leguminosae (Fabaceae), Palmae (Arecaceae), Umbelliferae (Apiaceae).

2. Nomenclature principles

- ***Botanical nomenclature is independent from zoological nomenclature.*** The botanical and zoological codes of nomenclature are generally similar, but some differences still remain. Consequently, a plant can share the same name as an animal. Example: *Cecropia* is a name of a tropical plant genus and a night butterfly. The code of botanical nomenclature applies to green plants and red algae, blue algae, brown algae and fungi. Zoological nomenclature applies to some protozoans considered as animals.
- ***Naming taxa is regulated by the nomenclatural types***. The author who describes a new taxon has to choose a holotype which is a specimen which will be considered as the nomenclatural reference. The twins of the holotype are called isotypes. The holotype and the isotypes are references for the identification of known taxa.
- ***Nomenclature of taxa refers on the priority in their publication.*** The correct name of a taxon is the one which has been formerly published in the respect of the botanical nomenclature rules. The names given later to the same taxon are synonymous but are not correct names of the taxon.
- ***Scientific names use the latin language.*** The use of the latin language originates from the Middle Age where the botanical publications were done in latin until the 19^{th} century.

Note: The use of Latin has a long history in science and other subjects. For several centuries Latin was used as a language of learning and academic texts. As this language is no longer use d as a language for daily communication, the terms are fixed and the meaning of its words is less likely to change through generations. Latin names are used universally.

- ***The botanical nomenclature rules are retroactive***. They constitute a legal framework for botanical nomenclature.

Activity 3

1. Explain what is a binomial nomenclature system in plant classification.
2. For the plant *Solanum tuberosum* var. Mabondo,
   a) What does represent the first name?
   b) What does represent the second name?
   c) What does Mabondore represent?
   d) What is the family derived from that plant name?
3. Is the following statement true or false? “In an evolutionary classification system, the higher the taxon level, the more similar the members of the taxon become”. Justify your answer.
4. Give two reasons why Latin has been emphasized for use in labeling scientific name?

Feedback

For each plant organism you meet in your environment you can associate any taxonomic rank you wish. The species name is always given according to the binomial nomenclature system and according to specific rules. The major principles followed have been given in this section.

Section 4: Evolution of plants

Keywords
Algae
Evolution
Terrestrial plant

All modern terrestrial plants are the descendants of algae that adapted to terrestrial habitat roughly 500 millions years ago. Compared to water, land is an erratic habitat where temperature and moisture availability may change abruptly and dramatically. To survive on land they have developed particular adaptations. These new traits acquired during evolution can be traced through a study of the different groups of plants that exist on earth today.

- While algae could obtain nutrients from the surrounding water, land plants needed to extract minerals and water from the soil; and roots adapted to take on this task.
- Surrounded by air, the land plant is in constant threat of desiccation and must have waterproofing mechanisms, usually in the form of a waxy cuticle layer.
- Evolution of rigid structural support allowed plants to grow to new heights, and better compete for sunlight.
- Yet, height must have coevolved with vascular (transport) tissue, the internal plumbing system needed to transport water and nutrients from the roots skyward.
- Reproduction became problematic as well, as sperm could no longer swim through open water to a joyous meeting with the egg. Thus sperm cells protected within pollen grains that could instead use wind, and later, unwitting animals to be carried to the egg evolved.
- As conditions on land are much less predictable than in water, packaging the immature (and dormant) plant in a seed, allowed it to survive until favourable growth conditions (or the correct season) arrived.
- Initially the gametophyte (which produces gametes) was the larger, more apparent stage as in a moss. Later the sporophyte stage (which produces spores) became more dominant and complex. Eventually the gametophyte becomes reduced to being only microscopic.

There are four major plant groups that evolved in the following sequence:

1. Bryophytes; which include the mosses
2. Seedless vascular plants; which include the ferns
3. Gymnosperms; many of which are also called conifers
4. Angiosperms; the ‘flowering’ plants, which now predominate

Fossil and biochemical evidence indicates that plants are descended from multicellular green algae. Algae dominated the oceans of the precambrian time over 700 million years ago. Between 500 and 400 million years ago, some algae made the transition to land, becoming plants by developing a series of adaptations to help them survive out of the water.

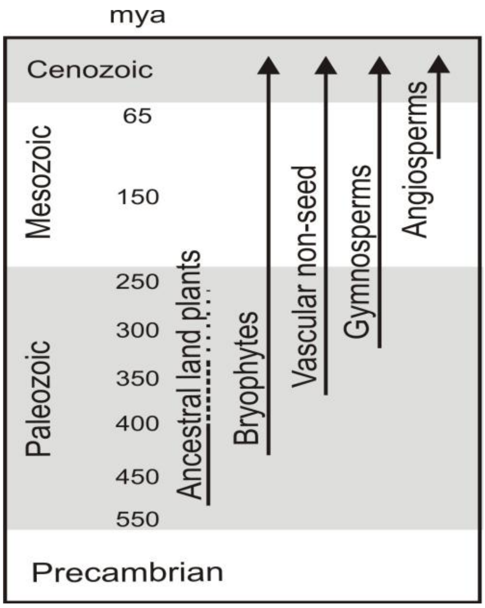

Figure3: Evolution of plant groups with approximate ages during geologic time (mya: million years ago).
Source:www. Marieta.edu-bio/introlab/plant%20Dirvesity.pdf)

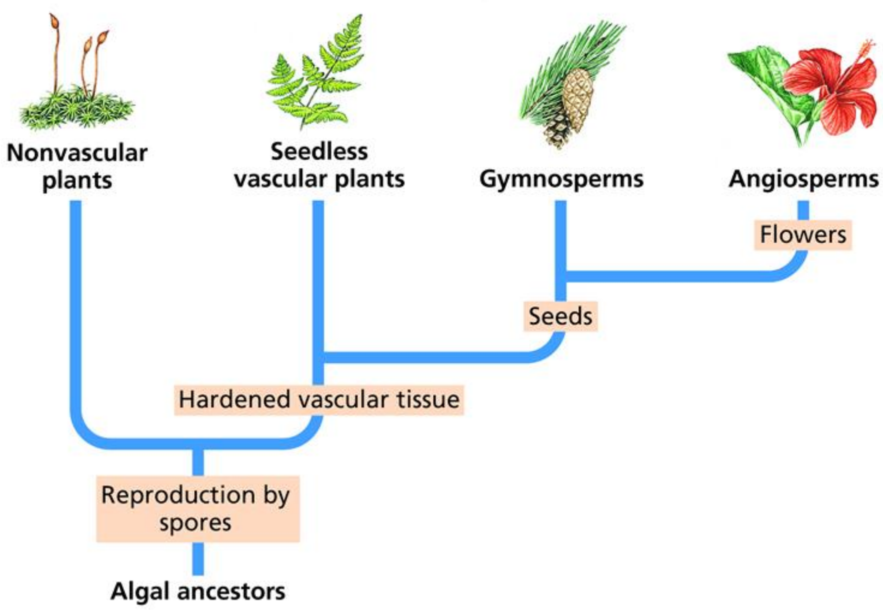

Figure 3 : Phylogenetic diagram representing a hypothesis for the evolutionary relationships between plants and their green algal ancestors. The earliest plants were nonvascular. These plants evolved into more-complex forms of plants, the vascular plants. (Source: http://go.hrw.com/venus_images/science/mbpev000002a.jpg)

Activity 4

1. How did the gametophyte and sporophyte stages evolve during the course of evolution?
2. What advantages does the seed confer to seed plants?

Feedback

Evolution of plants has resulted in increasing levels of complexity, from the earliest algal mats, through bryophytes, pteridophytes to the complex gymnosperms and angiosperms of today. You are requested to identify which traits have been acquired by seed plants and made them more adapted to land life than other plant groups.

Block summary

The block has introduced plant diversity in giving some foundation concepts and principles. The importance of plants was also introduced. The plant evolution has been discussed since the apparition of the first living organism up to now and the main characteristics of plants identified. The principles of classification and the botanical nomenclature principles have been developed. Today the binomial system is used to name species. The plant classification has evolved from the artificial system to the molecular one which is the most reliable system. By using the different modern systems of classification, plants are divided into 3 categories: bryophytes, pteridophytes and spermatophytes with several phyla in each group.

Answers to the activities in block 1

Activity 1

1. Classification of plants enables:
   - establishing relationships among plants,
   - knowing their characteristics
   - providing an organized way to study them
2. Classification is the arrangement of plants into groups having the same characteristics and identification is the use of the main characteristics of flowers, fruits, leaves and stem to name a plant
3. Plant systematic is the science which aims to identify, to classify and to study plant evolution.
4. The basic taxon in plant classification is a species
5. Variety-species-genus-family-order-class-phylum-kingdom

Activity 2

1. Artificial classification: arrangement based on superficial characters, and not expressing the true natural relations between organisms.
   Natural classification: classification that takes into account all the similarities and differences between organisms.

2. Molecular information obtained from DNA, RNA and protein sequencing is used and provide more reliable information to molecular systematics which establishes true evolutionary relationships among organisms.

Activity 3

1. Binomial system in plant classification is naming plants by using two words: the first one is the name of the genus and the second is the specific epithet.
2.
   a) Genus name
   b) Specific epithet
   c) Variety name
   d) Solanaceae
3. False. Members of higher taxons comprise more unrelated organisms. Thus the higher the taxon is, the less similar the members are.
4.

- The use of Latin has a long history in science and other subjects. For several centuries Latin was used as a language of learning and academic texts
- As language is not in daily use the terms are fixed and words meaning is less likely to change through generations.
- Latin names are used universally. International practices have been established for naming.

5. *Solanumincanum* L. is the valid name because it has been published earlier.

Activity 4

1. During the course of evolution, the gametophyte stage is progressively reduced; thus, in the higher (i.e., vascular) plants, the sporophyte is the dominant phase in the life cycle, whereas in the more primitive nonvascular plants the gametophyte remains dominant.
2. Seeds enable plant embryos to be dispersed at long distances from the parent plant by wind or animals. The seed also allows some plants to survive until favourable growth conditions are available.

   Plants have developed roots that extract minerals and water from the soil. The vascular tissue to transport water and nutrients from the roots skyward was also established.

BLOCK
2

Algae

Keywords

Thallus

Alga forms

Pigments

Spores

Introduction

Alga is a collective term for all chlorophyll bearing organisms which are thalloid. Their body is showing no differentiation into true tissues or organs (such as roots, leaves or stem) and is thus called a thallus. This term is used even if the plant is unicellular. Algae have chloroplasts and produce their own carbohydrates by photosynthesis, as plants do. Due to their phylogenetic position, the green algae are considered as ancestors of plants and older classification systems placed Algae in the Plantae kingdom. However, algae lack tissue differentiation and thus have no true roots, stems, or leaves. Despite those differences, this group will be studied in this module which is normally allocated to true plants.

What is in this block?

This block has 2 sections:

Section 1: Characteristics of Algae

Section 2: Major groups of Algae

Estimated study time

We estimate that you will need 12 hours to study the content of this block and do all activities.

Learning objectives

By the end of this block, you will be able to:

- enumerate the general characteristics of algae
- distinguish between the basic forms of algae
- classify algae in different major groups and give examples of algae from each group
- discuss the importance of algae in aquatic ecosystems

Section 1: Characteristics of Algae

Algae occur in most habitats, ranging from marine and freshwater to desert sands and from hot boiling springs to snow and ice. They exhibit a great diversity in the organisation of the body. They have four basic forms:

- ***Unicellular algae*** consist of a single cell. Most unicellular algae are free living aquatic organisms and together are known as phytoplankton. Phytoplankton forms the base of nearly all marine and freshwater food chain. Example: *Chlamydomonas.*

- ***Colonial algae*: such as *Volvox*, consist of groups of individual cells acting in a coordinated manner. Some of the cells may become specialized, allowing for a division of labor.
- ***Filamentous algae**: such as *Spirogyra*, are multicellular algae that are slender, rod shaped, and composed of cells joined end to end. Some filamentous algae have structures that anchor the organism to the ocean bottom.
- ***Multicellular algae***: are usually large and complex and often appear plantlike. Many large multicellular algae are also known as seaweeds. The plantlike body portion of a seaweed is called a thallus and its cells are usually haploid. Exemple: *Fucus (what makes the two to be different then? Highlighted in yellow!)*

The cells constituting the algal thalli are basically of two kinds, prokaryotic and eukaryotic. Algae are divided into two categories: blue algae or Cyanophytes with imperfect cells and classified in Prokaryotes and the other types of algae with perfect cells and classified in Eukaryotes.

The prokaryotic cells which constitute thalli of cyanophytes have a cell wall which contains a specific strengthening component not found in the cell wall of other algae: the mucopeptide.

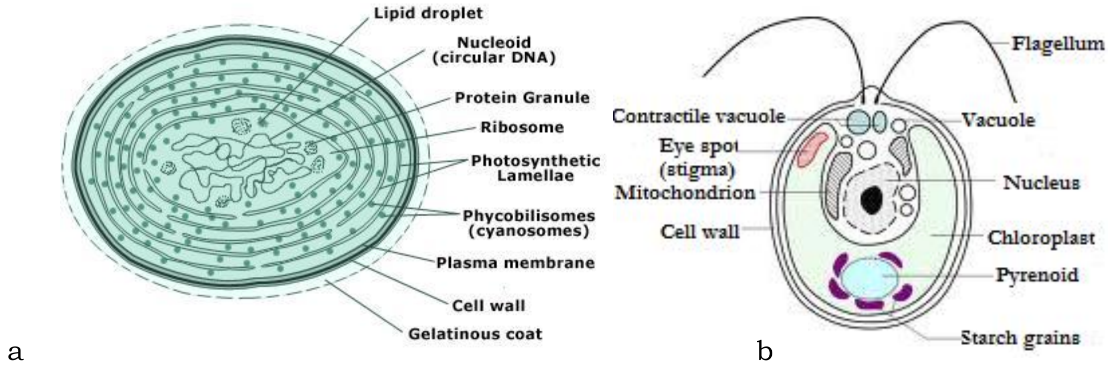

Figure 4: Fine structure of prokaryotic cell of a blue-green alga and eukaryotic cell of a unicellular green alga (*Chlamydomonas*).
(Source : https://www.google.rw/search?g=blue-green-and + eukoryote+cell. Images)

Algal pigments

The colour of the algal thallus which varies in different classes of algae is due to the presence of definite pigments in their cells. Each pigment has its characteristic colour and the thallus colour is due to the predominance of one pigment in a combination of several others. Three major classes of photosynthetic pigments occur among the algae: chlorophylls, carotenoids (carotenes and xanthophylls) and phycobilins. The algal group name is usually derived from the predominant type of pigment: Chrorophyta (greenish pigment or chlorophyll), Rhodophyta (red pigment or phycoerythrin), Cyanophyta (bluish pigment or phycocyanin), etc.

Reproduction of algae

Algae regenerate by sexual reproduction, involving male and female gametes, by asexual reproduction, or by both ways.

Many small algae reproduce asexually by ordinary cell division or by fragmentation, whereas larger algae reproduce by spores. Some red algae produce ***monospores*** (walled, non flagellate, spherical cells) that are carried by water currents and upon germination produce a new organism. Some green algae produce non motile spores called ***aplanospores***. In contrast, ***zoospores*** (observed in certain algae and fungi) lack true cell walls and bear one or more flagella. These flagella allow zoospores to swim to a favourable environment, whereas monospores and aplanospores have to rely on passive transport by water currents.

Activity 1

1. Define:

   a) thallus   b) zoospores

2. What arethe main differences between prokaryotic algae and eukaryotic algae?
3. Enumerate the three major pigments found in algae.

Feedback

Algae are photosynthetic organisms that occur in most habitats, ranging from marine and freshwater to desert sands and from hot boiling springs to snow and ice. Their size also varies from small, single-celled forms to complex and giant multicellular algae. The pigments that their cells contain make them be autotrophic organisms as plants..

Section 2: Major groups of Algae

Keywords

Prokaryotic algae
Eukaryotic algae
Endosymbiosis
Algal bloom

The nature of the pigment present in the algal cells forms a quick guide to the primary classification of algae in divisions (phyla). The other features considered for algae classification are: presence or absence of a definitely organized nucleus in the cell, chemical nature of stored food material, number, kind, point of insertion and relative length of flagella on the motile cell, and chemical composition of the cell wall.

The committee on the International Code of Botanical Nomenclature has recommended certain suffixes for use in the classification of Algae. These are -phyta for phylum (division), -phyceae for class, -ales for order -aceae for family.

In old classification the Cyanophyta were considered as algae but it is now known that they are not related to any of the other algal groups, which are all eukaryotes. In fact, Cyanophyta are organisms traditionally included among the algae, but they have a prokaryotic cell structure typical of bacteria and conduct photosynthesis directly within the cytoplasm, rather than in specialized organelles.

The diagram below shows the major characteristics of the algal groups as proposed by a classification where Cyanophytes are among Algae.

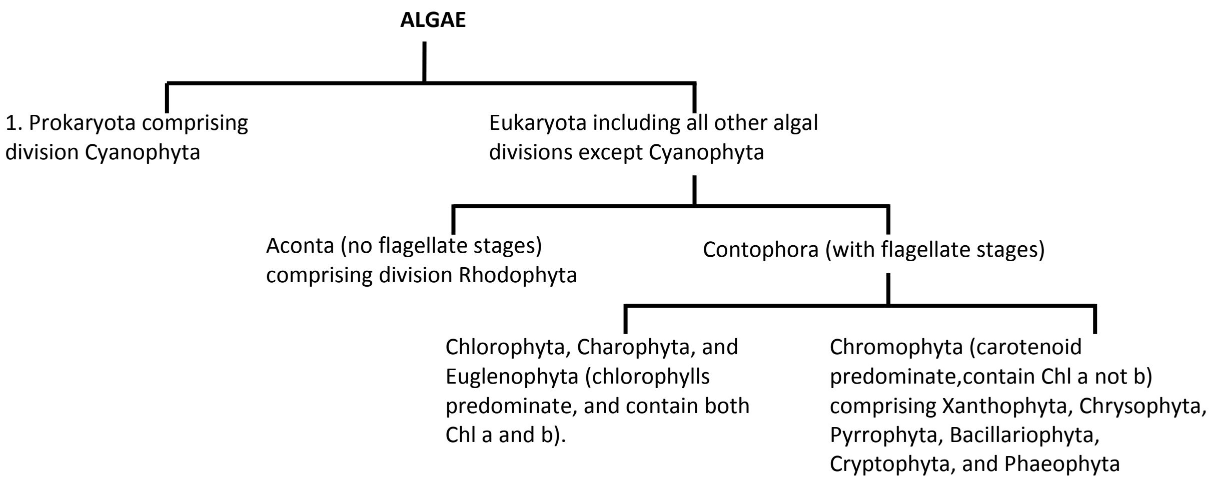

Figure 5: Scheme for the primary classification of algae as proposed by Christensen (1964). (Source: Vashishta, 2001).

2.1.Prokaryotic Algae (Cyanophyta or blue green algae)

The blue-green algae are the simplest of the algae. Blue-greens are not true algae. They have no nucleus, no chloroplast, and the structures that are evident in photosynthetic true algae. The composition of cell wall is similar to bacterial cell wall. Infact blue-greens are more akin to bacteria which have similar biochemical and structural characteristics.

The blue-green algal cell is an example of typical prokaryotic cell: it lacks membrane bound cell organelles characteristic of eukaryotic cells (see Fig. 4a). Thus it has no nucleus or well-defined nucleus, chromatophores, mitochondria, endoplasmic reticulum, and dictyosomes. The photosynthetic apparatus is made of elongated, flattened closed sac or disc-like structures called thylakoids or lamellae that contain pigments (chlorophyll a, carotene, xanthophyll and phycobilins).

The blue-green algae are widely distributed over land and water, often in environments where no other vegetation can exist. They are found in almost every conceivable habitat, from oceans to fresh water to bare rock to soil.

Their fossils have been identified as over three billion years old. They were probably the chief primary producers of organic matter and the first organisms to release elemental oxygen, into the primitive atmosphere, which was until then free from O_2. Thus blue-greens were most probably responsible for a major evolutionary transformation leading to the development of aerobic metabolism and to the subsequent rise of higher plant and animal forms. They are referred to in literature by various names, chief among which are Cyanophyta, Myxophyta, Cyanochloronta, Cyanobacteria, blue-green algae, blue-green bacteria.

Despite their name, different species can be red, brown, or yellow; blooms (dense masses on the surface of a body of water) of a red species are said to have given the Red Sea its name. There are two main sorts of pigmentation. Most cyanobacteria contain chlorophyll *a*, together with various proteins called phycobilins, which give the cells a typical blue-green to grayish-brown colour. A few genera, however, lack phycobilins and have chlorophyll *b* as well as *a*, giving them a bright green colour.

When viewed under the light microscope, blue-greens show a variety of movements, such as gliding, rotation, oscillation, jerking and flicking.

Architecturally the thallus of a blue-green alga may be a solitary cell or a colony.

- ***Unicellular forms***: the thallus is a unicell which is usually spherical or oval. There is immediate separation of daughter cells from each other after cell division but in most cases a secretion of mucilage by the daugter cells make them remain together after division.

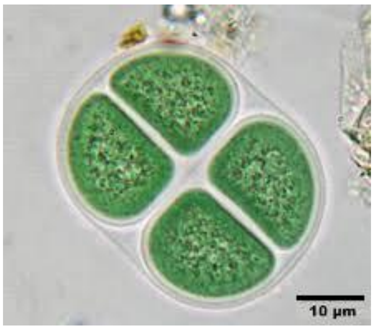

Figure 6: *Chroococcusturgidus* that forms colonies of 2, 4, or 8 cells surrounded by a clear mucus sheath.
(Source: http://www.dr-ralf-wagner.de/Bilder/Chroococcus_turgidus.jpg)

- ***Colonial forms***: in most blue-green algae, cells after division remain attached by their cell walls or are held in a common gelatinous matrix to form a loose organisation of cells which is termed as colony. The colony may either be filamentous or non-filamentous. Each colony is generally enclosed in a gelatinous sheath. The filamentous colony is a result of repeated cell division in a single plane in a single direction forming a chain or trichome.

Oscillatoria, Spirulinaand Nostoc are examples of filamentous blue-green algae.

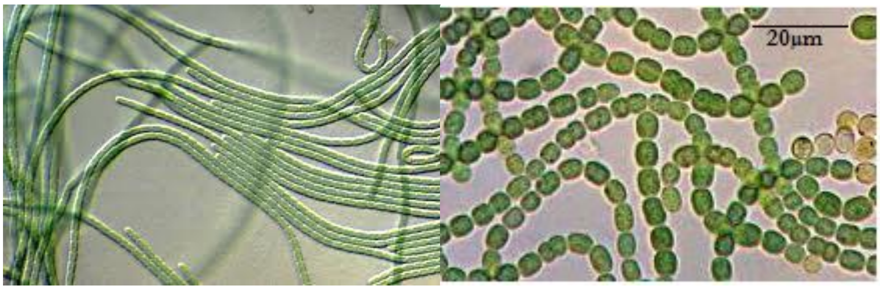

Figure 7: Colonial blue algae. a. *Oscillatoria:* each filament is slender, un-branched and cylindrical, consisting of a row of short cells.b. *Nostoc*: filaments are made up of spherical or barrel-shaped cells of uniform size that are blue-green.
(Source : https://www.google.rw/search?g=colonial blue-green-algae)

Importance of blue-green algae:

Not only have cyanobacteria been an important element for forming the earth's oxygen atmosphere, but it has also contributed to many other attributes important to human life. Many Proterozoic oil deposits are attributed to the activity of cyanobacteria.

The blue-green algae furnish food for the fish and other aquatic animals. Among the most favoured blue-algae consumed by fishes are*Oscillatoria, Spirulina, Anabaena* and *Microcystis.*

Recent investigations have proved that some of the blue-green algae (Ex: *Oscillatoria, Nostoc, Anabaena, Spirulina* and *Cylindrospermum*) increase the fertility of the soil by fixing atmospheric nitrogen. They thus serve as an excellent source of nitrogen and organic matter. For that reason they are important providers of nitrogen fertilizer in the cultivation of rice. In this sense, they resemble the bacteria that grow in nodules on the roots of bean-family plants (and that can also manufacture useful compounds from atmospheric nitrogen).

Humans also consume *Spirulina*. It contains all of the amino acids essential for humans, and its protein content is high (± 60%). It is a staple food in parts of Africa and Mexico. In China, Taiwan and Japan, several blue-greens are served as a side dish and a delicacy.

The negative value of the blue-green algae is that they contaminate water supply by providing colour, odour and giving fishy taste to the drinking water. The formation of water blooms results from the redistribution and often rapid accumulation of buoyant planktonic populations.In case of such blue-green algal blooms, the dead and decaying algae can reduce the oxygen levels in the water, causing stress or death to aquatic animals. During periods of drought, aquatic ecosystems can be severely degraded by algal blooms.

Note: Cyanobacteria are relatives of the bacteria, not eukaryotes, and it is only the chloroplast in eukaryotic algae to which the cyanobacteria are related. The chloroplast with which plants make food for themselves is actually a cyanobacterium living within the plant's cells. Sometime in the late Proterozoic or in the early Cambrian, cyanobacteria began to take up residence within certain eukaryote cells, making food for the eukaryote host in return for a home. This event is known as **endosymbiosis**, and is also the origin of the eukaryotic mitochondrion.

2.2. Eukaryotic Algae

Eukaryotic algae differ from prokaryotic algae (blue algae or Cyanophyceae) by their well-defined nucleus limited by a double membrane and by their cytoplasm containing cytoplasmic inclusions.

The main phylogenetic groups (divisions) of algae are Bacillariophyta (diatoms), Rhodophyta, Phaeophyta, Chrysophyta, Dinophyta, Euglenophyta, and Chlorophyta.

2.2.1. Chlorophyta

Division of the kingdom of protista consisting of the photosyntetic organism commonly known as green algae. Like the land plants green algae contain two forms of chlorophyll (a and b) which they use to capture the light energy to make sugars that are stored as starch inside plastids.

Green algae differ from plants in many ways. Because they live in water, they don't have a specialized transport or support systems. Their bodies are supported by the water, and almost all of the cells photosynthesize and have access to the nutrients present in the water. Therefore, the transport of nutrients is not necessary. Even though they synthesize, green algae do not have true leaves; they lack cuticles (a waxy layer on the outer wall of epidermal cells) and stomata (specialized cells for gas exchange).

The various species can be unicellular, multi-cellular, coenocytic (having more than one nucleus in a cell), or colonial. Chlorophyta are largely aquatic or marine, a few types are terrestrial, occurring on moist soil, on the trunks of trees, on moist rocks and in snow banks.

Some examples of very common green algae include *Spirogyra, Chlamydomonas, Chlorella, Acetabularia, Volvox,*etc.

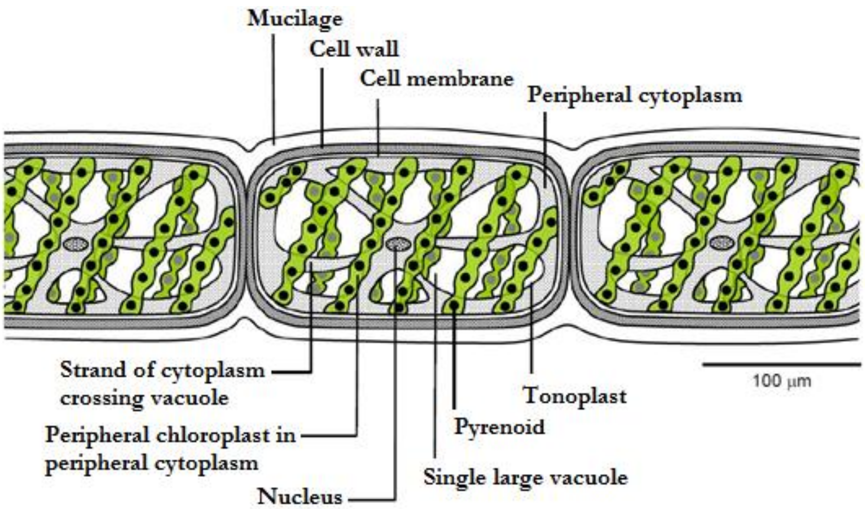

Figure 8: *Spirogyra*,a green alga which forms filamentous chains of cells, which float freely in ponds and other bodies of still water. Each cell has a distinctive and characteristic spiral green chloroplast. Many cells will typically be joined in long filamentous chains.
(Source: Cronodon.com/Bio tech/Algal)

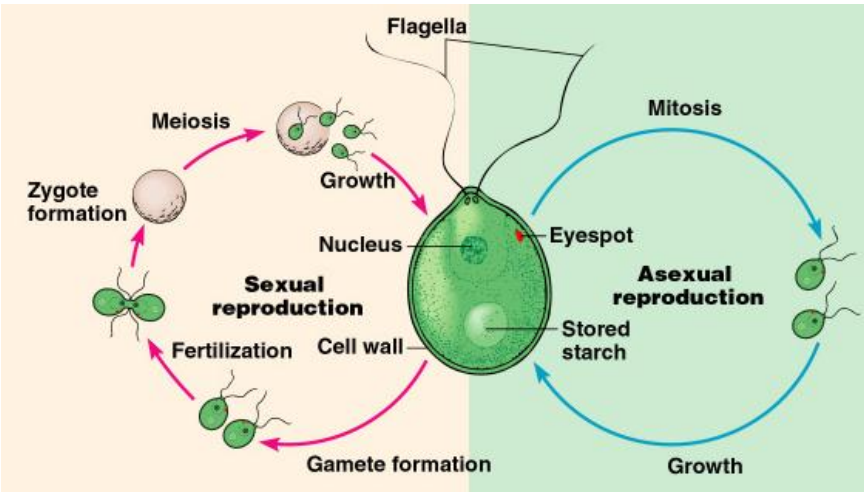

Figure 9: Life cycle of a unicellular green alga *Chlamydomonas*
(Source : https://www.google.rw/search?g=chlamidomonas+lift + cycle)

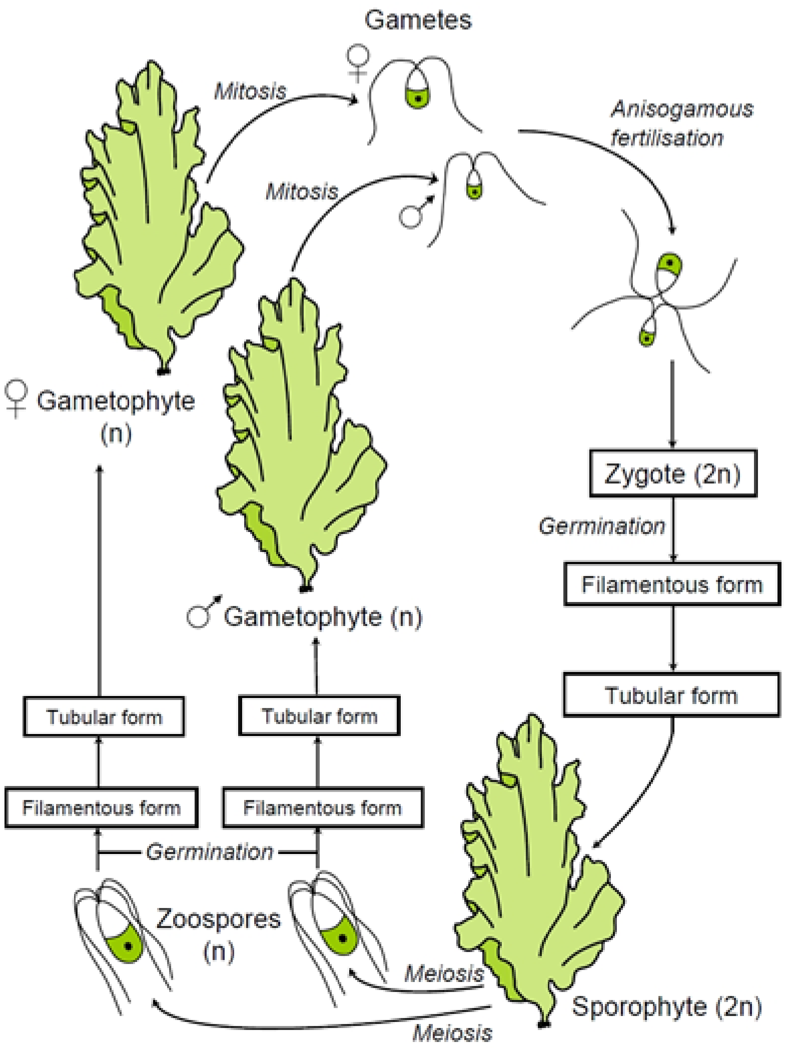

Figure 10 : Life cycle of a multicellular Green alga *Ulva lactuca*.
(Source: Cronodon.com/Bio tech/Algal)

2.2.2. Euglenophyta

Small phylum of the kingdom Protista, consisting of mostly unicellular aquatic algae. Some euglenoids contain chloroplasts with the photosynthetic pigments; others are heterotrophic and can ingest or absorb their food. Reproduction occurs by longitudinal cell division. Most live in freshwater. The most characteristic genus is *Euglena*, common in ponds and pools, especially when the water has been polluted by runoff from fields or lawns on which fertilizers have been used.

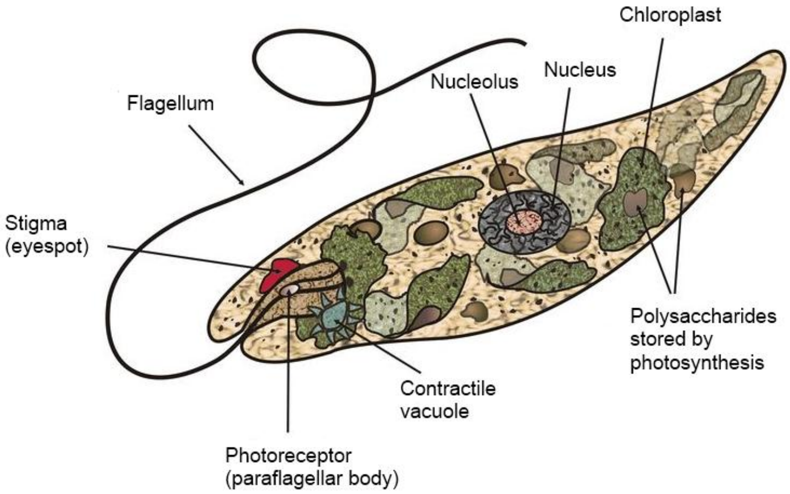

Figure 11: *Euglena*, a unicellular flagellate alga.
(Source : https://en.wikipedia.org/wiki/File:Euglena_diagram.jpg)

Most species of *Euglena* have photosynthesizing chloroplasts within the body of the cell, which enable them to feed by autotrophy, like plants. However, they can also take nourishment heterotrophically, like animals.

2.2.3. Dinophyta (Dinoflagellata)

Large group of flagellate protists. Some species are heterotrophic, but many are photosynthetic organisms containing chlorophyll. Various other pigments may mask the green of these chlorophylls. Other species are endosymbionts of marine animals and protozoa, and play an important part in the biology of coral reefs.

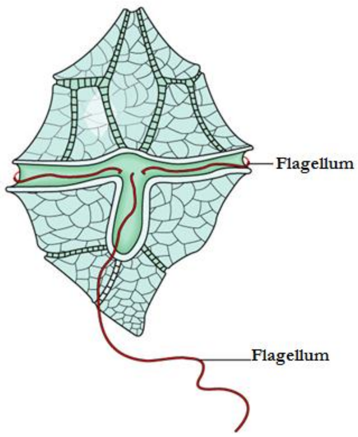

Figure 12: *Gymnodinium*
(Source: www.serc.si.edu)

2.2.4. Chrysophyta

Large group of eukaryotes algae commonly called *golden algae*, found mostly in freshwater. In many chrysophytes the cell walls are composed of cellulose with large quantities of silica. Formerly classified as plants, they contain the photosynthetic pigments chlorophyll *a* and *c.*

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2.2.5. Phaeophyta

Phylum of the kingdom protista consisting of those organisms commonly called *brown algae*. Many of the world's familiar seaweeds are members of phaeophyta. Like the chrysophytes brown algae derive their color from the presence, in the cell chloroplasts, of several brownish carotenoid pigments, as fucoxathin. With only few exceptions, brown algae are marine, growing in the colder oceans of the world, many in the tidal zone, where they are subjected to great stress from wave action; others grow in deep water.

Example: *Fucus vesiculosis*

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2.2.6. Rhodophyta

Photosynthetic organisms commonly known as *red algae*. Members of the division have a characteristic clear red or purplish color imparted by accessory pigments called phycobilins. The red algae are multicellular and are characterized by a great deal of branching, but without differentiation into complex tissues. Most of the world's seaweeds belong to this group, a few species occur in freshwater. Example: *Gracilaria*

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2.2.7. Bacillariophyta (Diatoms)

Bacillariophyta are unicellular organisms that are important components of phytoplankton (the autotrophic component that inhabits the upper part of the water column) together with Dinophyta and Cyanophyta. They constitute the primary sources of food for zooplankton in both marine and freshwater habitats. Most diatoms are planktonic, but some are bottom dwellers or grow on other algae or plants. Mostly unicellular forms, some are colonial and filamentous in structure. Cell wall is silicified, consisting of two perforated overlapping plates. It is highly ornamented on the surface. Chromatophores are brownish in colour due to large amounts of carotenoids.

Most diatoms exist singly, although some join to form colonies. Diatoms have deposited most of the earth’s limestone, and much petroleum is of diatom origin.

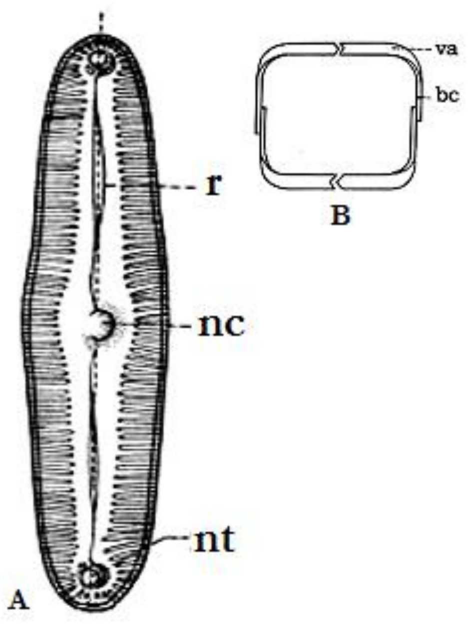


Figure 13 : Structure of a diatom: *Pinnularia viridis.* A: valvate side; B: cross section, r: raphe, nc: central nodule, nt: terminal nodule, va: valve, bc: connective.
(Source: Bourrelly, 1985)

Activity 2

1. Do blue green algae possess plastids? If yes, where are they located? If no, how do they do photosynthesis?
2. Discuss the economic importance of blue-green algae.
3. Discuss why Green algae are not currently classified into Plants despite similarities among these two groups.
4. Enumerate the main features of Rhodophyta algal group.
5. What is phytoplankton and what are its components?

Feedback

The nature of the pigment present in the algal cells forms a quick guide to the primary classification of algae in divisions (phyla). In addition to this criterion other features such as the cell structure and composition are also considered. Remember that this group (Algae) was studied in this module simply because algae are closely related to plants by certain characteristics.

Block summary

The Algae constitute a large group of photosynthetic organisms but their body is showing no differentiation into true tissues or organs (such as roots, leaves or stem). For this reason their body is called a thallus and they are said to be thalloid. The thallus may be unicellular, colonial, filamentous or multicellular. Their life fully depends on water. Various criteria are used to classify Algae such as the type of pigment, presence or absence of a definitely organized nucleus in the cell, chemical nature of stored food material, number, kind, point of insertion and relative length of flagella on the motile cell, and chemical composition of cell wall. The Algae are generally classified into seven phyla including Cyanophyta, Chlrorophyta, Bacillariophyta, Euglenophyta, Phaeophyta, Dinophyta, Rhodophyta and Chrysophyta.

Algal organisms are a source of nutrients for aquatic animals and they form the base of the aquatic food chain. Particularly, Cyanobacteria have played a significant role in producing O_2 in the primitive Earth's atmosphere. Because of their phylogenetic position Algae are considered as ancestors of plants.

Answers to activities in block 2

Activity 1

1.

   a) Thallus: a plant body that lacks differentiation into distinct parts (as stem, leaves, and roots).

   b) Zoospore: motile, flagellate spores

2. Prokaryotic algae lack nuclei and other organelles, which are specialized, membrane-bound compartments, whereas eukaryotic do have them.
3. Chlorophylls, carotenoids (carotenes and xanthophylls) and phycobilins.

Activity 2

1. No. Cyanophyceae do not have plastids. Photosynthesis occurs in the chromoplasm in which chlorophyll is dispersed.
2. Blue algae are important for the following reasons:

– they are a source of nutriments for fishes

– they fixe atmospheric Nitrogen for the synthesis of amino- acids and proteins

– they live in symbiosis with other plants

– they can contaminate water causing an offensive odour and hinder aquatic animal lives.

3. Green algae are not classified into plants because their body is not divided into tissue and organs (it is a thallus).

   However, they are considered to share a common ancestor with plants because they have the same photosynthetic pigments (chlorophyll a and b); they have similar cell walls, both store energy in the form of starch, and both have two stage life cycles.

4. Rhodophyta are characterized by clear red or purplish color imparted by accessory pigments called phycobilins. They are multicellular and are characterized by a great deal of branching, but without differentiation into complex tissues.
5. Phytoplankton refers to the autotrophic component that inhabits the upper part of the water column. The main components are diatoms (Bacillariophyta), blue-green algae (Cyanophyta) and dinoflagellates (Dinophyta).

BLOCK 3

Bryophytes or non vascular plants

Introduction

Bryophytes are small and inconspicuous plants. They have no vascular tissue or wood to lend them structural support, nor do they have large leaves or showy cones or flowers. This does not mean that mosses are not important. Due to its phylogenetic position, we will study this group before the remaining plant groups.

What is in this block?

This block has 2 sections:

Section 1: Characteristics of Bryophytes

Section 2: Major groups of Bryophytes

Estimated study time

We estimate that you will need 10 hours to study the content of this block and do all activities.

Learning objectives

By the end of this block, you will be able to:

- enumerate the general features of bryophytes
- distinguish between major groups of bryophytes according to their characteristics
- discuss the phylogenetic position of bryophytes
- discuss the ecological importance of bryophytes

Section 1: Characteristics of Bryophytes

Keywords

Moss

Sporophyte

Gametophyte

Rhizoids

Bryophytes are considered to be the most primitive of the plants: their lifestyles are strongly influenced by moisture availability as they are typically only found where water is readily available. They need water to reproduce sexually because the sperm must swim through water to an egg. In dry areas, bryophytes can reproduce sexually only when adequate moisture is available.

Bryophytes disperse through spores, not seeds.

Bryophytes lack a vascular system. Water is taken up by diffusion via leaves or rhizoids so that most water conduction is external.

Because they do not have vascular tissue, they are very small in height. There are no tree-size bryophytes because water could never travel adequately from the rhizoids to the very top.

The gametophyte stage is dominant: bryophytes are the only group of plants where the gametophyte stage is larger than the sporophyte stage.

The sporophytes are parasitic on gametophytes, they never have an independent existence.

In alternation of generations, as illustrated in Figure 15 the gametophyte (1n) undergoes mitosis to form gametes: eggs and sperm. Once an egg is fertilized by a sperm and produces a zygote, the plant begins the diploid phase of its life cycle. The zygote divides by mitosis to form a sporophyte plant. The sporophyte (2n) produces cells that undergo meiosis to form haploid spores. The life cycle begins again when the spores divide by mitosis to form new gametophytes. The spores are released by the most seedless plants (bryophytes and pteridophytes) but are retained by seed plants.

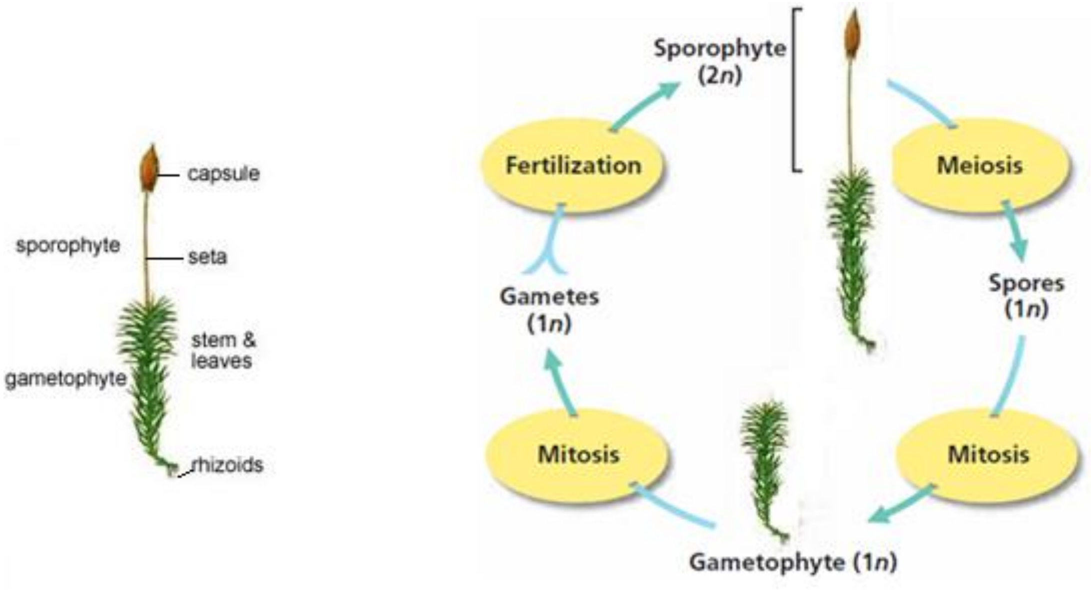


Figure 14: Sporophyte, gametophyte and life cycle of a typical bryophyte (moss) (Source : https//www.google.rw,search?) Check the accuracy of the reference!

Activity 1

1. Discuss about adaptation of Bryophytes to land life.
2. To which generation does the greenish leafy structure of a moss? Meaning of this sentence? A verb is missing!
3. Why a Bryophyte plant cannot attain a tree size?

Feedback

This section is an overview of the main characteristics of Bryophytes. Those characteristics show that this group of plants is the most primitive. They need water to reproduce sexually because the sperm must swim through water to an egg.

Section 2: Major groups of Bryophytes

Keywords

- Protonema
- Rhizoids
- Capsule
- Gametophore
- Antheridium
- Archegonium
- Gemma cup

1. Mosses (Phylum Bryophyta)

Almost every land is home of to at least one species of moss. Each moss gametophyte is attached to the soil by root like structures called ***rhizoids***. Unlike roots, rhizoids do not have vascular tissue but rhizoids do function like roots by anchoring the moss and by absorbing water and inorganic nutrients.

The gametophyte refers to all organs and tissues that are part of the haploid generation. There are two different developmental stages of the gametophyte: the ***protonema*** (plural protonemata), and the gametophore. The protonema is the first part of the moss that develops from the germinating spore. Its filamentous form is remarkably similar to green algae. This photosynthetic colonizer lies flat against its substrate, making it to seem as if the rock or tree it grows on is painted green. The protonema will eventually produce leafy shoots called ***gametophores***. The gametophyte may be male, may be female or may contain both male and female reproductive organs.

The moss sporophyte grows up from the top of the gametophyte. It remains attached to the gametophyte (the haploid mother), and is in fact, parasitic upon it. The sporophyte relies on the gametophyte to provide it with food and water, which are passed through transfer cells that lie in the placental layer between the gametophyte and the sporophyte. Transfer cells have convoluted cell walls that increase surface area for nutrient exchange. In most mosses the sporophyte will have these anatomical features: a foot, seta, a sporangium with a columella, spores, an operculum, peristome teeth, and a calyptra.

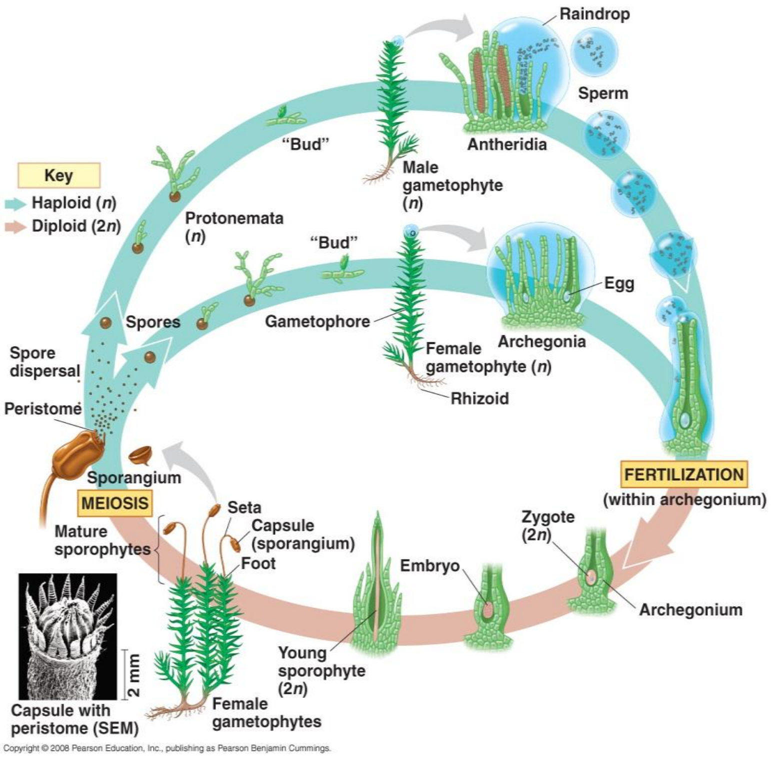


Figure 15 : Moss life cycle.
(Source : https//www.google.rw,search? g=Sporophyte, gametophyte and life cycle of a typical bryophyte)

Examples of moss include Polytrichum (common hair moss), Sphagnum (peat moss), etc.

2. Liverworts (Phylum Hepatophyta)

Liverworts come in two very distinct forms: leafy and thalloid. Leafy liverworts are obviously, leafy, and look very much like the mosses. They are most easily distinguished from the mosses by their leaf arrangement. Leafy liverworts have leaves that are arranged in two or three rows while the leaves in mosses are spirally arranged.

Liverworts have unicellular rhizoids that are located on the ventral (bottom) side of the gametophyte. Rhizoids look like roots, but do not absorb water or nutrients. Instead, they attach the plants to their substrate and help with external water retention and conduction.

In thalloid liverworts, the gametophyte looks like a flat, branching green ribbon. Gametes are produced beneath the umbrella-shaped structures and the fertilized eggs develop into gametophytes. The sporophyte generation is small and not easily visible: it only occurs as tiny bag-like structures underneath the little umbrella-shaped structures growing out of the thallus (see Figure 17).

In liverworts, asexual reproduction can be performed by the **gemmae**: clusters of cells that detach from the parent and develop into a new individual. The gemma cups are cup-like structures containing gemmae. The gemmae are small discs of haploid tissue, and they directly give rise to new gametophytes. They are dispersed from gemma cups by rainfall.

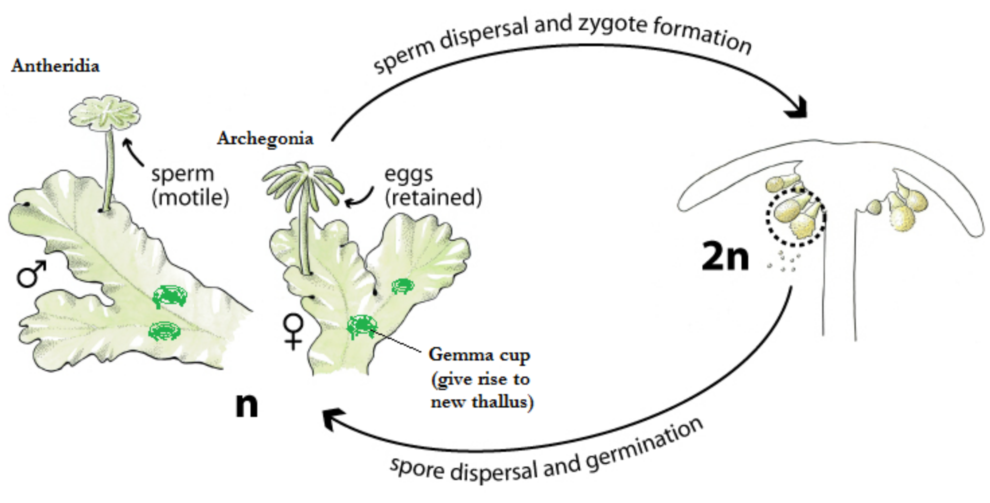


Figure 17: Life cycle of liverwort *Marchantia*.
During sexual reproduction the sperm cells must move from the antheridia to the archegonium where the eggs are formed and develop into sprophyte. In the mature sporophyte the spore-producing cells will undergo meiosis to form haploid spores to disperse, upon which point the life cycle can start again. The gemmae cups can release gemmae that can give a new gametophyte (asexual reproduction).
(Source : https//www.google.rw,search?g=life +cycle+of+liverwort-marchantia)

3. Hornworts (Phylum Anthocerophyta)

The name "hornwort" refers to the long, thin, hornlike sporophytes that grow out from the top of the plant. When the sporophyte is absent, Hornworts look very similar to thalloid liverworts. Hornworts do not have a stem or leaves; the gametophyte of a hornwort is anchored to the ground by rhizoids.

The sporophytes of Hornworts are different from the sporophytes of mosses and liverworts in that they are green and carry out photosynthesis. The sporophytes continue to grow throughout the plant's life.

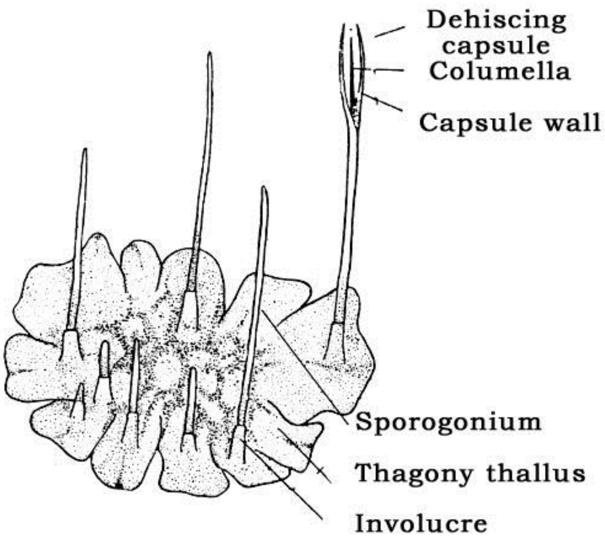


Figure18: Gametophyte (thallus) and sporophyte (horn) of a hornwort *Anthoceros*. (Source:Panday, 2001)

Ecology and importance of bryophytes

- Mosses are called pioneer plants because they are often the first species to inhabit a barren area. Mosses gradually accumulate inorganic and organic matter on rock surfaces, creating a layer of soil in which other plants can grow. They also help prevent soil erosion by covering the soil surface and absorbing water.
- Peat moss (of the genus *Sphagnum*) is a major component of bogs in northern parts of the world where it is mined and dried for use as fuel.
- Bryophytes were for a long time used in medicine and pharmacy; their importance as indicators of pollution is well known.

  They are also a food source for animals in cold climates.

However, the reduction and degradation of the significant habitats of Bryophytes in the world have led to the reduction of a big number of species and has affected the genetic diversity.

Activity 2

1. Define:
    a) protonema
    b) gemma
2. Explain how in all bryophytes the gametophyte generation is said to be dominant.
   Distinguish between Anthocerophyta and other bryophyte sporophytes.
3. For each bryophyte group give one example of associated plant (genus name only).

Feedback

This section enables to distinguish among the different groups of Bryophytes. Do not confuse the terms "Bryophytes" and "Bryophyta". The first is a general name that covers all the non vascular plants whereas the latter is one of the phyla of non vascular plants and includes only mosses.

Answers to activities in block 3

Activity 1

1. The bryophytes are not well adapted to land life. They require moisture for their sexual reproduction; they don't have vascular tissues that should help them to conduct adequately water and mineral; they don't have true roots that should enable them to absorb more nutrients and fix them in that soil.
2. Gametophyte generation
3. It has no support tissue and water cannot travel adequately from the rhizoids to the top.

Activity 2

1.

a) Protonema: filament that develops from germinating spore in moss.

b) Gemma: cluster of cells that detach from the parent and develop into a new individual (asexual reproduction).

2. It means that the gametophyte is more prominent, longer-lived plant is the haploid gametophyte. The diploid sporophytes appear only occasionally and remain attached to and nutritionally dependent on the gametophyte.

3. The sporophyte of Hornworts is different from the sporophyte of mosses and liverworts in that they are green and carry out photosynthesis. The sporophyte continues to grow throughout the plant's life.

- Bryophyta (mosses): Polytrichum, Sphagnum
- Hepatophyta (liverworts): Marchantia
- Anthocerophyta (hornworts):Anthoceros

Block summary

Bryophytes or non vascular plants and small land plants which still display dependence to water availability for their life. They lack vascular tissue and they must absorb water and nutrients at the surface and transport the materials from cell to cell by diffusion, which explains their small sizes.

The sporophyte of Bryophytes is relatively reduced and is parasitic on the gametophyte issued from spore germination. The gametophyte is very conspicuous and dominates the life cycle.

The major groups of Bryophytes include the three phyla Bryophyta (mosses), Hepatophyta (liverworts) and Anthocerophyta (hornworts).

Bryophytes are called pioneer plants because they can colonize a barren area in which any other plant cannot survive. In temperate regions, mosses feed animals and peat moss is used as fuel. Mosses are also used as indicators of pollution.

BLOCK
4

Tracheophytes or Vascular plants

Introduction

Vascular plants also known as Tracheophytes and also higher plants, form a large group of plants that are defined as those land plants that have lignified tissues (the xylem) for conducting water and minerals throughout the plant. They also have (non-lignified) tissue to conduct products of photosynthesis. Beside these major characteristics, vascular plants exhibit other features that enable them to be considered as the most adapted to land life. This block is an overview of the major vascular plant groups with their adaptive characteristics their ecological and economic importance.

What is in this block?

This block has 2 sections:

Section 1: Seedless vascular plants (Pteridophytes)

Section 2: Seed plants (Spermatophytes)

Estimated study time

We estimate that you will need 12 hours to study the content of this block and do all activities.

Learning objectives

At the end of the block, students will be able to:

- enumerate the general characteristics of vascular plants
- explain the life cycles of different groups of vascular plants
- discuss adaptations of vascular plants to land life
- state examples of common plants from each group of vascular plants

Keywords

Pteridophyte
Fern
Lycopod
Horsetail
Fiddlehead
Prothallus
Sporophyll
Tracheid

Section 1: Seedless vascular plants (Pteridophytes)

Pteridophytes (pteris = fern) or tracheophytes producing spores possess true stems, leaves and roots as well as a differentiated reproductive system. But pteridophytes produce neither flowers, nor seeds. In seedless vascular plants the spores are the mobile sexual reproductive parts. These plants dominated the Earth until about 200 mya. They comprise ferns and their allies. They are subdivided into 4 divisions: Psilophyta, Lycophyta, Sphenophyta and Filicophyta.

1. Phylum psilophyta (whisk ferns)

This unusual group of small herbaceous plants is characterized by a leafless and rootless body possessing a stem that exhibits a primitive dichotomous type of branching: it forks into equal halves. The photosynthetic function is assumed by the stem, and the underground rhizome anchors the plant. The vascular tissue is organized into a poorly developed central cylinder in the stem.

Psilotum and *Rhinia* are examples of Psilophyta members.

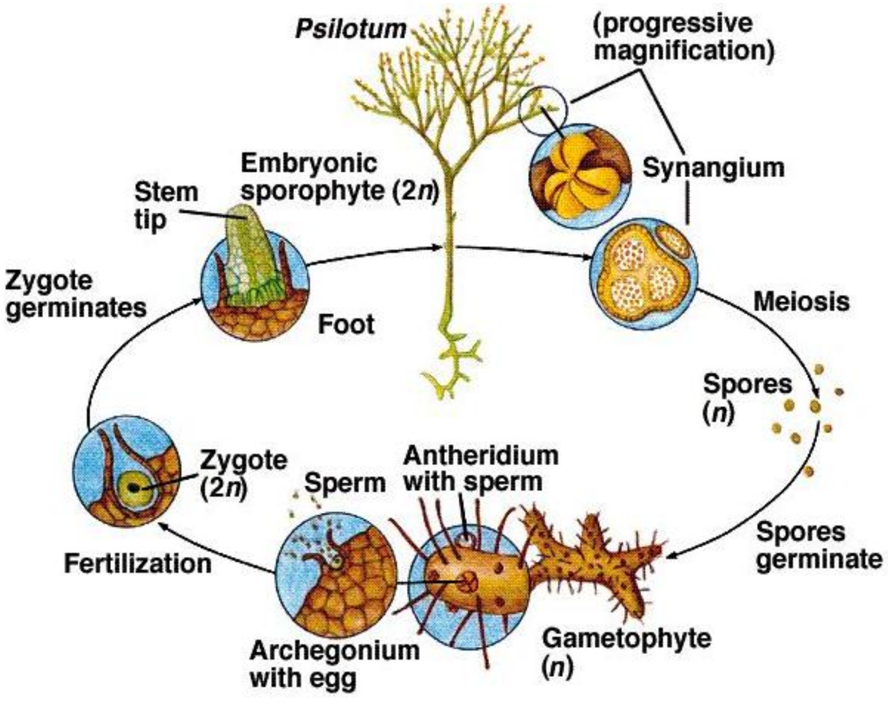


Figure 16: Life cycle of Psilotum.

(Source: https//www.google.rw,search?g=life cycle of *tracleophyte psilotu)*

(Source: https//www.google.rw,search?g=life cycle of *tracleophyte psilotu)*

Collectively, the four groups (Filicophyta, Lycophyta, Sphenophyta and Psilophyta) are sometimes referred to as **pteridophytes,** because each reproduces by spores liberated from dehiscent sporangia (free sporing).

Despite their name, whisk ferns are not ferns at all. They have no roots or leaves and produce spores on the ends of short branches. These features suggest that whisk ferns resemble early land plants.

Although the lower vascular plants have adapted to terrestrial life, they are similar to bryophytes in that, as an apparent vestige of their aquatic ancestry, all produce motile (flagellated) male gametes (antherozoids, or sperm) and must rely on water for fertilization to take place.

2. Phylum lycophyta (Lycopods)

They differ from all other vascular plants in having microphylls, leaves that have only a single vascular trace (vein) rather than the much more complex megaphylls found in ferns and seed plants. Lycopods are differentiated into stem, root, and leaf (microphylls). Sporangia are positioned on the upper (adaxial) surface of the leaf (sporophyll).

As a group, the lycopods were prominent in the great coal-forming swamp forests of the Carboniferous Period (300mya). Although all living lycopods are small herbaceous plants, some extinct types were large trees.

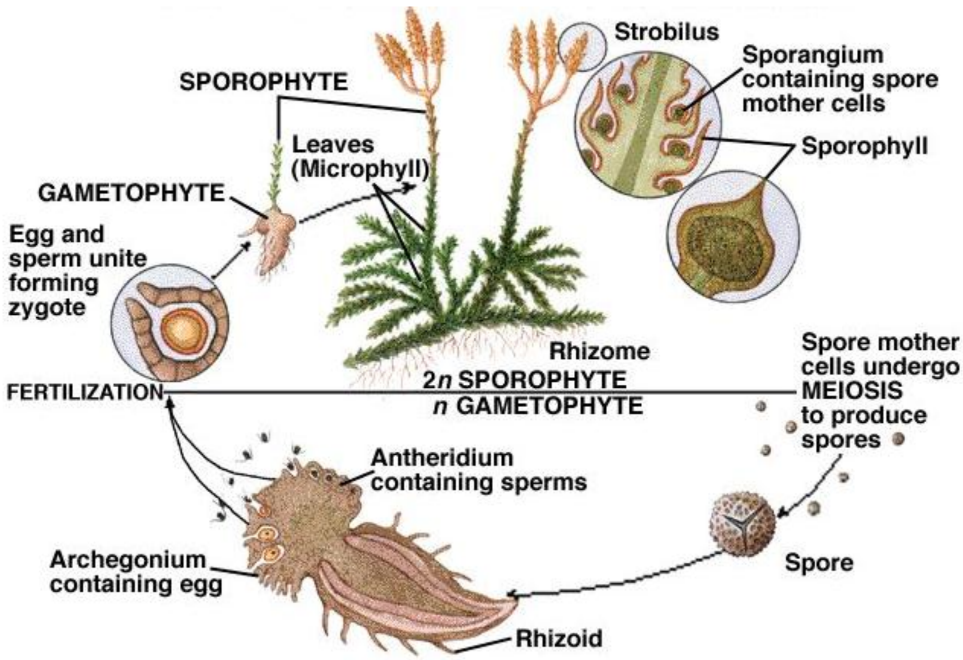


Figure 17: Life cycle of *Lycopodiumand Selaginella*
(Source: https//www.google.rw,search?g=life cycle of lycopodium+and+selaginella)

3. Phylum sphenophyta (Horsetails)

Appear almost like 'naked' stems, with occasional whorls of scale like leaves. The spores are typically produced in small cone-like structures at the shoot tips.

The fossil record indicates that these plants together with Lycophyta were dominant during the Carboniferous period (300 millions of years) and grew to the size of trees. The partially decomposed bodies of these plants along with tree ferns eventually created the coal deposits that we now use as an energy source. Because of their long evolutionary lineage, the lycopods and horsetails are often called "living fossils."

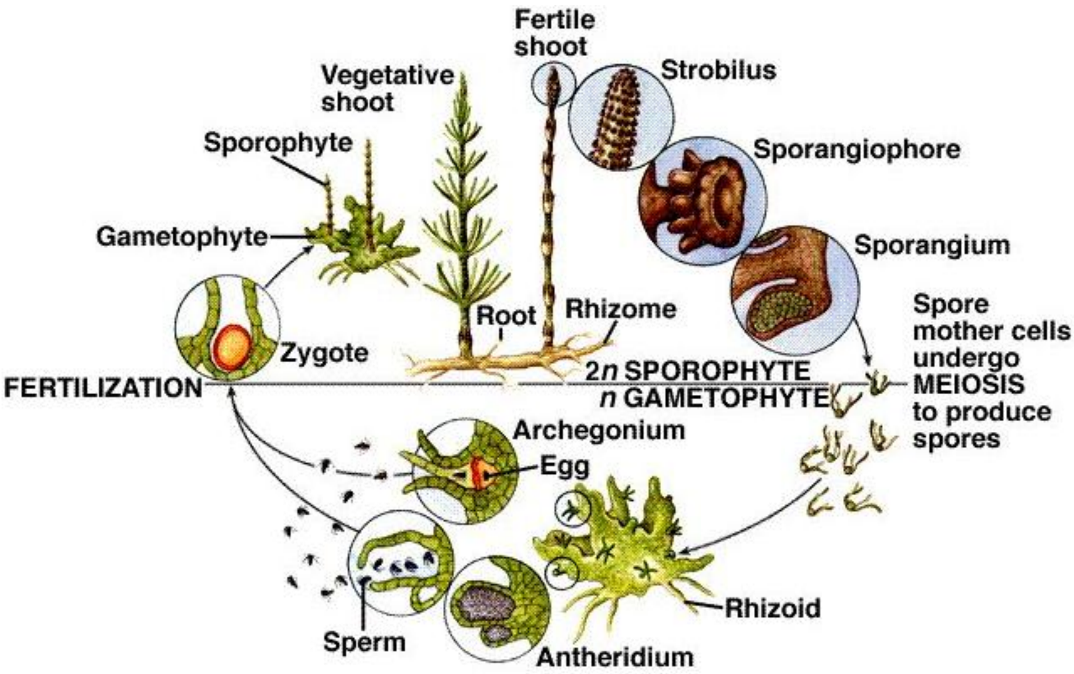


Figure 18: Life cycle of *Equisetum*
(Source: nick rent lab siu.edu/PLB304/lecturer 06 ptered/ferm)

The phylum Sphenophyta includes horsetails of the genus *Equisetum.*

4. Phylum filicophyta (Ferns)

The Filicophyta (alternately **Pteridophyta**) are the familiar group of free-sporing vascular plants commonly called "Ferns". The ferns typically bear their sporangia in clusters (sori) on the undersides of their conspicuous leaves. The group exhibits a large degree of morphological variation ranging from large "tree ferns" to tiny floating aquatic forms.

Ferns typically possess a **rhizome** (horizontal stem) that grows partially underground; the deeply divided fronds (leaves) and the roots grow out of the rhizome. Fronds are characteristically coiled in the bud (**fiddleheads**) and uncurl in a type of leaf development called **circinate veination**. Fern leaves are either whole or variously divided. The leaf types are differentiated into rachis (axis of a compound leaf), pinnae (primary divisions), and pinnules (ultimate segments of a pinna).

Each frond is a potential **sporophyll** (spore-bearing leaf) and as such can bear structures that are associated with reproduction. When growth conditions are favourable, a series of brown patches appear on the under surface of the sporophylls. Each one of the patches (called a **sorus**) is composed of many sporangia, or spore cases, which are joined by a stalk to the sporophyll. The spore case is flattened, with a layer of sterile or non fertile, cells surrounding the spore mother cells. Each spore mother cell divides by reduction division (meiosis) to produce haploid spores, which are shed in a way characteristic to the ferns.

Through mitosis each fern spore has the potential to grow into a green heart-shaped independent gametophyte plant (**prothallus)** capable of photosynthesis. It is in the prothallus that gametes are formed and fertilization will give rise to the zygote which develops into a sporophyte.

In contrast to bryophytes, in which the sporophyte is nutritionally dependent on the gametophyte during its entire existence, the fern sporophyte is dependent on the gametophyte for nutrition only during the early phase of its development; thereafter, the fern sporophyte is free-living.

In some ferns the sexes are separate, meaning a gametophyte will bear only male or female sex organs. Other species have gametophytes bearing both sex organs.

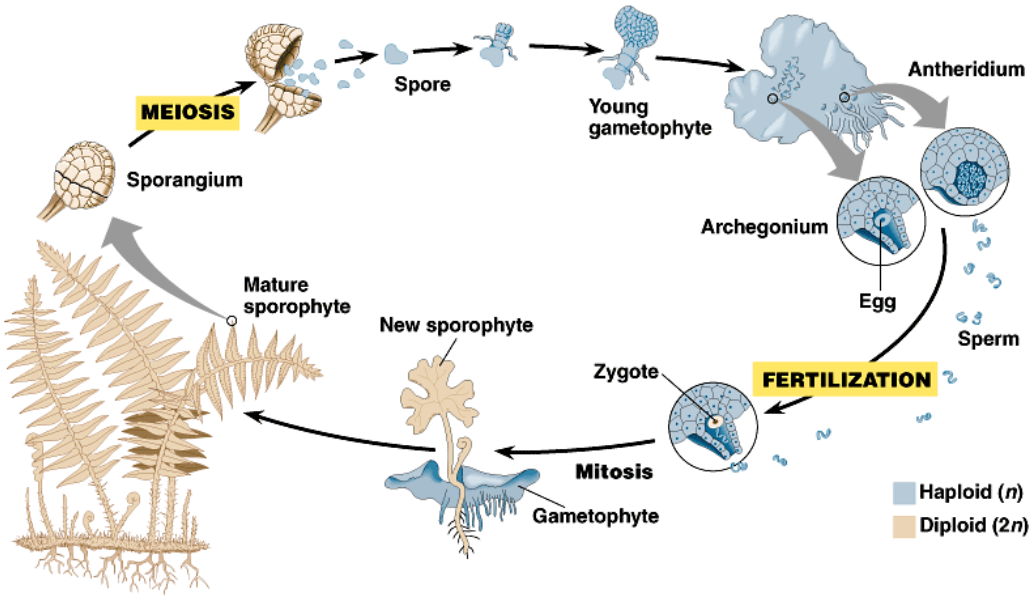


Figure 19: Life cycle of a fern.
(Source:ib.bakeley.edu/ course/ bio b/ plants fall 109)

Ecology and importance of Pteridophytes

Pteridophytes, particularly Lycopods and giant horsetails, constitute a group of plants that reached their apogee in the Carboniferous period (300 mya). They are the first terrestrial vascular plants.

As the first tracheophytes, pteridophytes were also the first plants to extensively colonize the terrestrial environment forming forests. They also constituted an important source of food for terrestrial animals. By presenting conductive vessels they could be larger, a feature inherited from them by seed plants.

The majority of the Pteridophytes are well adapted to terrestrial conditions even though fertilization still requires the presence of water since the male gametes are swimming.

Approximately three quarters of the species of Pteridophytes are found in tropical regions; the majority of tropical ferns are epiphytic. In Rwanda the most common pteridophytes belong to the genera *Pteridium, Nephrolepis, Lycopodium, etc.*

Pteridophytes are adapted to various habitats: some are terrestrial, others grow in wet and shady places; some are adapted to xeric conditions and others (like *Azolla* and *Marsilea*) are aquatic.

Pteridophytes have formed big forests whose fossilization has originated in coal deposits which have an economic importance.

Azolla lives in symbiosis with the cynobacteria, fixing atmospheric nitrogen. Therefore, *Azolla* plays a significant role in the maintenance of the fertility of rice crops by fixing Nitrogen.

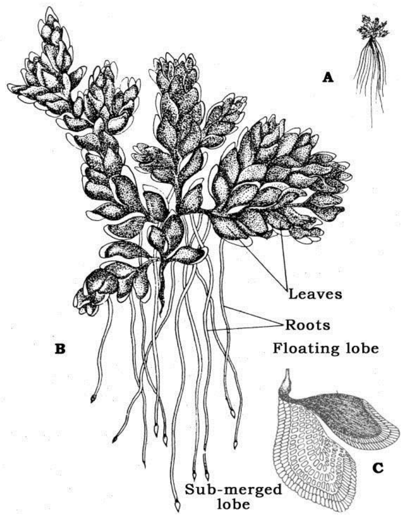


Figure 20: *Azolla microphylla.* A : Sporophyte, B : Organisation of sporophyte, C : Leaves shape. (Source: Pandey, 2001).

Some pteridophytes are used as ornamental plants (example: various ferns, *Lycopodium* and *Selaginella*) or as medicinal plants. For instance the male fern rhizome in "*Dryopteris filix-mas*" is used to cure the tapeworm and other parasites of the digestive tract and thexerophitic fern "*Notholaena aurea"* is used to cure stomach pains).

Activity 1

1. Why are pteridophytes better adapted to dry land than bryophytes?
2. Give the main characteristics of Psilophyta. Why are they considered as the most primitive group of Pteridophytes?
3. Compare the life cycle in Bryophytes and Pteridophytes
4. Define
    a. Sporophyll
    b. Prothallus
5. How are gametes formed in the pteridophyte life cycle, by mitosis or meiosis? What is the type of meiosis that occurs in pteridophytes?
6. For each phylum of seedless vascular plants give one example of associated plant (genus name only).
7. What is the evolutionary importance of pteridophytes?

Feedback

This section treats on seedless vascular plants. It is a group exhibiting primitive characteristics of land plants. Eventhough they have dominated carboniferous forests they have been today replaced by seed plants as you can notice it in your environment.Again do not confuse pteridophyte and Pteridophyta!

Section 2: Seed plants (Spermatophytes)

Keywords

Flower
Cone
Perianth
Anther
Carpel
Pollen
Microspore
Megaspore
Embryo sac
Double fertilization
Endosperm
Monocot
Dicot

An often used system of classifying plants is to place all the seed-bearingplants in the phylum Spermatophyta*(sperm* meaning "seed"). The spermatophytes are then divided into the gymnosperms (naked-seeded plants) and the angiosperms (enclosed seeds). An angiosperm (flowering plant) has its seeds enclosed in an ovary, in maturity called the fruit. In many forms of gymnosperm, the seed are not enclosed but, rather, lie on the surface of a cone scale.

Gymnosperms and angiosperms share with pteridophytes a dominant, independent sporophyte generation; the presence of vascular tissue; differentiation of the plant body into root, stem, and leaf derived from a bipolar embryo (having stem and root-growing apices); and similar photosynthetic pigments. For that reason these three groups of plants are also called "higher plants".

In comparing pteridophytes and seed plants and their life histories, certain significant differences are seen, including the following:

- The gametophyte in seed plants has been reduced in size, usually consisting of a few to a dozen cells. The gametophyte is not free-living but is embedded in the sporophyte and thus less vulnerable to environmental stress than the gametophytes of bryophytes and pteridophytes.
- Finally, the spores of seed plants are male and female, as are the sporangia that contain them. The spores are not dispersed as in the bryophytes and pteridophytes but develop into gametophytes within the sporangia.
- In the most advanced seed plants, the male gametes (sperm) are carried to the egg by a later extension of the pollen grain called the **pollen tube**. The advantage of this system is that the non flagellated sperm are no longer dependent on water to reach the egg.
- Another terrestrial adaptation of the seed plants not found in ferns is pollen dispersed by wind or animals. Pollen is a unit of genetic material as well as part of the seed-formation process. The dispersal of pollen by wind or animals, in addition to dispersal of seeds, promotes genetic recombination and distribution of the species over a wide geographic area.
- Unlike pteridophytes, the seed plants have stems that branch laterally and vascular tissue that is arranged in strands (**bundles**) around the pith (**eustele**).

2.1. Gymnosperms

The term *gymnosperm* ("naked seeds") represents four extant divisions of vascular plants whose ovules (seeds) are exposed on the surface of cone scales. The cone-bearing gymnosperms are among the largest and oldest living organisms in the world. They dominated the landscape about 200 million years ago.

Most gymnosperms are evergreen, but some are deciduous (the leaves fall after one growing season). The leaves of many gymnosperms have a thick cuticle and stomata below the leaf surface.

The four divisions of gymnosperms are Cycadophyta, Gnetophyta, Ginkgophyta and Coniferophyta.

2.1.1. Cycadophyta

Microspores and megaspores are formed on sporophylls in male and female cones respectively. Each scale in the male cone has two sporangia in which meiosis occurs to produce tetrads of spores, just as in a fern sporangium. Male gametophyte development starts in the microspore (or pollen grain) before it is shed. Mitotic divisions result in two prothallial cells, a tube cell and a generative cell. The sporangium breaks open to shed the immature gametophytes which are carried on the wind and may chance to arrive at a sporophyll on a female cone.

Cycas species are larger and are often used as ornamentals in tropical areas. The cycads can be viewed as beneficial as they form symbiotic associations with nitrogen fixing bacteria, but they have also been the subject of extermination programs since they are highly toxic to livestock. Their life cycle is rather similar to the conifers' but they have free-swimming sperm (a primitive feature) and sometimes they are pollinated by insects (an advanced feature).

Figure 21: *Cycas revolute*
(Source: https//ag.arizona.edu/pruna/gardening/aride plant/cycas revolta.htm)

2.1.2. Gnetophyta

The gnetophytes (division Gnetophyta) comprise a group of three unusual genera. *Ephedra* occurs as a shrub in dry regions in tropical and temperate North and South America and in Asia, from the Mediterranean Sea to China. Species of *Gnetum* occur as woody shrubs, vines, or broad-leaved trees and grow in moist tropical forests of South America, Africa, and Asia.

Welwitschia, restricted to extreme deserts in a narrow belt about 1,000 km long in south-western Africa (Namib desert), is an unusual plant composed of an enormous underground stem and long strap-shaped leaves that lie along the ground. The three genera differ from all other gymnosperms in possessing vessel elements (as compared with tracheids) in the xylem and in specializations in reproductive morphology.

Figure 22: *Welwitschia mirabilis,* a native of Africa.
(Source: http://www.doctortee.com/dsu/tiftickjian/plant-anat/introduction.html)

2.1.3. Ginkgophyta

The ginkgophytes (division Ginkgophyta), although abundant, diverse, and widely distributed in the past, are represented now by a sole surviving species, *Ginkgo biloba* (maidenhair tree). The species was formerly restricted to southeastern China, but it is now probably extinct in the wild. The plant is commonly cultivated worldwide, however, and is particularly resistant to disease and air pollution. The ginkgo is multibranched, with stems that are differentiated into long shoots and dwarf (spur) shoots. A cluster of fan-shaped deciduous leaves with open dichotomous venation occurs at the end of each lateral spur shoot. Sexes are separate, and distinct cones are not produced.

Figure 23: *Ginkgo biloba* (leafy branch)
(Source;esmateria.com/2012/10/05 ginkgo-biloba)

2.1.4. Coniferophyta

Conifer stems are composed of a woody axis containing primitive water- and mineral-conducting cells called **tracheids**. Tracheids are interconnected by passages called bordered **pits**. Leaves are often needle-like or scale-like and typically contain canals filled with resin.

The tree or shrub is the sporophyte generation. In conifers, the male and female sporangia are produced on separate structures called **cones** or **strobili**. Individual trees are typically monoecious (male and female cones are borne on the same tree).

A cone is a modified shoot with a single axis, on which is borne a spirally arranged series of pollen- or ovule-bearing scales or bracts. The male cone, or **microstrobilus,** is usually smaller than the female cone (**megastrobilus**) and is essentially an aggregation of many small structures (**microsporophylls**) that encase the pollen in **microsporangia**.

Life cycle

Microspores and megaspores are formed on sporophylls in male and female cones respectively. Each scale in the male cone has two sporangia in which meiosis occurs to produce tetrads of spores, just as in a fern sporangium. Male gametophyte development starts in the microspore (or pollen grain) before it is shed. Mitotic divisions result in two prothallial cells, a tube cell and a generative cell. The sporangium breaks open to shed the immature gametophytes which are carried on the wind and may chance to arrive at a sporophyll on a female cone.

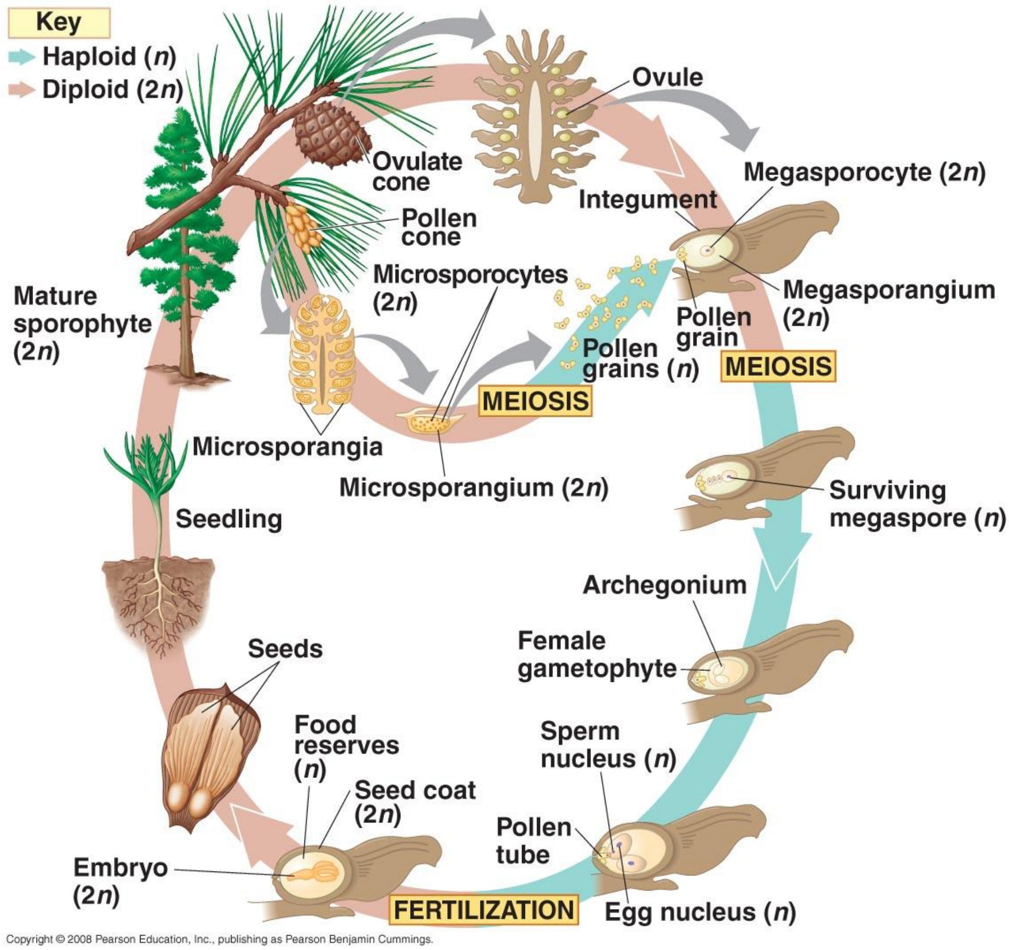


Figure 24: Life cycle of a gymnosperm (*Pinus*)
(Source: ib berkeley.edu/course/biob/plant fall 109)

Examples of gymnosperm plants: *Pinus* (pine),*Cupressus* (Cypress),*Podocarpus,* etc.

2.2. Angiosperms (Phylum Magnoliophyta)

2.2.1. Characteristics and evolution of Magnoliophyta

The phylum Magnoliophyta (often called Anthophyta) is the largest phylum of plants and includes over 240.000 species of flowering plants.

Angiosperms or flowering plants are seed plants characterized by the presence of a flower and fruit. Botanists define a fruit as a ripened ovary that surrounds the seeds of Angiosperms. The ovary is the female part of the flower that encloses the egg(s). Flowers are modified shoots bearing a series of leaf-like modified appendages and containing ovules (immature seeds) surrounded and protected by the female reproductive structure, the carpel or pistil.

Flowers develop from flower buds. Each flower bud contains 4 concentric whorls of tissue. From the outer to the inner, these develop into:

- a whorl of sepals (collectively called the **calyx**)
- a whorl of petals (collectively called the **corolla**)

- stamens in which the microsporangia form
- carpels in which the megasporangia form.

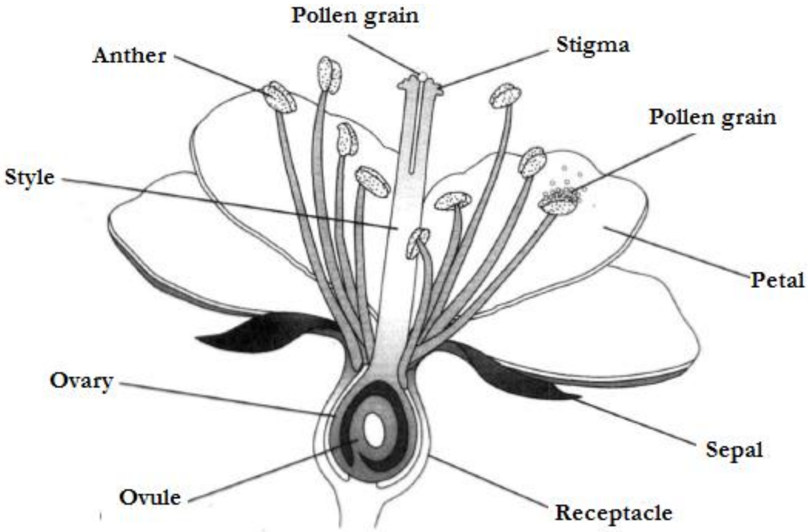


Figure 25: A generalized flower
(Source eplantscience.com)

In most angiosperms, the flowers are perfect: each has both microsporangia and megasporangia. Some angiosperms are imperfect, having either microsporangia or megasporangia but not both.

Monoecious plants have both types of imperfect flower on the same plant. Dioecious plants have imperfect flowers on separate plants; that is, some plants are male, some female. Example: date palm.

Angiosperms first appeared in the fossil record about 135 million years ago. 90 mya they had probably begun to outnumber Gymnosperms.

Several factors led to the success of this new kind of plants to land life. These include:

- Angiospermy, the enclosed condition of the seed, which gave the flowering plants a competitive advantage and enabled them to come to dominate the extant flora due to efficient protection and dispersal of seed.
- In many angiosperms, seeds germinate and produce mature plants, which in turn produce new seeds, all in one growing season. This is a tremendous advantage over Gymnosperms, which often take 10 or more years to reach maturity and produce seeds.
- Flowering plants have also fully exploited the use of insects and other animals as agents of pollination (the transfer of pollen from male to female floral structures) which is more advantageous than wind pollination method used by Gymnosperms.
- In addition, the water-conducting cells and food-conducting tissue are more complex and efficient in flowering plants than in other land plants.

- Double fertilization is a phenomenon unique to angiosperms. Each pollen grain produces two sperm; one fuses with an egg to form the zygote, and the other fuses with one or more polar nuclei in the female gametophyte (megagametophyte, or also "embryo sac") to form an **endosperm**. In approximately 70 percent of the known cases, the second sperm fuses with two endosperm nuclei to produce a 3n (triploid) **endosperm**. The endosperm is a special nutritive tissue for the embryo and, after seed germination for the seedling.
- Finally, angiosperms are more diverse than Gymnosperms, so they occupy more niches, such as in aquatic, epiphytic, and parasitic environment. The reduced female gametophyte, like the reduced male gametophyte, may be an adaptation allowing for more rapid seed set, eventually leading to such flowering plant adaptations as annual herbaceous life-cycles, allowing the flowering plants to fill even more niches.

2.2.2. Reproduction of magnoliophyta

Stamens

Each stamen consists of a lobed **anther**, containing the microsporangia and supported by a thin **filament**. In the anthers of each stamen there are pollen sacs. Within the pollen sacs there are diploid **microspore mother cells**, or microsporocytes.

Meiosis of the microspore mother cells in the anther produces four haploid microspores. Each microspore by mitosis forms a pollen grain containing one generative cell and one tube cell. The pollen grain is the **male gametophyte**.

At some point, depending on the species, the germ cell divides by mitosis to produce 2 sperm cells.

Carpels

Carpels consist of a **stigma**, usually mounted at the tip of a **style** with an **ovary** at the base. Often the entire whorl of carpels is fused into a single **pistil**. The megasporangia, called ovules, develop within the ovary.

Meiosis of the megaspore mother cell in each ovule produces 4 haploid cells: a large megaspore and 3 small cells that disintegrate.

Development of the megaspore

The nucleus of the megaspore undergoes 3 successive mitotic divisions. The 8 nuclei that result are distributed and partitioned off by cell walls to form the **embryo sac**. This is the mature **female gametophyte generation** which comprises:

- The e18 will start the new sporophyte generation if it is fertilized. It is flanked by 2 **synergid cells**.
- The **large central cell**, which in most angiosperms contains 2 polar nuclei, will after its fertilization develop into the **endosperm** of the seed.
- **3 antipodal cells**.

Pollination and double fertilization

When pollination occurs and the pollen grain makes contact with the stigma (the apex of the pistil) the tube cell elongates its cytoplasm forming the pollen tube that grows towards the ovary. The pollen tube with its contents makes up the mature male gametophyte generation.

The generative cell divides forming two sperm nuclei (male gametes) that migrate through the pollen tube. The pollen tube enters the ovule through the micropyle and ruptures and the process of double fertilization takes as follows:

- One sperm cell fuses with the egg forming the diploid **zygote.**
- The other sperm cell fuses with the polar nuclei forming the **endosperm nucleus.** Most angiosperms have two polar nuclei so the endosperm is **triploid** (3n).
- The tube nucleus disintegrates.

After double fertilization, each ovule develops into a **seed**, which consists of

- A **plumule**, made up of two embryonic leaves, which will become the first true leaves of the seedling, and a terminal (apical) bud. The terminal bud contains the **meristem** at which later growth of the stem takes place.
- One or two **cotyledons** which store food that will be used by the germinating seedling.
- The **hypocotyl** and **radicle**, which will grow into the part of the stem below the first node ("hypocotyl" = below the cotyledons) and primary root respectively.

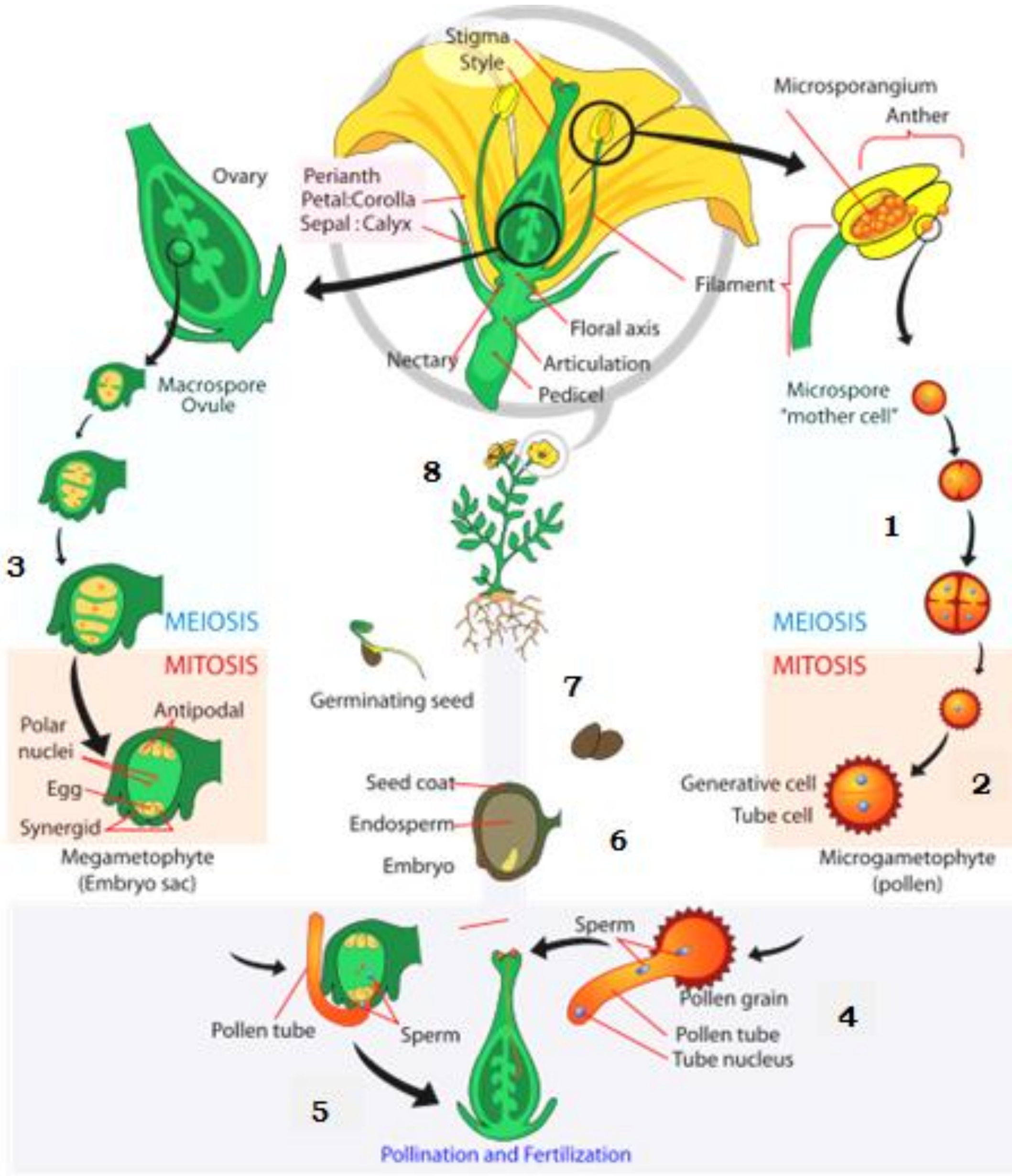


Figure 26: Angiosperm life cycle.
1. Microspores are produced during meiosis on the anther. 2. Pollen grains develop from a microspore. Two sperm form through division of generative cells and the pollen tube is produced. 3. Four megaspores are produced by meiosis in the megasporangium of the ovule, with one surviving to form a gametophyte. 4. Two sperm cells are discharged through the pollen tube into each ovule after pollination. 5. Double fertilization results in a zygote (2n) and an endosperm (3n). 6. A developing zygote (embryo) and the food source are packaged into a seed. 7. The embryo becomes a mature sporophyte when the seed germinates. 8. After germination a seedling develops into a mature plant.
Source:
(http://upload.wikimedia.org/wikipedia/commons/e/e1/Angiosperm_life_cycle_diagram.svg)

2.2.3. Classification of magnoliophyta

The Magnoliophyta phylum comprises two classes: Magnoliopsida and Liliopsida.

Class Magnoliopsida (Dicotyledons)

Class consisting of roughly 170,000 species of angiosperms, often referred to as the dicotyledons(dicots for short).

Vegetative characteristics:

- Dicots are diverse in habit, with half of all the species being more or less woody-stemmed, a reflection of the usual presence of a vascular cambium in the class ;
- Annuals, biennials, vines, epiphytes, aquatics, parasites, and saprotrophs are also well represented in dicots ;
- Vascular bundles of the stem are usually borne in a ring that encloses the pith. Vessel elements present except in some putatively primitive woody or aquatic families ;
- Most dicots have a primary root system derived from the radicle, although some have an adventitious root system commonly seen in the class of monocots ;
- Cotyledons are usually 2, seldom 1, 3, or 4. Leaves are mostly net-veined.

Reproductive characteristics:

- Floral parts, especially the perianth, are arranged in a spiral or more commonly in definite numbers: typically borne in sets of 5, less often 4, seldom 3.
- Pollen is typically 3-pored (or derived) except in some putatively primitive dicot families.

Class Liliopsida (Monocotyledons)

Class consisting of nearly 60,000 species of angiosperms, often referred to as the monocotyledons (monocots for short).

Vegetative characteristics:

- Monocots are predominantly herbaceous, with less than 10% of the species being more or less woody-stemmed: a reflection of a typical **vascular cambium** in the class.
- Woody monocots, in contrast to woody dicots, usually have an unbranched stem with a terminal crown of large leaves.
- Vessel elements are often lacking or sometimes restricted to specific organs. Vascular bundles of the stem are usually scattered or borne in 2 or more rings.
- The mature root system is completely adventitious.
- A single cotyledon is present or the embryo sometimes undifferentiated.
- Leaves are mostly parallel or parallel-derived veined.

Reproductive characteristics:

- Floral parts are typically borne in sets of 3, seldom 4.
- Pollen is uniaperturate (one pore).

Comparison between Dicots (Magnoliopsida) and Monocots (Liliopsida)

Plant type	Embryo	Leaves	Stems	Flower parts	Exemples
Monocots	One cotyledon	Parallel venation	Scattered vascular bundle	Usually occur in 3	Rice , corn, reeds, Aloe, grasses, bamboo, onion, pineapple, palm, banana, wheat, sugar cane, agave papyrus, orchid, etc.
Dicots	Two cotyledons	Net venation	Radially arranged vascular bundles	Usually occur in 4 or 5	Bean, pea, roses, potato, carrot, apple, beet, tomato, avocado, papaya, Amaranthus, Eucalyptus, sunflower, mango, cactus, coffee, tea, cassava, cabbage,hibiscus, spinach, etc.

Ecology and Importance of Angiosperms

Angiosperms are a huge group consisting of around 250,000 different species classified into 400-500 families. Their morphology is diversified: trees, shrubs, herbs. They are found quite in all the different habitats of the world: terrestrial habitats, aquatic habitats, deserts, humid zones, etc. They are dominant everywhere except in particular zones such as the coniferous forests of the subpolar regions and the toundra in Polar Regions.

Angiosperms are very important economically. Because angiosperms are the most numerous component of the terrestrial environment in terms of biomass and number of individuals, they provide an important source of food for animals and other living organisms.

For humans Angiosperms provide food, clothes, wood for multiple purposes, medicine and drugs, industrial raw material (perfumery, brewery,etc.), food adjunct, beverages, etc. Human beings depend quite exclusively on angiosperms to meet their needs.

Activity 2

1. What is the meaning of "Gymnosperm"?
2. How Angiosperms differ from Gymnosperms? Explain how Angiosperms have been more successful than Gymnosperms.
3. How are the male gametophytes and the male gametes formed in angiosperms?
4. Explain the double fertilization that occurs in Angiosperms.
5. List five monocot plants and five dicot plants from your nearest environment and specify their economic importance if any.
6. Outline the economic importance of Angiosperms in the world.

Feedback

In this section Angiosperms which are the latest land plants are considered as the most adapted to land life. They are also the most abundant and thus, you can observe them and notice their features to better understand the content of this section.

Block summary

Tracheophytes constitute a large group of land plants with lignified tissues (the xylem) for conducting water and minerals. They also have non-lignified tissue (phloem) to conduct products of photosynthesis. They have roots, stems, leaves and an internal vascular network.

In vascular plants the sporophyte is the dominant phase of the life cycle. In seedless vascular plants (Pteridophytes), the gametophyte is usually a separate small organism quite different from the sporophyte. In seed plants, the gametophyte is a very small parasite in the sporophyte.

The gametophytes of seed plants are microscopic. The female gametophyte consists of a handful of cells buried in the tissues of the sporophyte. The male gametophyte, the pollen grain, has a brief free-living stage while it is carried from plant to plant by wind, water, or animals. No longer relying on flagellated sperm, and with their developing embryos protected from desiccation, seed plants break the last link with their aquatic ancestors (algae).

Tracheophytes can be further divided into two groups, seedless and seed plants. Seedless plants include the phylum of Pteridophyta and other plants closely associated with them. Seed plants (plants that produce seeds for reproduction) include Gymnosperms and Angiosperms. In Gymnosperms seeds are not enclosed in fruits. In angiosperms or flowering plants, the seeds are within a protective fruit.

Gymnosperms are among the largest and oldest living organisms in the world. They dominated the landscape about 200 mya. Angiosperms have evolved later than gymnosperms and they are dominant and more diverse than Gymnosperms on Earth today.

Angiosperms are very important economically. Because angiosperms are the most numerous component of the terrestrial environment in terms of biomass and number of individuals, they provide an important source of food for animals and other living organisms. Angiosperms also provide oxygen; they provide lumber for buildings and other objects, fibers for clothes, are the basis for many drugs, etc…

Answers to activities in block 4

Activity 1

1. Although bryophytes and pteridophytes have water-dependant gametes for fertilization the emergence of conductive vessels in this last group facilitated life in a terrestrial environment. The vascular system of the pteridophytes collects water from the moist soil and distributes it to the plant parts. Bryophytes do not have this option and they depend entirely on the water that reaches the aerial part of the plant by diffusion and so they need to live in humid or rainy places.
2. Psilophyta phylum is characterized by a leafless and rootless body possessing a stem that exhibits a primitive dichotomous type of branching. The photosynthetic function is assumed by the stem, and the underground rhizome anchors the plant. The vascular tissue is organized into a poorly developed central cylinder in the stem.

They are primitive because they lack roots and leaves; they produce motile (flagellated) male gametes and must rely on water for fertilization to take place like in bryophytes.

3. In Bryophytes, the sporophyte is nutritionally dependent on the gametophyte during its entire existence. In pteridophytes the sporophyte is dependent on the gametophyte for nutrition only during the early phase of its development; thereafter, the pteridophyte sporophyte is free-living. The lasting or dominant form in pteridophytes is the diploid (2n) sporophyte. In bryophytes the dominant form is the gametophyte (n).
4.
    a) Sporophyll: spore-bearing leaf or a leaf that bears spores (or sporangia).
    b) Prothallus: the pteridophyte gametophyte (the haploid individual that forms gametes) and which develops by mitosis from a spore.
5. In pteridophytes gametes are made by mitosis from special cells of the gametophyte. As in all plants, in pteridophytes, meiosis is sporic, i.e., cells of the sporophyte undergo meiosis and generate spores that then by mitosis develop into the gametophyte.
6.
    - Phylum Psilophyta (whisk ferns): *Psilotum, Rhinia*
    - PhylumLycophyta (lycopods): Lycopodium, Selaginella
    - PhylumSphenophyta (horstails): Equisetum

- PhylumFilicophyta (ferns): Pteridium, Nephrolepis, Dryopteris, Azolla, Marselia, etc.

7. As the first tracheophytes, pteridophytes were also the first plants to extensively colonize the terrestrial environment forming forests in the Carboniferous period (300 mya). They also constituted an important source of food for terrestrial animals. By presenting conductive vessels they could be larger, a feature inherited from them by seed plants.

Activity 2

1. Gymnosperm means "naked seed". It is a group of vascular plants whose ovules (or seeds) are exposed on the surface of cone scales.
2. Gymnosperms do not produce flowers, but rather produce seeds on their cones.

Angiosperms have been more successful because of:

- Angiospermy, the enclosed condition of the seed, which gave the flowering plants a competitive advantage and enabled them to come to dominate the extant flora due to efficient protection and dispersal of seed

- Full exploitation of insects and other animals as agents of pollination (the transfer of pollen from male to female floral structures) which more advantageous than wind pollination method used by Gymnosperms.
- Double fertilization is a phenomenon unique to angiosperms. The endosperm is a special nutritive tissue for the embryo and, after seed germination for the seedling.

3. In the anthers of each stamen there are pollen sacs. Within the pollen sacs there are microspore mother cells, or microsporocytes. These cells undergo meiosis forming microspores. Each microspore by mitosis forms a pollen grain containing one generative cell and one tube cell. The pollen grain is the male gametophyte.
4. During double fertilization one sperm cell fuses with the egg forming the diploid zygote. The other sperm cell fuses with the polar nuclei forming the endosperm nucleus. Most angiosperms have two polar nuclei so the endosperm is triploid (3n).
5. Examples should be taken from the following and many others with respective uses by humans.
   - Dicots: Bean, pea, roses, potato, carrot, apple, beet, tomato, avocado, papaya, Amaranthus, Eucalyptus, sunflower, mango, cactus, coffee, tea, cassava, cabbage, hibiscus, spinach, etc.
   - Monocots: Rice , corn, reeds, Aloe, grasses, bamboo, onion, pineapple, palm, banana, wheat, sugar cane, agave, papyrus, orchid, etc.
6. Angiosperms provide an important source of food for animals and other living organisms. Particularly for humans Angiosperms provide food, oxygen, clothes, wood for multiple purposes, medicine and drugs, industrial rough material, food adjunct, beverages, etc...

BLOCK 5

Plant external structures

Introduction

The plant structure can be studied externally or internally. The external study deals with description of the physical form and external structures of plants while internal study concerns investigations of plant anatomy which refers to internal plant structures at the cellular level, and often involves the sectioning of tissues and microscopy for detailed observation.

What is in this block?

There are four sections in this block:

Section 1: The root system

Section 2: The shoot system

Section 3: The leaf morphology

Section 4: Morphology of the plant reproductive organs

Estimated study time

We estimate that you will need 9 hours, if you do all the activities in this block.

Learning objectives

At the end of the block, students will be able to:

- describe the morphology of plant organs
- discuss the functions of the plant organs
- label a drawing showing the external parts of a monocot and dicot organ

Keywords

Root

Fibrous root

Taproot

Section 1: The root system

In general organization, a plant has two organ systems: the shoot system, and the root system. The shoot system is above ground and includes the organs such as leaves, buds, stems, flowers (if the plant has any), and fruits (if the plant has any). The root system includes those parts of the plant below ground, such as the roots, tubers, and rhizomes.

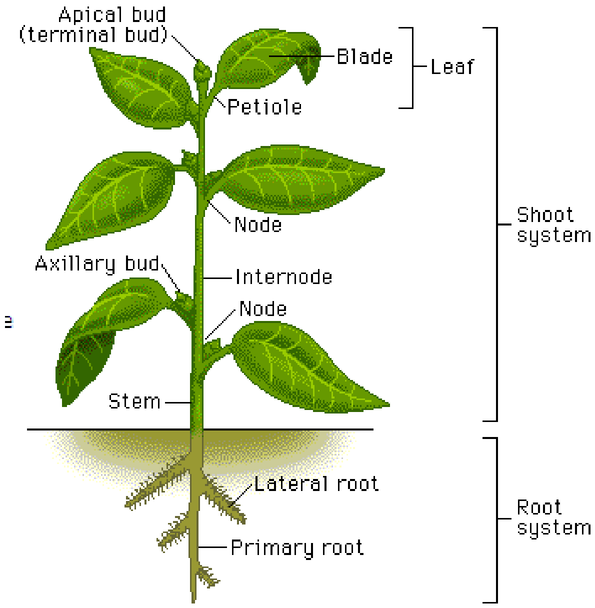


Figure 27: Primary plant body
(Source: www.biologyjunction,com/plantstructure bil,html)

1.1. Fibrous root system

Providing the plant's leaves and stems with water and nutrients, root systems are crucial to the growth and continued survival of a plant. In turn, the root systems grow as a result of photosynthesis that occurs in the leaves of the plant.

Grasses and other monocotyledons have a fibrous root system, characterized by a mass of roots of about equal diameter. This network of roots does not arise as branches of the primary root but consists of many branching roots that emerge from the base of the stem.

1.2. Taproot system

Taproots have a very distinguished, primary root that is generally thicker than the roots that branch off from it. The primary root enlarges and develops into the taproot from which lateral roots or branches develop. The tap root exists predominately throughout the entire life of the plant. The tap root system is common among conifers or cone-bearing trees, and dicots or herbaceous plants, bushes and trees. The first root to emerge from a seed is the radicle or primary root. In most dicots, the radicle enlarges and forms a prominent tap root. Smaller branch (lateral) roots grow from the taproot.

Fleshy tap roots such as sugar beets and carrots store large reserves of food, generally carbohydrates. Other plants that utilize the tap root system include the mango, sunflower, turnip, radish, etc.

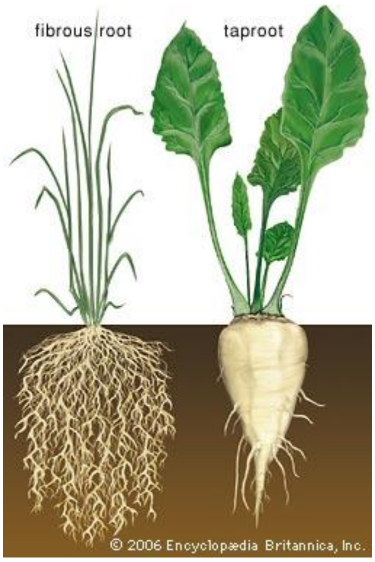


Figure 28: Illustration of taproot and fibrous root systems (Source: www.britanica.com/Ebchecked/media)

1.3. Tubers

Some roots are modified for the storage of food for the plant. In tuber roots the root system has the same cell structure as the root of the plant, and it grows both stem and foliage at the top while the bottom grows roots. These roots may be tap roots or adventitious roots. The most important food in reserve in such roots is different forms of starch. Sweet potato and cassava have very thick roots which store up food reserves, and are the examples of modified fibrous roots. Radish, turnip, beet and carrot are the edible modified tap roots.

Note: Stem tubers attach to rhizomes, which are a type of plant node, and they have the same cell structure as the stem. Irish potato and taro have tuberous stems.

1. 4. Root primary functions:

- ***Anchorage:*** roots permeate the soil to locate water and minerals. In doing so, they anchor the plant in one place for its entire life.
- ***Storage:*** roots store large amounts of energy. In biennials these reserves are concentrated in only one or a few roots. They are harvested in their first year of growth, before the plant uses the stored energy for vegetative growth and reproduction.
- ***Absorption:*** roots absorb large amounts of water and dissolved minerals from the soil.
- ***Conduction:*** roots transport water and dissolved nutrients to and from the shoot. The roots of plants even transport carbon dioxide for photosynthesis. In such case the leaves usually have thick cuticles and lack stomata.

Activity1

Q1: Describe the fibrous root system.

Q2: Explain the different functions of roots.

Feedback

This section describes the external morphology of roots. It gives the different types of roots as well as their different functions.

Section 2: The shoot system

The shoot originates in the embryo at the end opposite to the root and develops a complex **shoot apex** different from that of the root. The stem often forms a main trunk or stem and extends branches out into smaller horizontal extensions of the main stem from which the leaves grow. The main stem may branch into a secondary stem on some plants. Nodes from which leaves grow are spaced along the stem and branches. The space between the nodes is called the **internodes**. Lateral buds may appear at the nodes. A main terminal bud forms at the end of the main stem. Secondary terminal buds are found at the ends of branches. Lateral buds tend to form leaves, while terminal buds often become flowers.

Keywords

Shoot

Wood

Plant life span

Modified stem

This box is in a wrong place

2.1. Common types of stems

Plants can be categorized according to the stem structure. They can be:

- **Woody** plants have hard stems made of wood. The stems grow for more than one year as the plant does not die off when there is not a growing season.
- **Herbaceous** have soft stems that usually die completely at the end of the growing season.

According to its life span, plants can also be categorized in:

- **Annual plants**, live one growing season. They must produce seeds so that future plants of that kind can grow.
- **Biennial plants**, live two growing seasons. The first year they store food. The second year they produce the flowers and seeds.
- **Perennial plants**, live and grow for more than two years (like trees). Once they mature, they may produce flowers and seeds yearly.

2.2. Functions of the shoot system

The shoot system in plants has many functions. Hormone production, transport and storage are three of them. Others are photosynthesis and reproduction. The stem of the plant allows it to grow upright, and is a transport system for the water and minerals coming from the ground. The stem supports the leaves and flowers which develop in fruits that produce dissemination organs (seeds).

2.3. Modified stems

When stems change their form to perform functions other than the normal functions, they are said to be modified.

- **Bulb:** thickened, underground stem with fleshy storage leaves attached at base. (tulips, lilies, onions).
- **Corm:** short, thickened, underground stem with reduced scaly leaves (*Gladiolus*).
- **Crown:** compressed stem having leaves and flowers growing above and roots beneath (strawberry plant, dandelion).
- **Stolon:** (or runner): horizontal, above-ground stems often forming roots and/or plantlets at their tips or nodes (strawberry runners, spider plants).
- **Rhizome:** horizontal, underground stem typically forms roots and plantlets at tips or nodes (iris, cannas, banana, yam).
- **Spuvery** : compressed, fruiting twig found on some apples, pears, and ginkgo.
- **Tuberous stem***:* short, flattened, modified storage stem (tuberous Irish potato, dahlias). Unlike tubers, which have buds scattered all over, tuberous stems only have leaf buds on the "up" end.

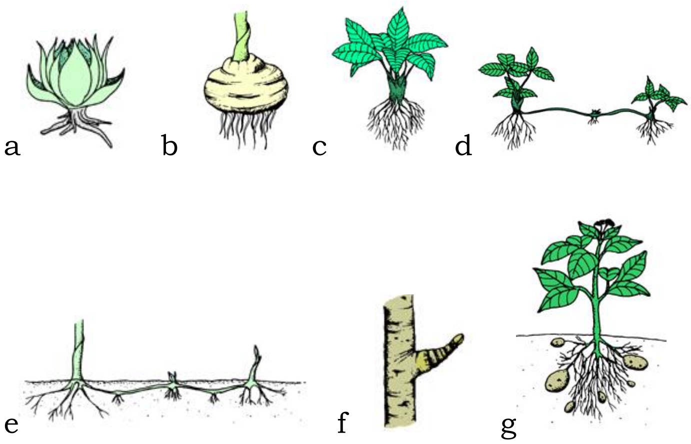


Figure 29: Modified stems a: bulb; b: corm; c: crown; d: stolon; e: rhizome f: spur; g: tuber. (Source: https://www.google.rw/search?g= Modified stems +m+vegetation+propogation)

Activity 2

1. List different categories of plants according to the stem structure
2. What is a biennial plant?
3. What kind of modified stem do the following plants have?
   a) taro (amateke)
   b) garlic (tungurusumu)
   c) ginger (tangawizi)

Feedback

The section describes the general organization of the stem as seen from outside. The stem morphology can be modified in order to adapt the plant to environmental conditions. Some of the plant parts we eat are obtained from modified stems. You will easily find examples in your daily life.

Section 3: The leaf morphology

The blade of a leaf is the flat, extended and most obvious part of the leaf. The edge of the leaf is called the margin. The petiole is the stem like connection between the leaf and branch. Visible on both sides of the blade are raised tube-like structures called veins that extend from the petiole onto the surface of the blade. The veins are vascular bundles that carry nutrients between the leaves and the body of the plant. The large central vein is called the midrib.

Keywords

Leaf types

Veination

Modified leaf

Box in a wrong place

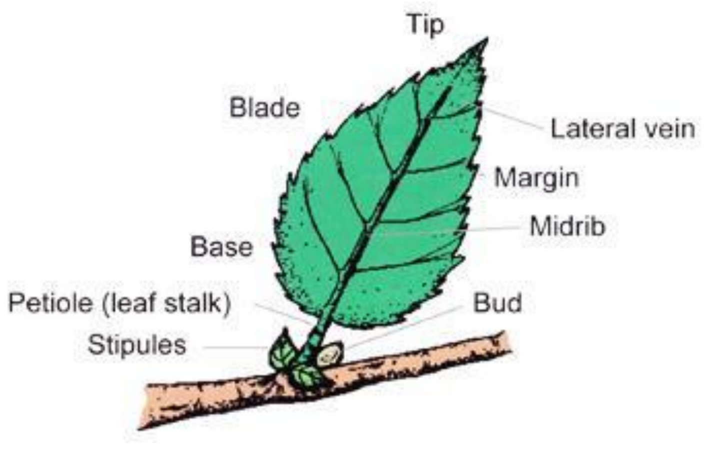


Figure 30: Leaf external features
(Source: www.ext,colostate. edu/mg/gardenotes/134.html)

For plant identification purposes, the shape of the leaf margin, leaf tip and leaf base are key features to note.

3.1. Leaf Arrangement on stem

- **Alternate**: arranged in staggered fashion along stem (tomato, tea, maize)
- **Opposite**: pair of leaves arranged across from each other on stem (coffee)
- **Whorled**: arranged in a ring.
- **Rosette**: spiral cluster of leaves arranged at the base (or crown) (dandelion).

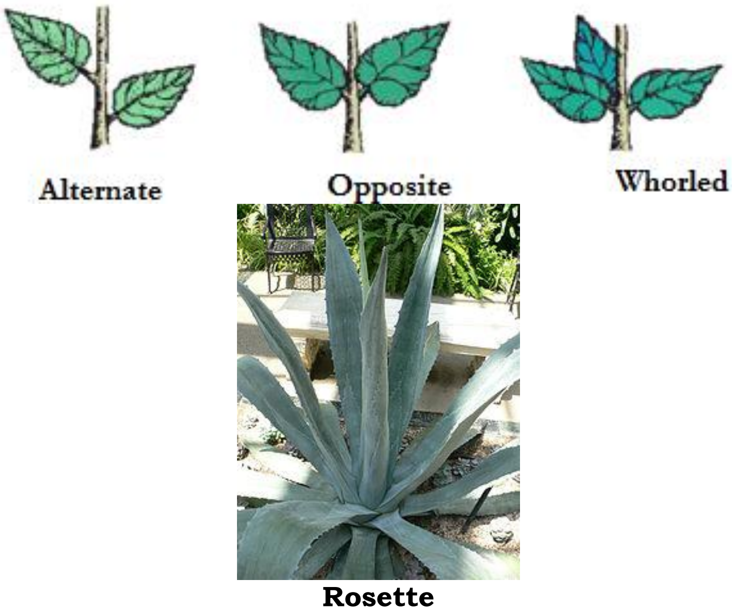


Figure 31: Leaf arrangement on stem
(Source: www.ext,colostate. edu/mg/gardenotes/134.html)

3.2. Leaflet arrangement on petiole

- **Simple:** leaf blade is one continuous unit (avocado, eucalyptus, maize, coffee).
- **Compound**: several leaflets arise from the same petiole (beans).

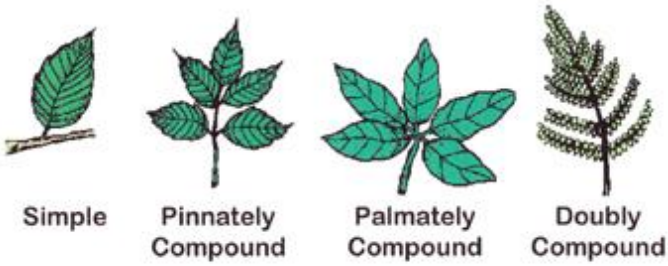


Figure 32: Leaf arrangement on petiole.
(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

Note: Sometimes identifying a "leaf" or "leaflet" can be confusing. Look at the petiole attachment. A leaf petiole attaches to the stem at a bud node. There is no bud node where leaflets attach to the petiole.

3.3. Leaf shape

Leaf shape is a primary tool in plant identification. Descriptions often go into minute detail about general leaf shape, and the shape of the leaf apex and base.

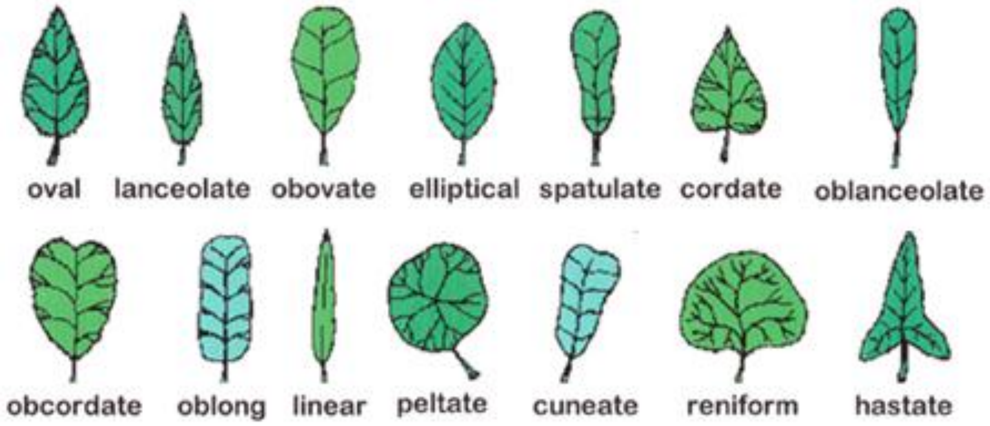


Figure 33: Leaf shapes.

(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

Shape of the leaf apex (tip) and base is another tool in plant identification.

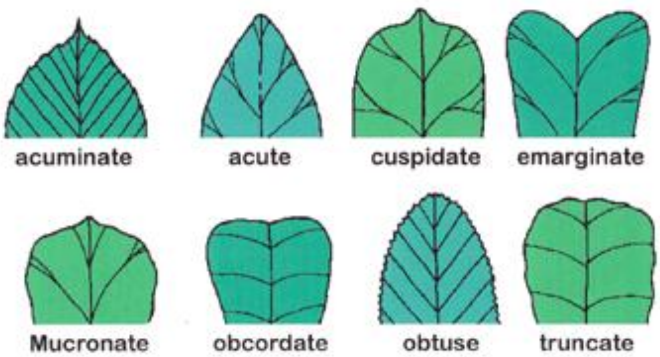


Figure 34: Leaf tip shapes.
(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

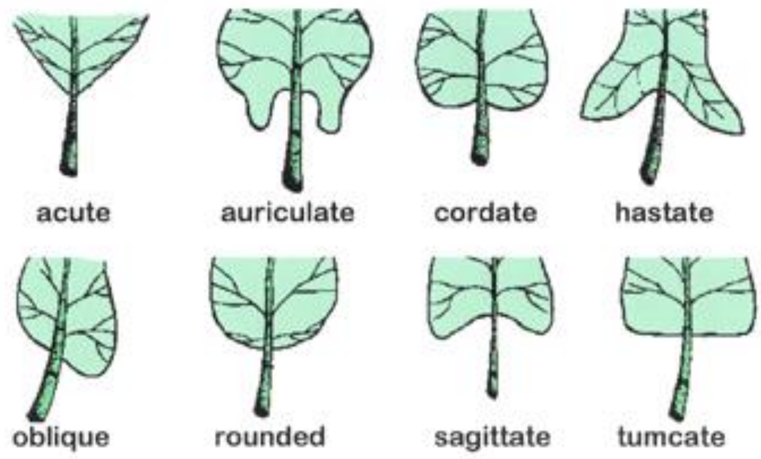


Figure 35: Leaf base shapes.
(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

3.4. Leaf margin

The leaf margin is another tool in plant identification.

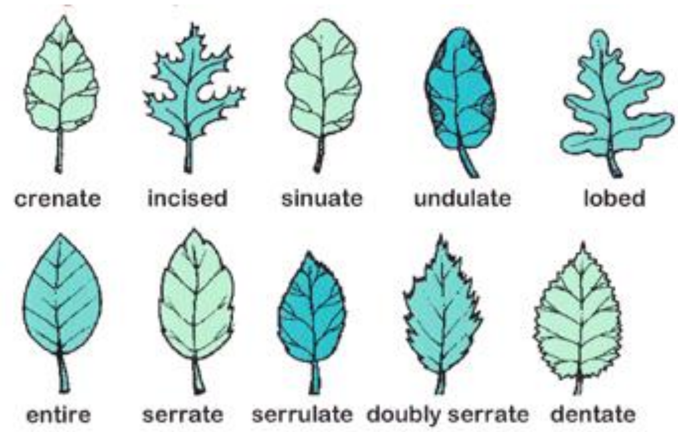


Figure 36: Leaf margin shapes.
(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

3.5. Leaf veination

- ***Parallel venation:*** veins run in parallel lines (monocot plants, e.g. grasses, lilies, banana, onion).
- ***Net-veined or reticulate-veined:*** leaves with veins that branch from the main rib and then subdivide into finer veinlets (dicot plants in general).
- ***Pinnate veination:*** veins extend from a midrib to the edge (guava, apple).
- ***Palmate veination:*** veins radiate fan-shaped from the petiole (cassava, papaya).

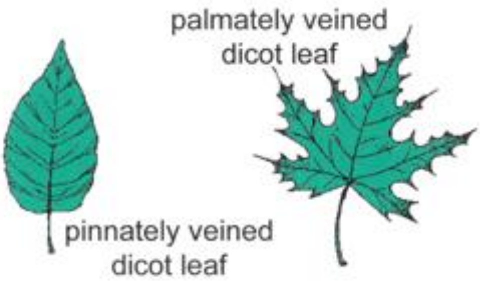


Figure 37: Leaf venation.
(Source: www.ext,colostate.edu/mg/gardenotes/134.html)

3.6. Modified leaves

As plants colonized a wide variety of environments, from deserts to lakes to tropical rain forests, modifications of plant organs that would adapt the plants to their specific habitats arose. Leaves, in particular, have evolved some re-markable adaptations.

- ***Bract* (floral leaves):** specialized, often highly colored leaf below flower that often serves to lure pollinators.
- ***Tendril:*** modified sinuous leaf used for climbing or as an attachment mechanism (peas, grapes).
- ***Spine:*** modified leaf used to prevent from being eaten by predators (Cactus).

Figure 38: Spines on a cactus stem are an example of leaf modification.
(Source: http://www.edupic.net/Images/Plants/cactus_spines409.JPG)

- ***Insectivorous leaves:*** carnivorous plants absorb nitrogen from their animal prey through their leaves specially modified as traps (*Dionaea, Drosera*).

Figure 41: ***Dionaea*** **with its modified leaves. Source: (http://kent.la.coocan.jp/Dionaea_index_frame.htm)**

Activity 3

1. Describe the leaf arrangement on stems.
2. Enumerate three types of modified leaves and explain their respective functions.

Feedback

In this section, you find a large variety of leaves according to various criteria. In your environment you have full opportunity to get familiar to this diversity of leaves if you use illustrations provided in this section.

Section 4: Morphology of the plant reproductive organs

4.1. The flower

The flower is the site of sexual reproduction for the plant. Flowers are divided into three whorls: **the calyx**, **the corolla**, **the androecium** and the **gynoecium**.

Keywords

Flower
Inflorescence
Androecium
Gynoecium
Fruit
Seed

The **perianth** is the non reproductive part of the flower consisting of the corolla, or **colored petals**, and the calyx. The calyx is the green part of the flower formed by the **sepals**, which support the petal display.

The **androecium** is the male reproductive part of the flower and includes the **stamen** -a pollen-carrying leaf that consists of the **filament**, which is a stalk-like projection, and the **anther**, a bag of pollen at the end of the filament.

The **gynoecium** is female reproductive part of the flower consisting of the **carpe**l, which, like the stamen, is a transformed leaf. At the base of the carpel is the **ovary**, an expanded structure holding the **ovules** to be fertilized. The **style** connects the ovary and the stigma, a structure at the top of the style that collects pollen. At the base of the flower is the **receptacle**,that supports the flower structure, and the **peduncle**, which attaches the flower to the stem.

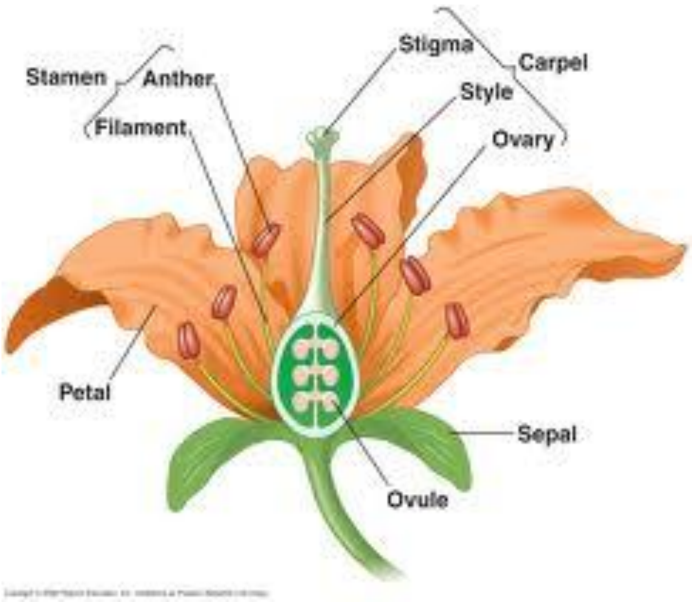


Figure 39: The flower parts
Source: leveragehy.org/biology-puctures-plarts of flower.html

Sexually a flower can be described in three ways:

1. ***Staminate flowers*: Flowers bearing only male sex parts. These are sometime referred to as "*male flowers*"**.
2. ***Carpellate / pistillate flowers*:** Flowers bearing only female sex parts. These are sometimes referred to as "*female flowers*".
3. ***Hermaphhrodite / complete flowers*:** Flowers bearing both male and female sex parts**.**

In many cases flowers are borne as a group on a common stalk, called an ***inflorescence***. They are many different types of floral inflorescences. The type of inflorescence present is sometimes used to aid in classifying flowering plants. Below are a number of common floral inflorescences.

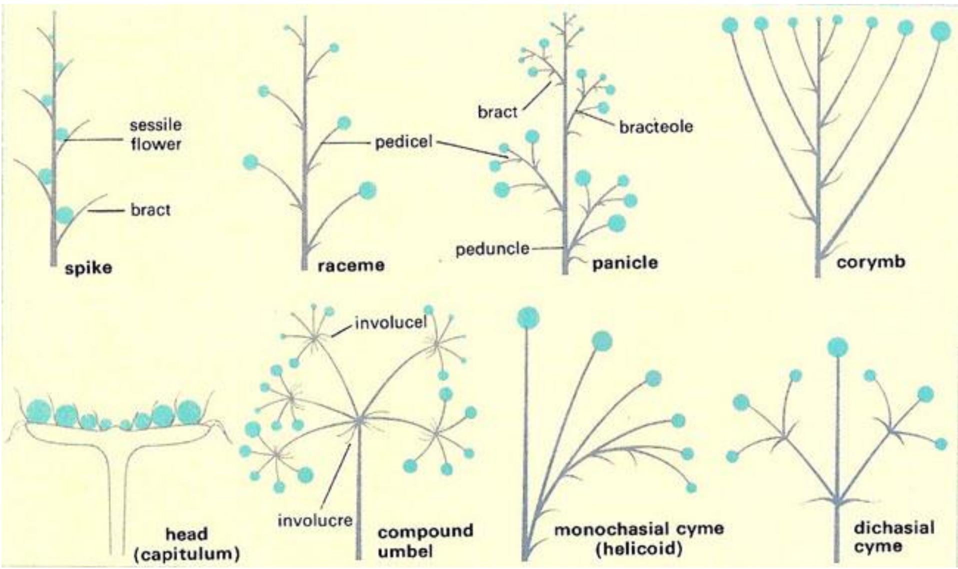


Figure 40: Types of inflorescences.
(Source: http://www.daviddarling.info/encyclopedia/I/inflorescence.html)

4.2. The fruit

The fruit is a matured ovary of flowering plants, with or without accessory parts. The fruit consists of the **pericarp** and the **seed**. The pericarp is usually divided into three parts, the **exocarp** or skin which protects the fruit and seed, the **mesocarp** or flesh of the fruit and the **endocarp** which is an often hard covering which covers the seed.

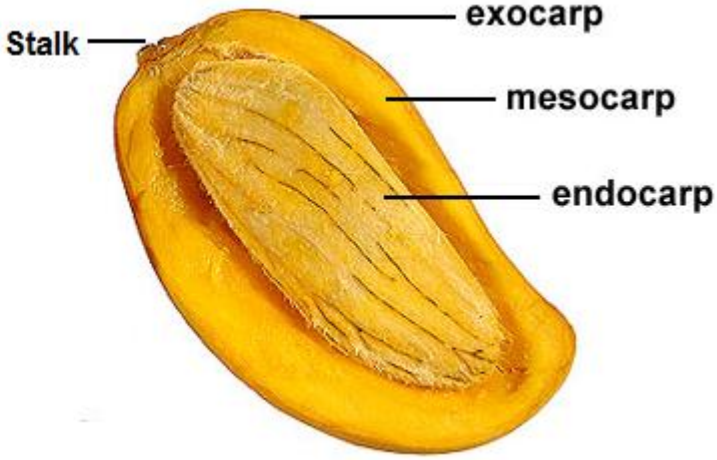


Figure 41: Main parts of a mango fruit
(Source :Wayneyword.paloma.edu/ww0802.html)

Gymnosperms produce naked seeds in structures like pine cones; they generally don't produce flowers and are pollinated by the wind. Angiosperms produce flowers that develop into some sort of fruit with seeds and are usually pollinated by animals.

The basic parts of a seed are included in two structures, the **embryo** and **endosperm**. The embryo is the embryonic plant. The **radical** is the part of the embryo that emerges first and becomes the main root. The **plumule** is the first leaf the plant will unfurl. The **hypocotyl** is the bit between the radical and the plumule that will become the plant's stem. The endosperm is the food supply for plant in its early stages of germination. The endosperm is generally protected by the seed coat or **testa**, which protects the seed from harm.

Activity 4

1. Describe the types of flower referring to the presence/absence of sex parts.
2. Describe a typical fruit structure.

Feedback

This section describes the flower, fruit and the seed which are involved in the perpetuation of the plant. Only a typical flower and fruit are here described regardless the high morphological variation found among the different groups of seed plants.

Block summary

A plant has two organ systems: the shoot system, and the root system.

The root system comprises the network of roots in a vascular plant, generally underground, that absorbs water and nutrients. The shoot system is above ground and includes the organs such as leaves, buds, stems, flowers and fruits.

The stem is a part of plants that support leaves and flowers. There are many varieties of stems depending to environmental conditions in which a plant lives. According to its life span the stem can be annual, biennual and perennial depending on the nature of a plant.

Flowers are divided into three sections: the perianth, the androecium and the gynoecium. The perianth is the non reproductive part of the flower consisting of the corolla, or colored petals, and the calyx. When perianth is absent we talk of perigon. The calyx is the green part of the flower formed by the sepals, which support the petal display. The flower develops into a fruit containing the seed(s). The primary function of these structures is reproduction in which plants perpetuate themselves.

Answers to activities in block 5

Activity 1

1. Fibrous roots usually grow in clumps, and these roots have a primary root from which other roots extend. Fibrous roots also have branched roots that grow out of the main root. All of the roots are approximately the same size, and the primary root is also not any thicker than the rest of the roots. Generally, flowering plants and ferns have fibrous roots.

2.

- Anchorage: roots permeate the soil to locate water and minerals. In doing so, they anchor the plant in one place for its entire life.
- Storage: roots store large amounts of energy. In biennials these reserves are concentrated in only one or a few roots. They are harvested in their first year of growth, before the plant uses the stored energy for vegetative growth and reproduction.
- Absorption: roots absorb large amounts of water and dissolved minerals from the soil.
- Conduction: roots transport water and dissolved nutrients to and from the shoot. The roots of plants even transport carbon dioxide for photosynthesis. The leaves of these plants usually have thick cuticles and lack stomata.

Activity 2

1.

- **Shoot –** First year growth on a woody or herbaceous plant.
- **Twig –** Woody stem less than one year old.
- **Branch –** Woody stem more than one year old.
- **Trunk –** Main support stem(s) of woody plants.
- **Water sprouts –** Juvenile adventitious shoots arising on a branch. Generally very rapid, upright-growth, and poorly attached to the main limb.
- **Suckers –** Juvenile adventitious shoots arising from the roots, generally rapid, upright-growing.
- **Canes –** Stems with relatively large pith and usually living for only one to two years.

2. Biennial plant lives two growing seasons. The first year it stores food. The second year it produces the flowers and seeds.
3. a) Taro: rhizome b) garlic: bulb c) ginger: rhizome

Activity 3

1. Leaf Arrangement on Stems can be:
   - Alternate – Arranged in staggered fashion along stem
   - Opposite – Pair of leaves arranged across from each other on stem
   - Whorled – Arranged in a ring
   - Rosette – Spiral cluster of leaves arranged at the base (or crown)
2.
   - Bract: specialized, often highly colored leaf below flower that often serves to lure pollinators.
   - Tendril: used for climbing or as an attachment mechanism.
   - Spine: to protect the plant against pregdators
   - Insectivorous leaves: to trap insects

Activity 4

1.
   - Staminate flowers: Flowers bearing only male sex parts. These are sometime referred to as "male flowers".
   - Carpellate / pistillate flowers: Flowers bearing only female sex parts. These are some times referred to as "female flowers".
   - Hermaphrodite / complete flowers: Flowers bearing both male and female sex parts.
2. The fruit is a matured ovary of flowering plants, with or without accessory parts. The fruit consists of the pericarp and the seed. The pericarp is usually divided into three parts, the exocarp or skin which protects the fruit and seed, the mesocarp or flesh of the fruit and the endocarp which is an often hard covering which covers the seed

BLOCK 6

Plant internal structures

Introduction

Plant anatomy is the study of internal structure of plant organs by technique of section cutting. This study is facilitated by the use of microscope by which the structure of the cells and tissues can be observed and described. Modern plant anatomy tries to relate structure to function, ecological adaptation, and evolution.

What is in this block?

This block has the seven sections sections:

Section1: Meristems

Section 2: Dermal tissue system

Section3: Ground tissue system

Section 4: Vascular tissue system

Section 5: Root anatomy and function

Section 6: Stem anatomy and function

Section 7: Leaf anatomy and function

Estimated study time

We estimate that you will need 11 hours, if you do all the activities in this block.

Learning objectives

At the end of the block, students will be able to:

- describe the internal structure of a seed plant;
- locate the different plant tissues in dicots and monocots;
- label a drawing showing the internal parts of a monocot and dicot organ;
- explain primary and secondary growth in monocots and dicots;
- associate the function to the structure of each type of plant tissue;
- prepare anatomical sections in various plant organs and describe tissues under light microscope.

Section 1: Meristems

Keywords

Meristem tissues
Cambium
Collenchyma
Sclerenchyma
Parenchyma
Xylem
Phloem
Wrong place

Meristem is a region of plant tissue consisting of actively dividing cells forming new tissues. The meristem cells are small, thin-walled, with no central vacuole and no specialized features. Meristematic tissue is located in:

- near tips of roots and stems. This is called **apical meristem**.
- in the buds and nodes of stems.
- in the cambium between the xylem and phloem in dicotyledonous trees and shrubs.
- under the epidermis of dicotyledonous trees and shrubs (**cork cambium**).
- in the pericycle of roots, producing lateral roots.

The cells produced in the meristems soon become differentiated into one or another of several types as shown by the Figure below.

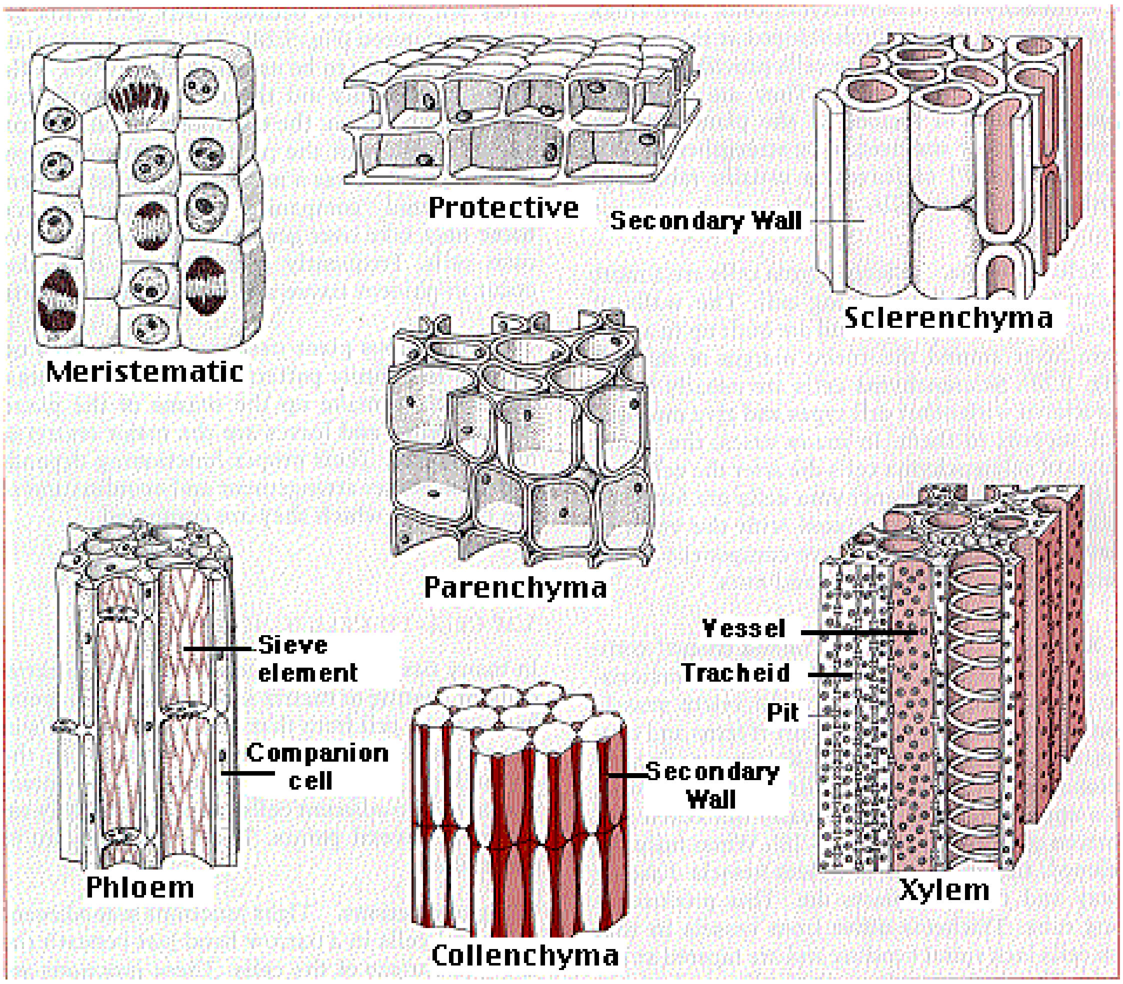
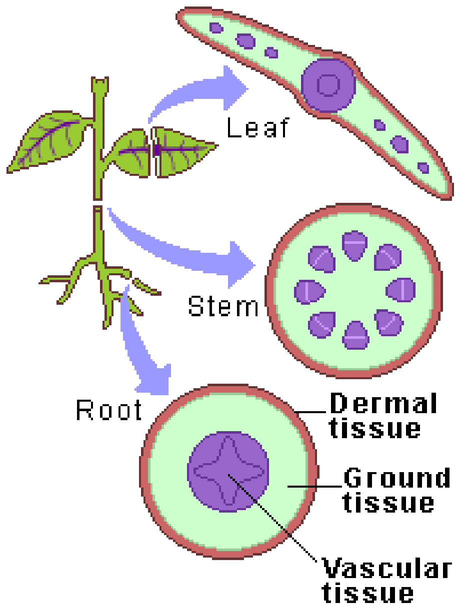


Figure 42: Meristematic cells and permanent tissues (Source:www.tutorbene.com/index.aspx/page d=85)

The different tissues are organized into tissue systems found in the different plant organs as shown in the table and diagram below presented.

Tissue system table:

Tissue system and its functions	**Component tissues**	**Location of tissue systems**
Dermal tissue system • protection • prevention of water loss	Epidermis Periderm (in older stems and roots)	
Ground tissue system • photosynthesis • food storage • regeneration • support • protection	Parenchyma tissue Collenchyma tissue Sclerenchyma tissue	
Vascular tissue system • transport of water and minerals • transport of food	Xylem tissue Phloem tissue	

Activity 1

1. Where is the dermal tissue system located within the plant body?
2. Give the main function of the ground tissue.
3. Can a germinating seedling have periderm? Why?

Feedback

Meristematic tissues in a plant consist of small, densely packed cells that can keep dividing to form new cells. They give rise to permanent tissues that play complementary functions to build the plant body.

Section 2: Dermal tissue system

The dermal tissue system consists of the epidermis and the periderm.

Keywords

Epidermis

Periderm

Hair

Gland

T the box is in a wrong place

2.1. Epidermis

The epidermis is generally a single layer of closely packed cells. It both covers and protects the plant and for this reason, it is also called protective tissue. It covers the surface of leaves and the living cells of roots and stems. Its cells are flattened with their top and bottom surfaces parallel. The upper and lower epidermis of the leaf are examples of protective tissues. Cells are compactly arranged without intercellular spaces.

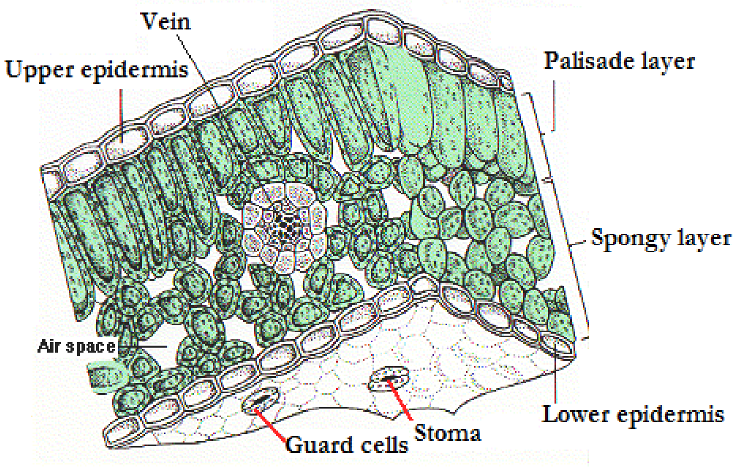


Figure 43: Location of epidermal tissue in the leaf
(Source: users rin.com/jkimball.ma utranet/biology/pages/L/leaf.html)

Epidermal tissue in contact with air is usually protected by a layer of wax called the cuticle. It may also be covered with hairs, water-filled cells, poison-filled barbs, or even digestive glands. These specialized structures provide protection from particular environmental conditions and may even serve as paths for the absorption of nutrients in the case of carnivorous plants. Epidermal tissue may be modified for achieving various functions such as:

- **Digestive glands:** special digestive glands are found in insectivorous plants (e.g. *Drosera*). They consist of a multicellular stalk and a head with three or four layers of cells covered by perforated cuticles as shown on the figure below.

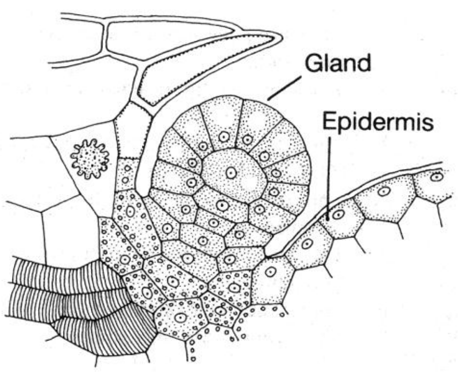


Figure 44: Digestive gland of *Nepenthes, a* carnivorous plant.
(Source: Pandey and Chada, 1996)

- **Stinging hairs**: these are found in *Urtica* (igisura) all along the body, more specifically on the surface of leaves and young stem. Each hair is like a fine capillary tube, calcified at its lower end and silicified at its upper end. Its basal part is embedded in epidermal tissue and upper end is spherical which ruptures the object on coming in contact. These hairs secrete poisonous and muscle irritating substances.
- **Nectaries**: nectaries include floral nectaries (found on the floral parts) extra floral nectaries (found on vegetative parts). Cells of nectaries have dense cytoplasm and contain numerous well developed mitochondria, endoplasmic retilum etc. They secrete sugary substances called nectar or honey composed of sucrose, glucose and fructose which are delivered from the phloem.
- **Hydathodes**: these are specialised water stomata through which water is released in the form of liquid (see Figure 47). The phenomenon is called guttation which is commonly found among plants inhabiting humid tropics. The guttated water contains a mixture of various salts, sugars amino acids and other organic substances. Three types of hydathodes are recognized: unicellular hydathodes, trichome hydathodes (multicellular) and hydathodes with water conducting elements (found in angiosperms like Colocasia [amateke]).

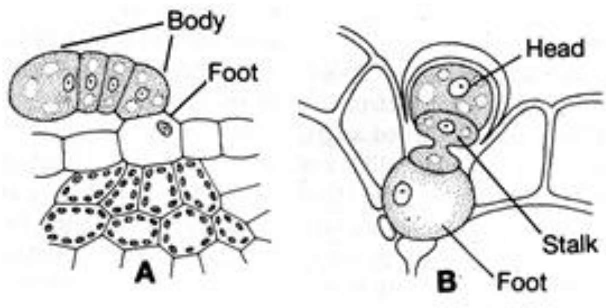


Figure 45: Trichome hydathodes. A-*Phaseolus multifloru s* and *B-Piper nigrum.* *(*Source: Pandey and Chada, 1996)

2.2. Periderm

The periderm, also called bark, replaces the epidermis in plants that undergo secondary growth. The periderm is multilayered as opposed to the single layered epidermis. It consists of cork cells (phellem), phelloderm, and phellogen (cork cambium). Cork cells are nonliving cells that cover the outside of stems and roots to protect and provide insulation for the plant. The periderm protects the plant from pathogens, injury, prevents excessive water loss, and insulates the plant.

Activity 2

1. Distinguish between epidermis and periderm.
2. Give an example of plant having stinging hairs.
3. What is the role of digestive glands in insectivorous plants?

Feedback

The dermal tissue system is the outer covering of a plant. It is in direct contact with the external environment. Its primary function is protection and controls interactions with the plants' surroundings.

Section 3: Ground tissue system

Ground tissue system is the tissue surrounded by the dermal tissue and consists of three types of plant cells.

Keywords

Parenchyma
Collenchyma
Sclerenchyma

3.1. Parenchyma

Ground tissue functions in storage, metabolism and support. Parenchyma cells are the most common type of cell found in ground tissue. The cells of parenchyma are large, thin-walled, and usually have a large central vacuole. They are often partially separated from each other and are usually stuffed with plastids.

In areas not exposed to light, colourless plastids predominate and food storage is the main function. The cells of the potato are parenchyma cells (see Figure 49).Where light is present, e.g., in leaves, chloroplasts predominate and photsynthesis is the main function.

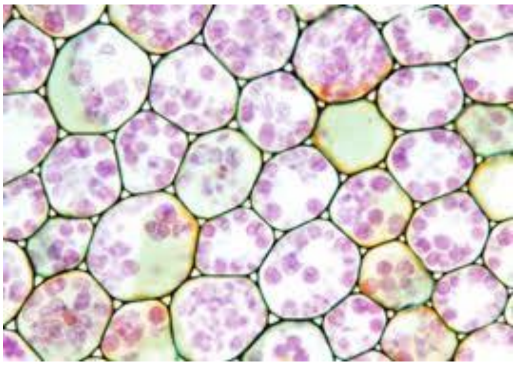


Figure 46: Potato parenchyma with starch grains (Source: www.hbg.fev.ukf.sk/studium matervaly)

3.2. Collenchyma

Collenchyma tissue is composed of narrow, elongated cells with thick primary walls. Collenchyma cells provide structural support to the growing plant body, particularly shoots, and their thickened walls are not lignified, so they can stretch as the organ elongates. Collenchyma cells are typically arranged in bundles or layers near the periphery of stems. The petiole ("stalk") of leaves is usually reinforced with collenchyma.

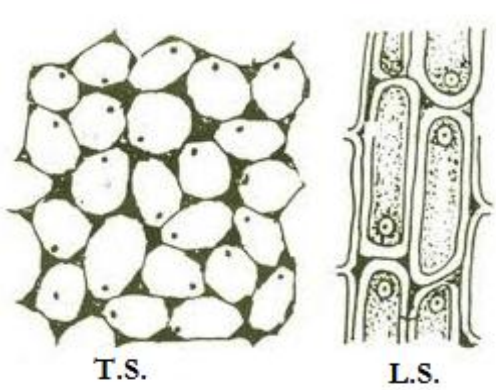


Figure 47: Collenchyma. T.S. transverse section, L.S.: Longitudinal section (Source: www. Transtutors.com/homework-help/plant-tissues-collenchyma)

Collenchyma cells provide structural support. Most notably, they serve growing parts of the plant, such as shoots and leaves. Plants are exposed to numerous structural challenges and they are able to survive things such as rain downpours, wind, and other stresses because of their cellular composition. Collenchyma cells function to provide support and fill in vacant spaces that will be used for later growth.

Collenchyma cells have thickened cell walls that enable them to provide additional support to the areas where they are found. If there were no collenchyma cells, most plants would suffer damage when they are blown by the wind or pounded by rain because they would be too fragile. The collenchyma cells protect the plant by serving as an inner framework, much like bones do for humans and other animals.

3.3. Sclerenchyma

Sclerenchyma consists of two types of cells; **sclereids** and **fibers**. Both have thick secondary walls and are frequently dead at maturity. Mature sclerenchyma cells are dead and have secondary cell walls thickened with cellulose and usually impregnated with lignin. In contrast to collenchyma, which is pliable, sclerenchyma is elastic. The cell cavity or lumen is very small or it may disappear completely. Sclereids occur in a variety of shapes, ranging from roughly spherical to branched, and are widely distributed throughout the plant. In contrast, fibers are narrow, elongated cells that are commonly associated with vascular tissues.

The main function of sclerenchyma is to provide mechanical support, particularly to parts of the plant that are no longer elongating. Sclerenchyma cells are usually found associated with other cells types and give them mechanical support. Sclerenchyma is found in stems and also in leaf veins. Sclerenchyma is also found where hardness is an advantage such as in the seed coat of hard seeds and in the spines of the cactuses. Starch granules can be stored in the young, living fibres.

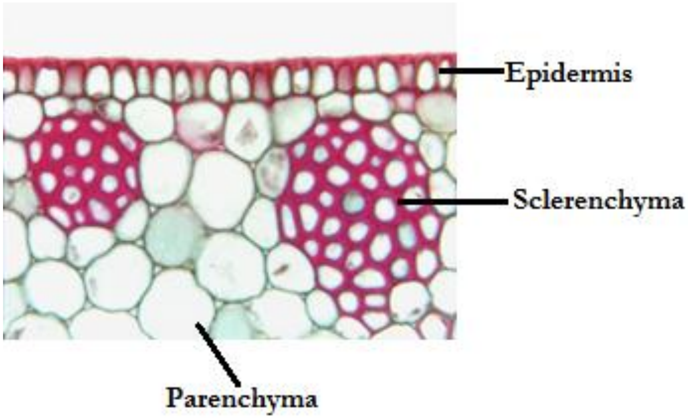


Figure 48: Transverse section of leaf of *Dracaena* [Umugwegwe]. This section contains both sclerenchyma (the two masses of cells with red-stained walls, but not the epidermis along the top) and parenchyma (all the other cells). This figure shows the difference between the thin primary walls of parenchyma cells and the thick secondary walls of the fibers.
(Source: http://www.sbs.utexas.edu/mauseth/weblab/webchap3par/3.1-7.htm**)**

Activity 3

1. Distinguish between cell walls of parenchyma, collenchyma and sclerenchyma.
2. What is the main functions of sclerenchyma ?

Feedback

The ground tissue is mostly made of parenchyma, usally with some collenchyma and fewer sclerenchyma. Depending on its structure and location, its functions vary. You can find it in any plant organ.Practical sessions will help you to better recognize this type of tissue.

Section 4: Vascular tissue system

Vascular plants contain two main types of conduction tissue, the xylem and phloem. These two tissues extend from the leaves to the roots, and are vital conduits for water and nutrient transport. The structure of xylem and phloem tissue depends on whether the plant is a flowering plant (including dicots and monocots) or a gymnosperm. Xylem and phloem tissues are produced by meristematic cambium cells located in a layer just inside the bark of trees and shrubs. In dicot stems, the cambium layer gives rise to phloem cells on the outside and xylem cells on the inside. All the tissue from the cambium layer outward is considered bark, while all the tissue inside the cambium layer to the center of the tree is wood.

Keywords

Xylem

Phloem

Vascular bundle

Lignin

Move the box to the left side!

4.1. Xylem

Xylem conducts water and dissolved minerals from the roots to all the other parts of the plant. In angiosperms, most of the water travels in the **xylem vessels**. These are thick-walled tubes that can extend vertically through several feet of xylem tissue. Their diameter may be as large as 0.7 mm. Their walls are thickened with secondary deposits of cellulose and are usually further strengthened by impregnation with **lignin**. The secondary walls of the xylem vessels are deposited in spirals and rings and are usually perforated by pits. Xylem vessels arise from individual cylindrical cells oriented end to end. At maturity the end walls of these cells dissolve away, and the cytoplasmic contents die. The result is the xylem vessel, a continuous nonliving duct.

Xylem also contains **tracheids**.These are individual cells tapered at each end so the tapered end of one cell overlaps that of the adjacent cell. Like xylem vessels, they have thick, lignified walls and, at maturity, no cytoplasm. Their walls are perforated so that water can flow from one tracheid to the next. The xylem of ferns and conifers contains only tracheids.

In woody plants, the older xylem ceases to participate in water transport and simply serves to give strength to the trunk.

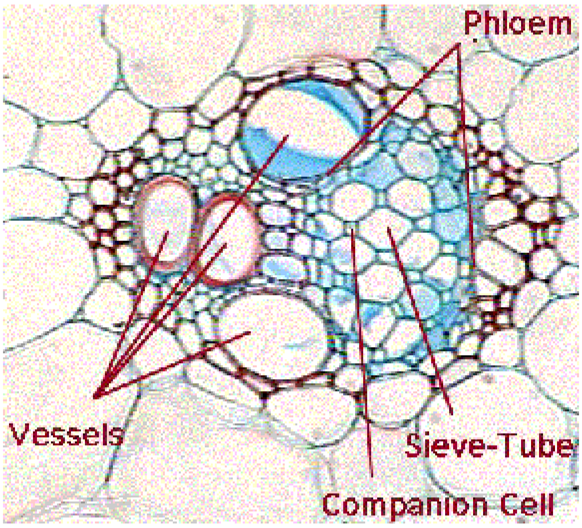


Figure 49: Vascular bundle with xylem and phloem cells. (Source:gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.130/Stem/Zea_cross_section/Vascular_Bundle_labelled.)

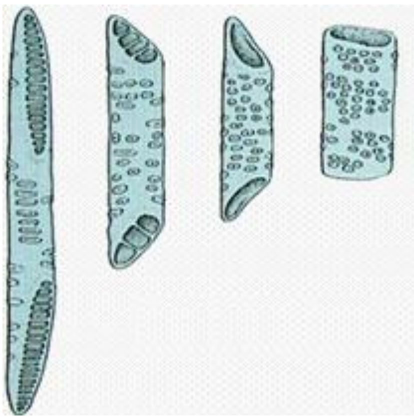


Figure 50: Conducting cells of xylem. (Source: Purves et al., Year?????)

Conducting cells of the xylem; tracheids (left) are more primitive, while the various types of vessels (the other three) are more advanced. While tracheids are found in all vascular plants, vessels are found only in angiosperms.

4.2. Phloem

The main components of phloem are **sieve elements** and **companion cells.** Sieve elements are so-named because their end walls are perforated. This allows cytoplasmic connections between vertically-stacked cells. The result is a sieve tube that conducts the products of photosynthesis sugars and amino acids from the place where they are manufactured (a "source"), e.g., leaves, to the places ("sinks") where they are consumed or stored; such as roots, growing tips of stems and leaves, flowers, fruits, tubers, corms, etc.

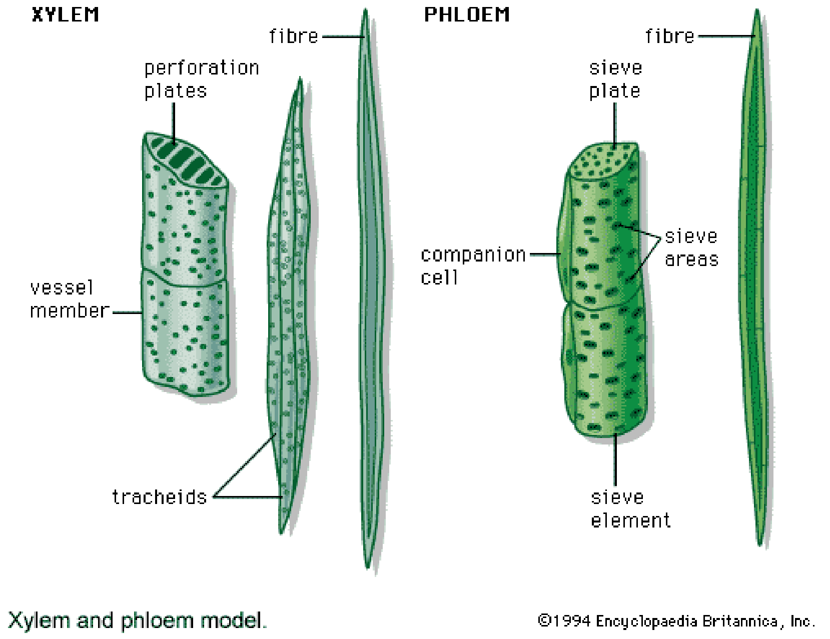


Figure 51: The xylem and phloem cells
(Source: www.excultup.com/interbiology/plant anatomy.aspx)

While tracheid cells are nonliving, sieve-tube and companion cells of the phloem are living. Companion cells possess a nucleus and actively transport sugar into and out of sieve-tubes.

Activity 4 ✎

1. Enumerate the major components of xylem.
2. Describe the structure of sieve elements.

Feedback

Vascular tissue is a complex conducting tissue, formed of more than one cell type. The primary components of vascular tissue are the xylem and phloem. You are requested to locate this important type of tissue and match the functions to it.

Keywords

Meristem
Root zones
Root growth
Pericycle
Endodermis
Cambium

Section 5: Root anatomy and function

5.1. Root internal zones

There are three internal zones in a plant root. **The meristem**, which is at the tip of the root, is the area in which new cells grow and divide. Behind the meristem, cells absorb water and food in the **elongation zone**. Here, the enlarged cells push the root into the soil. In the **maturation zone**, which is behind the elongation zone, cells develop into different types of plant tissue, such as vascular and epidermal tissue.

5.1.1. Root cap

Tips of roots are covered by a thimble-shaped root cap that has its own meristem that pushes cells forward into the cap. Besides protecting the growing root tip and its meristem, the root cap senses light and pressure exerted by soil particles. Within a few days, columella cells differentiate into peripheral cells. The peripheral cells of the root cap and the epidermal cells of the root produce and secrete large amounts of mucigel, a slimy substance made by dictyosomes. Mucigel is a hydrated polysaccharide containing sugars, organic acids, vitamins, enzymes, and amino acids.

5.1.2. Quiescent center

This structure is located just behind the root cap and consists of 500-1,000 seemingly inactive cells. These cells are usually in the G1 phase of the cell cycle and divide only about once every 15-20 days. Quiescent and meristematic cells are different in sensitivity to environmental problems such as radiation. For example, meristematic cells stop dividing when exposed to X-rays while quiescent cells are unaffected by radiation and soon begin dividing to reform the meristem. Cells in the quiescent center function as a reservoir to replace damaged cells of the meristem. It is important because it organizes the patterns of primary growth in roots.

5.1.3. Sub apical region

This region of roots has traditionally been divided into three regions; the zones of cellular division, cellular elongation, and cellular maturation. These divisions are useful for teaching but are not sharply defined. They do not always accurately define what is happening in a particular region of the root.

5.1.4. Zone of cellular division

Surrounding the quiescent center is a dome shaped apical meristem located 0.5-1.5 mm behind the root tip. This meristematic region is the zone of cellular division and it is made of small densely cytoplasmic cells. Meristematic cells in roots divide every 12-36 hrs, in some plants; the meristem produces almost 20,000 new cells each day.

5.1.5. Zone of cellular elongation

This area occurs 4-15 mm behind the root tip. Cells in this zone elongate by as much as 150-fold by filling their vacuoles with water. This zone is easily distinguished from the root cap and zone of cellular division by its long, vacuolate cells. Cellular elongation in the elongating zone shoves the root cap and apical meristem through the soil at rates as high as 4 cm per day. Cells behind the elongating zone do not elongate.

5.1.6. Zone of cellular maturation

Differentiation is completed in this zone, which occurs 1-5 cm behind the root tip. This zone is easily distinguishable by the presence of several root hairs. Root hairs increase the absorptive surface area of the root several thousand fold and are usually less than a millimeter long. In most plants they form from asymmetric divisions of the protoderm and usually live only a few days, with old hairs farthest from the tip constantly being replaced by new ones closer to the tip. Root hairs only form in the maturing, non elongating region of the root. Because root hairs are fragile extensions of epidermal cells, they usually break off when plants are transplanted.

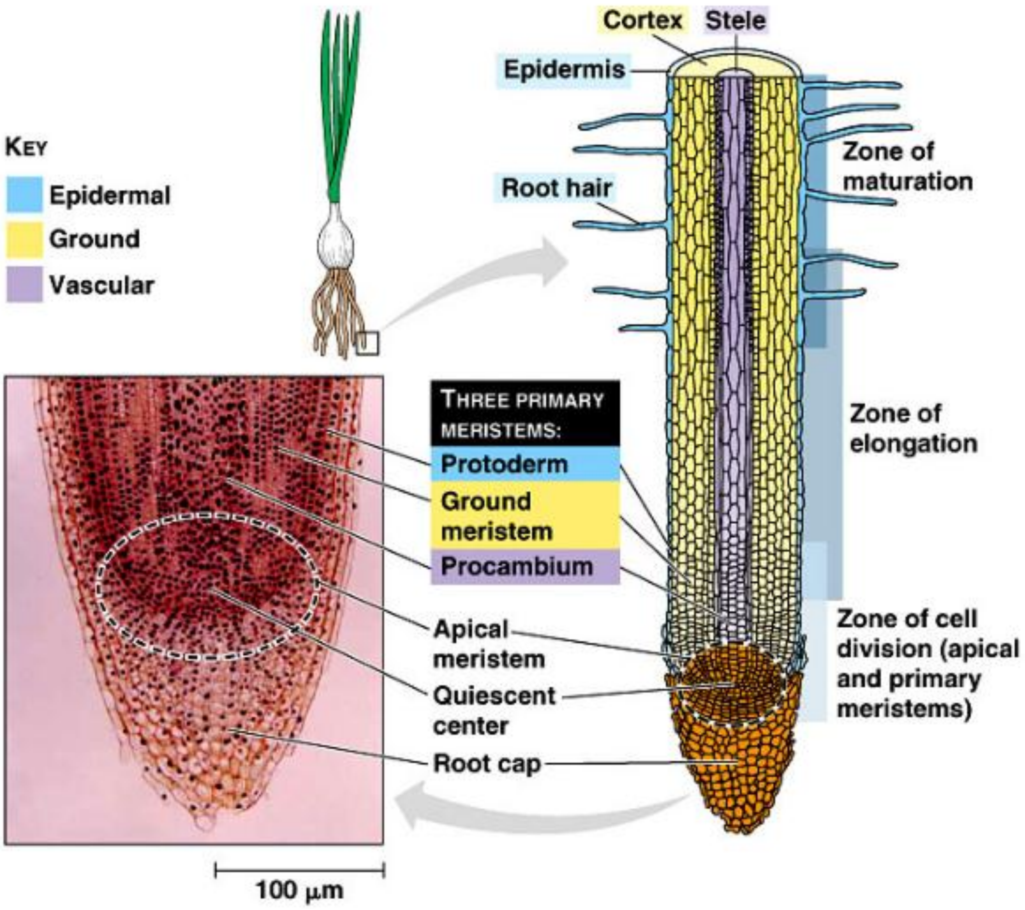


Figure 52: Root primary structure
(Source : wwwuic.edu/classes/bios/bios100/lecturesof 04am/lect1.html)

From outside inward, root tissue is composed of layers of cells arranged in the following order:

In the outermost layer or epidermis, cells absorb water and nutrients through fine root hairs which extend into the soil. The root hairs also increase the surface area available for absorption.

The next layer of cells is the cortex, which conducts water into the root's vascular system. **Casparian strips** are fatty cells which determine the types of nutrients absorbed. Branch roots develop from an inner layer of cells known as the **pericycle**. The **endodermis** is a filtration layer of cells between the cortex and pericycle. In the center of the dicot root there is vascular tissue (**stele**) and in the monocot root the vascular bundles surround the pith (see Figure 56).

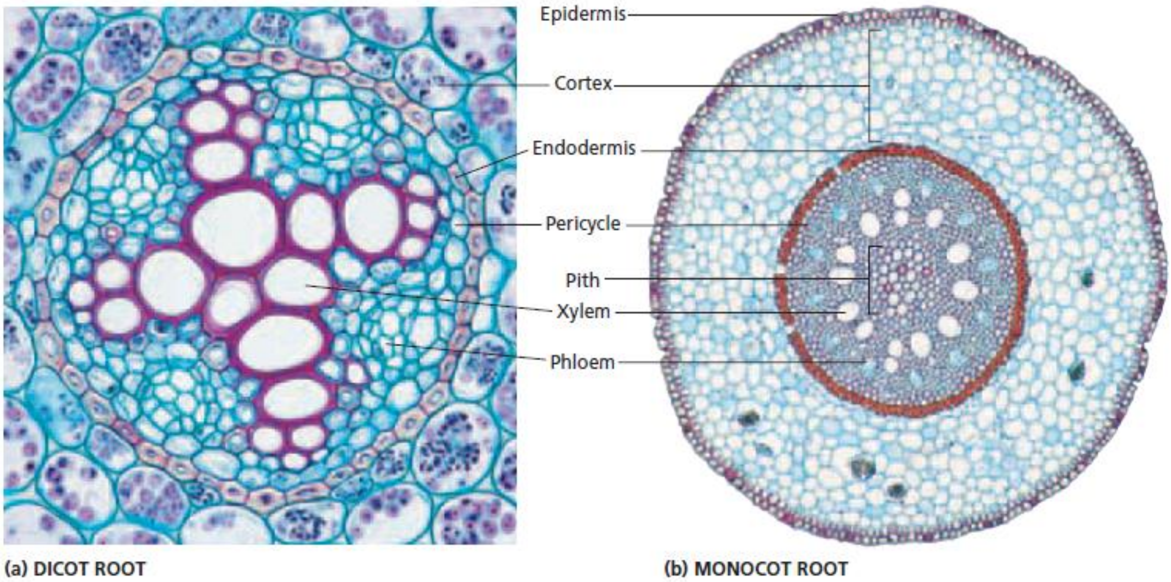


Figure 53: Primary structure of dicot and monocot roots. (a) This cross section of a dicot root shows the arrangement of vascular tissue and ground tissue. Note how the Xylem tissue forms an" X" surrounded by the cortex and endodermis, which are components of ground tissue.(b)This cross section of a monocot root shows a prominent endodermis, the innermost boundary of the cortex. The center of the roots, called the pith, is made up of parenchyma. (Source: Holt, Rinehart and W intson, 2006)

5.2. Root secondary structure

Dicot and gymnosperm roots often experience secondary growth. Secondary growth begins when a pericycle and other cells form a vascular cambium between primary xylem and primary phloem. The vascular cambium produces secondary xylem toward the inside of the root and secondary phloem toward the outside. The expansion of the vascular tissues in the center of the root cruches all the tissues external to the phloem, including the endodermis, cortex, and epidermis. A cork cambium develops in the pericycle, replacing the crushed cells with cork.

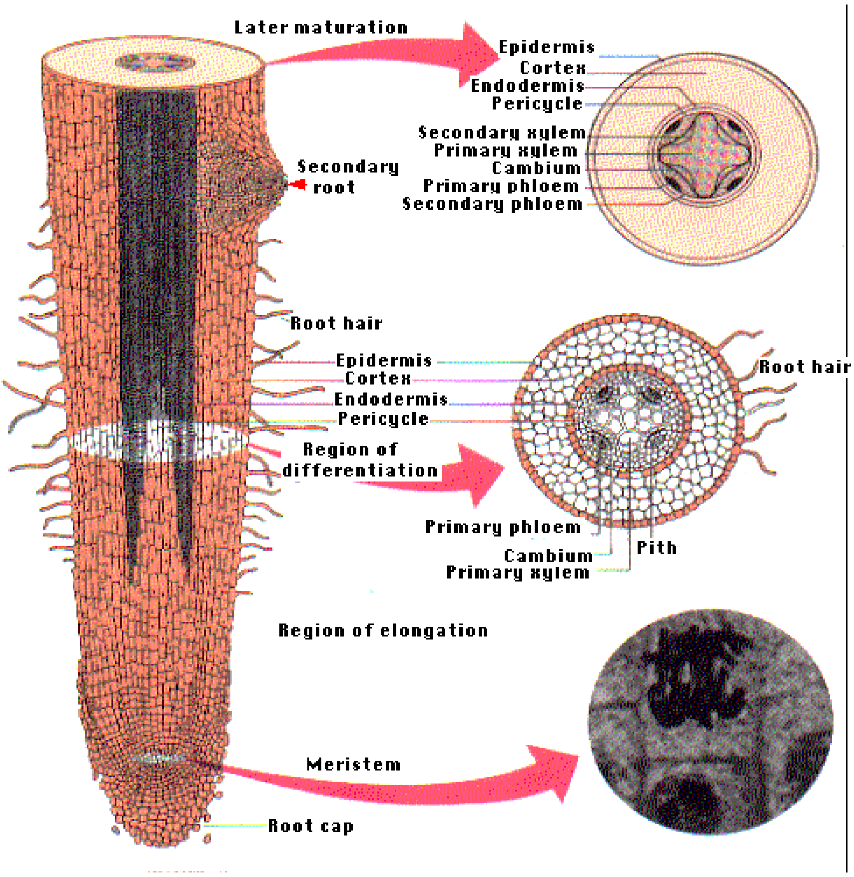


Figure 54: Secondary Structure Dicotyledonous root.
(Source: Becky Earley Information provided by: http://wwwfac.wmdc.edu)

5.3. Root functions

- Roots are equally important in plant growth as leaves and stems because they provide the parenchyma cells of stems and leaves with a steady supply of water and dissolved minerals.
- Besides anchoring a plant in the soil, roots serve two other primary functions. First, they absorb water and a variety of minerals or mineral nutrients that are dissolved in water in the soil.
- Phloem tissue carries sugars made in leaves to roots. Sugars that roots do not immediately use for energy or building blocks are stored. In roots, these carbohydrates are usually converted to starch and stored in parenchyma cells. You are probably familiar with the storage roots of carrots, sweet potatoes, and cassava.
- The roots of some species in the pumpkin family (Cucurbitaceae) store large amounts of water, which helps the plant to survive during dry periods.

Activity 5

1. State the cell layers as observed in the primary root from out inward.
2. Where is the quiescent center located and what is its function?
3. With suitable example explain the storage function of the root.

Feedback

The root anatomy fits with its functions. Root structures are adapted for several functions.In dicots the root secondary structure is established during secondary growth. Refer to your documentation to get more information about this process.

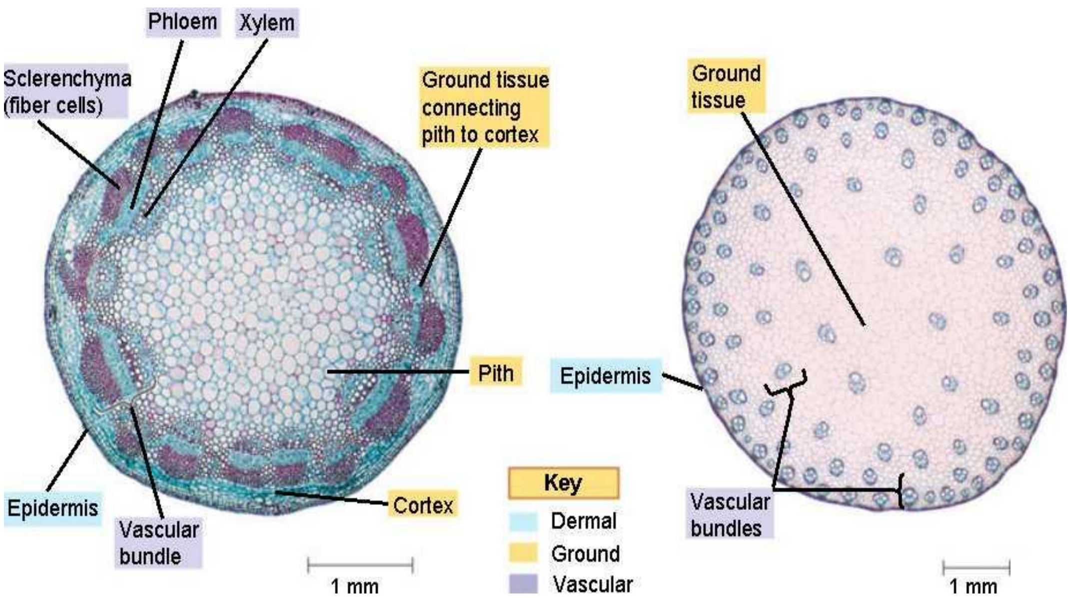
Section 6: Stem anatomy and functions

Keywords

Annual ring
Cork
Bark
Wood pith
Sink
Source

6.1. Primary structure of stems

A stem is one of two main structural axes of a vascular plant, the other being the root. Stem usually consist of three tissues, **dermal tissue**, **ground tissue** and **vascular tissue**. The dermal tissue covers the outer surface of the stem and usually functions to water proof, protect and control gas exchange. The ground tissue usually consists mainly of parenchyma cells and fills in around the vascular tissue.



(a) **Dicot stem** (b**) Monocot stem**

Figure 55: Cross section in primary dicot and monocot stem (Source: Holt, Rinehart and Winston, 2006)

(a) A cross-section through a dicotyledonous stem showing the arrangement of the vascular bundles. The two main transport tissues in a vascular bundle are phloem and xylem and between these is a very important layer of cells, the cambium, which is able to divide. (b) A cross-section of monocot stem showing scattered vascular bundles and there is no cambium.

6.1.1. Primary Vascular bundles in stem of dicot plants

The Xylem

The xylem differentiates from the part of the vascular bundle nearest the centre of the stem and then progressively towards the cambium in the middle of the bundle. Protoxylem is the xylem which differentiates first and may consist of a different combination of xylem cells when compared to the metaxylem which differentiates later and lies closer to the cambium. The xylem is responsible for transporting water and dissolved nutrients.

The phloem

The phloem starts differentiating on the side of the vascular bundle orientated towards the outside of the stem and then progressively towards the middle, towards the cambium in the middle of the bundle. As in the xylem, the phloem which first differentiated is known as the protophloem and the metaphloem is the later phloem. The protophloem is often associated with sclerenchyma fibres –the phloem fibres. The phloem transports organic substances through the stem.

The cambium

Between the xylem and the phloem lies an important layer of cells, the cambium, which are still able to divide i.e. they are meristematic. The cambium which lies inside the vascular bundles is called the fascicular cambium. The fascicular cambium consists of vascular bundles which are united by sections of parenchyma cells. These parenchyma cells also become meristematic, and so form the interfascicular cambium. The fascicular and interfascicular cambiums form a continuous cylindrical layer inside the stem. The cells divide to form new xylem cells towards the inside of the stem and new phloem toward the outside of the stem by a process called secondary thickening which involves the formation of wood.

6.1.2. Primary vascular bundles in stem of monocot plants

In a monocotyledenous stem such as the example of *Zea mays* on the left, the vascular bundles are not arranged in a circle but are usually scattered throughout the ground tissue. There is no clearly defined pith as there is in many dicotyledonous species. As in the dicots the xylem of the bundles is pre-orientated toward the middle of the stem.

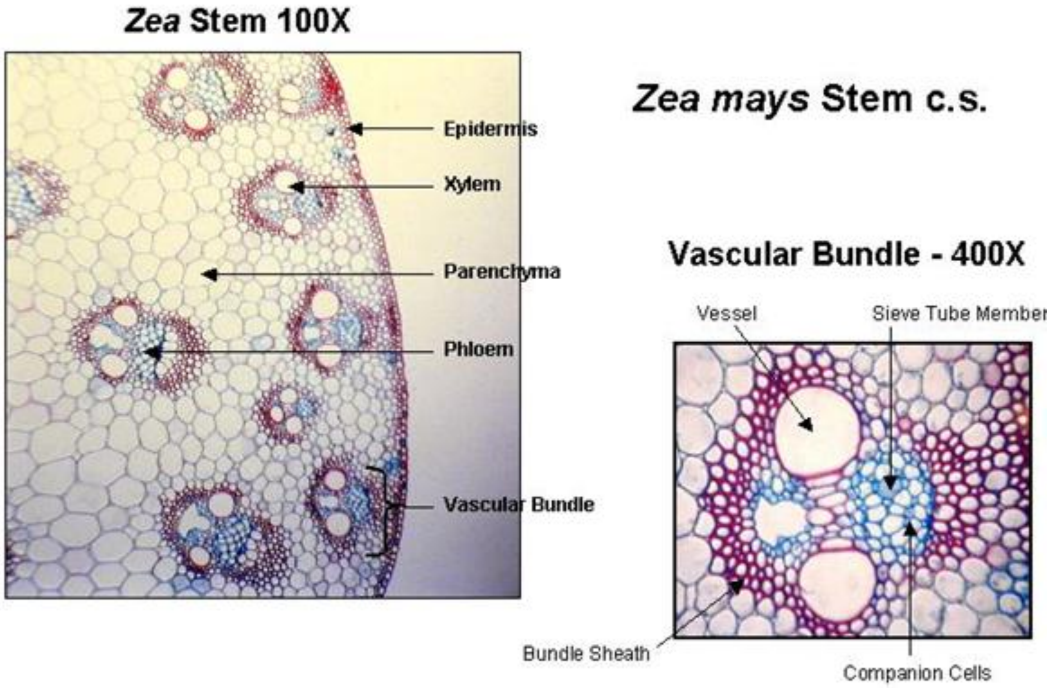


Figure 56: A cross-section through monocotyledonous stem *(Zea mays)* showing the arrangement of the vascular bundles.
(Source mindcrave wordpress.com/2012/03/210/8-12 the vascular)

The vascular bundles of monocotylenous plants do not contain a layer of meristematic tissue (cambium) as the dicots do. Thus no new cells can be formed inside the vascular bundles of monocots and their vascular bundles are termed closed whereas those of dicot plants are open.

As in dicots, the first xylem and phloem to differentiate is called the protoxylem and protophloem. Metaxylem and Metaphloem differentiates out later, towards the middle of the bundle. The protophloem may also be associated with sclerenchyma fibres.

6.2. Secondary dicot stem structures

6.2.1 Different secondary tissues in dicot stem

In a typical dicotyledonous plant stem the vascular bundles are arranged in a circle in the middle of the stem surrounding a central pith. To the outside of the vascular bundles is the cortex which is covered by a single layer of epidermis cells. The xylem of the vascular bundles is orientated towards the middle of the stem and the phloem towards the outside as shown by the following Figure.

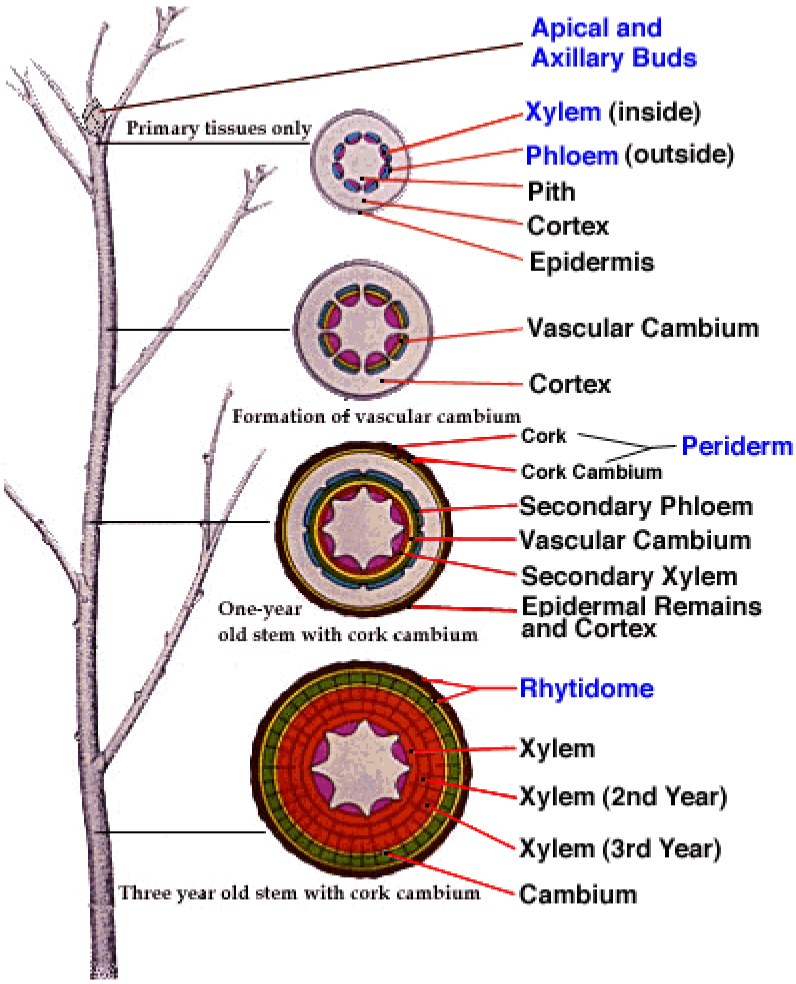


Figure 57: Various secondary stages in cross section of a dicot stem (Source :Preuniversity.grkraj.org/html)

6.2.3. The woody dicot stem

Dicot stems often produce abundant secondary growth. Stems increase in thickness due to the division of cells in the vascular cambium. The vascular cambium in dicot and gymnosperm stems first arises between the xylem and phloem in a vascular bundle. It forms secondary xylem to the inside and secondary phloem to the outside. It usually produces much more secondary xylem than it does secondary phloem. Secondary xylem is called **wood**. Wood is xylem. When counting the annual rings of a tree, one is counting rings of xylem.

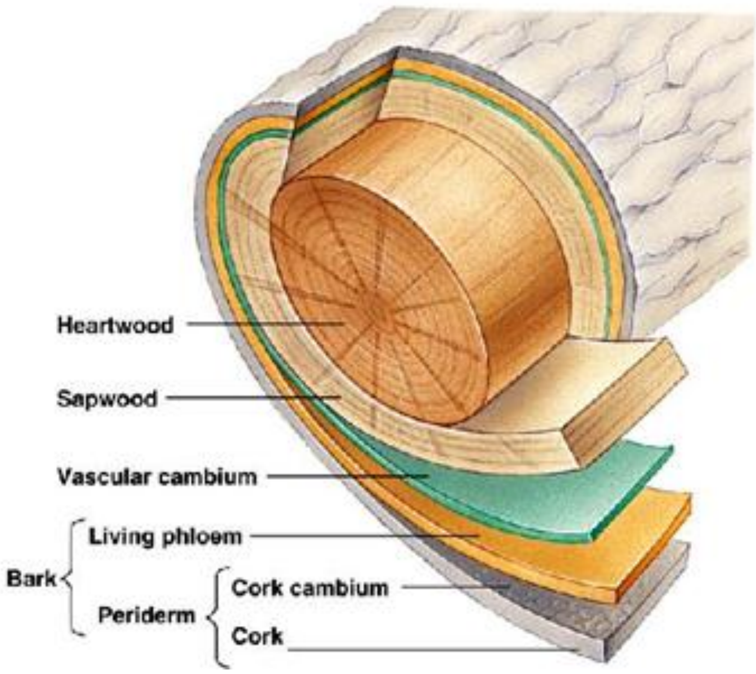


Figure 58: Cross section in old tree
(Source: Montagepage,fuselabs.com/public/)

Older portions of the xylem eventually stop transporting water. They often become darker than the newer xylem due to the accumulation of resins and other organic compounds produced by the few live cells remaining in the xylem. This darker wood in the center of a tree is called **heartwood**. The functional, often lighter-colored wood nearer the outside of the trunk is the **sapwood**.

The pith is the part of the wood located at the center of a stem during the first year of growth. It does not grow any larger after the first year. It is not always visible in older wood. It is the light center and first dark ring of the next diagram.

The drawing in Figure 61 shows a sector of a cross section through a 5-year old twig from a basswood tree (*Tilia*). The stem has three areas: bark (the outside layer of a tree trunk or branch), wood (xylem) and pith.

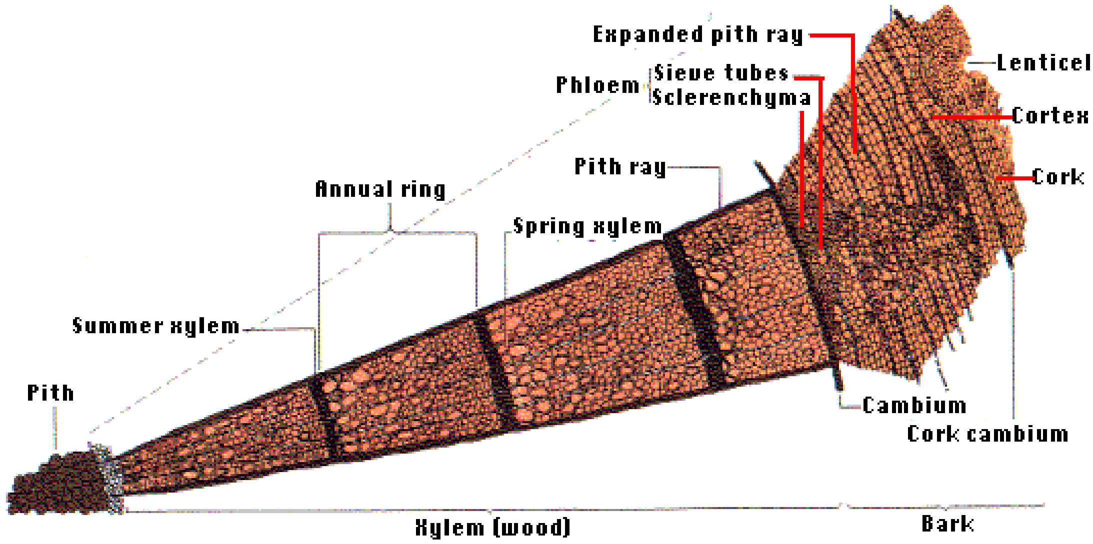


Figure 59: Estimation of age in old tree
(Source: http:users,rcn.comjkimball.ma.utranet/biologypages/s/stem.html)

Bark

The phloem produced near the outside of the stem is part of the **bark**.

The bark is the protective outside covering of woody plants and consists of cork, cortex, cork cambium, and phloem.

- ***Cork***: the outer part of the bark is protected by layers of dead cork cells impregnated with suberin. Suberin is waxy and cuts down water loss from the stem. But suberin is as impervious to air as it is to water. The gas exchange needs of the living cells beneath the cork are met by openings in the cork called lenticels.
- ***Cortex***: layers of parenchyma cells. These store food (as they do in the root). In the very young stem (before cork has formed), they may have chloroplasts and carry on photosynthesis.
- ***Cork cambium***: in older stems, a meristem forms between the cork and cortex. Mitosis of its cells produces more cork.
- ***Expanded pith rays***: regions of parenchyma that store food. They alternate with
- ***Phloem***: bundles of sieve tubes surrounded and supported by sclerenchyma. Translocation of food through the stem takes place in the sieve tubes.

Wood

- Heartwood: found at the center of a trunk or large branches. It often has a dark color. Many branches, especially the smaller ones, do not have any heartwood. The heartwood is dead wood made of *xylem* cells.
- Sapwood: the live, outer part of the wood. The sap moves upward through it. Sap is mostly water and minerals that the roots have taken out of the soil. All of the wood in small or medium-sized branches is sapwood. As branches get thicker, the center part may become heartwood. Heartwood and sapwood are both made of *xylem* cells.

Pith

- Located at the center of a stem during the first year of growth. It does not grow any larger after the first year. It is not always visible in older wood. It is the light center and first dark ring of the next diagram.

6.3. Stem functions

Stem functions is the transportation of nutrients and water, the storage of nutrients and the support of leaves. Sugars, some plant hormones, and other organic compounds are transported in phloem. The movement of sugars occurs from where the sugars are made or have been stored, called a **source**. The place they will be stored or used is called a **sink**. Botanists use the term translocation to refer to the movement of sugars through the plant.

For example, most of the time, sugars move from the leaves to the roots, to the shoots apical meristems, and to the developing flowers and fruits. Sugars may be newly made in photosynthetic cells or may have stored as a starch in roots or other stems.

Movement of sugars in the phloem is explained by the **pressure-flow hypothesis**, which states that sugars are actively transported into sieve tubes. Figure 63 below shows how sugars enter the sieve tubes. Water is also transpored in by osmosis. Thus, a positive pressure builds up at the source end of the sieve tube. This is the pressure part of the pressure-flow hypothesis. At the sink end of the sieve tube, this process is reversed. Sugars are actively transported out, water leaves the sieve tube by osmosis, and pressure is reduced at the sink. The difference in pressure causes water to flow from source to sink. This water is also carrying dissolved substances with it. Transport in the phloem can occors in different directions at different times.

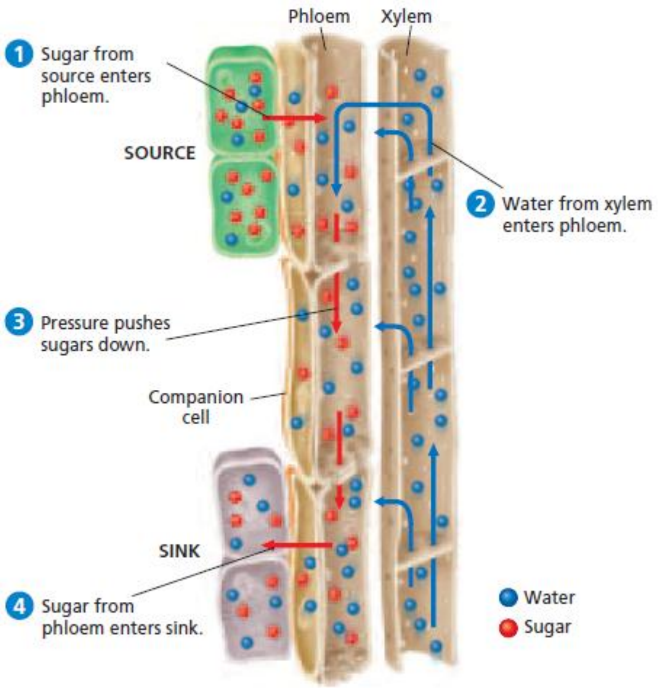


Figure 60: Pressure-flow hypothesis for transport in the phloem
1: Sugars from a source enter the sieve tubes of the phloem. 2:Water moves from the xylem to the phloem byosmosis. 3: The water creates pressure that moves the sugars down the phloem. 4: The sugars exit the phloem and enter the sink, where they will be used or stored.
(Source: Holt, Rinehart and Wintson, 2006)

Activity 6

1. Enumerate the components of the bark.
2. Distinguish between vascular cambium and cork cambium
3. Describe the movement of sugar in the phloem.

Feedback

The stem organisation is quite different in dicots and monocots as there is no secondary growth in monocot stem. Despite this difference the stem function is still the same in both groups. Observe and interpret carefully the diagrams provided in this section to better capture this anatomical difference.

Section 7: Leaf anatomy and functions

Keywords

Epidermis
Mesophyll
Cuticle
Parenchyma
Collenchyma
Vein

7.1. Dicot leaf tissue organization

The leaves are the primary photosynthetic organs of plants, serving as key sites where energy from light is converted into chemical energy. Similar to the other organs of a plant, a leaf is comprised of three basic tissue systems, including the dermal, vascular, and ground tissue systems. These three motifs are continuous throughout an entire plant, but their properties vary significantly based upon the organ type in which they are located. All three tissue systems are illustrated in Figure below, which is a cutaway drawing of a typical leaf.

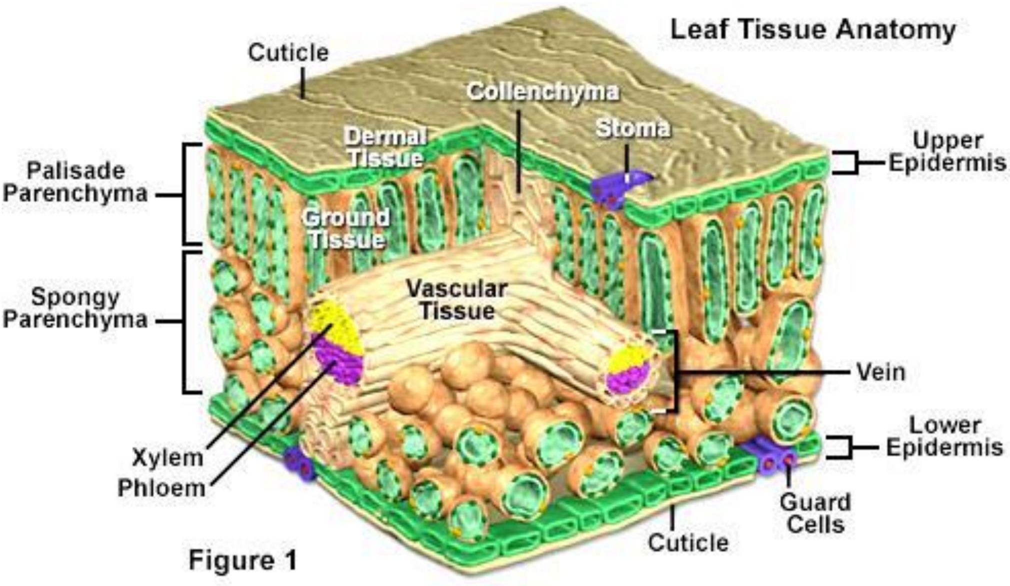


Figure 61: Typical dicot leaf structure
(Source: montagepages fuselabs.com/pubic/craig)

The dermal tissue of a plant, more specifically referred to as the **epidermis**, is an outer protective layer of typically polygonal cells, which helps defend against injury and invasion by foreign organisms. The epidermis of the leaf also functions in a more specialized manner by secreting a waxy substance that forms a coating, termed the **cuticle**, on the surface of the leaf. An adaptation unique to terrestrial plants, the cuticle functions chiefly in the retention of water. As presented in Figure 63, the cells that comprise the epidermis of a leaf are arranged very tightly together in a single stratum.

Microscopic pores known as **stomata** are the only breaches in the otherwise continuous layer of the leaf epidermis. Each individual pore, or stoma, is, in fact, a small opening between a pair of specialized cells known as **guard cells**. By modifying the size of the stomata, guard cells are able to regulate gas exchange and transpiration. Such modifications are influenced by various environmental factors. For example, when the weather is unusually hot and dry, the guard cells of plants in danger of losing too much water narrow the stomata width in order to reduce evaporation from the leaf interior.

In order for leaves to obtain water and minerals from the roots and for food manufactured in mature leaves to be transported to the roots and other nonphotosynthetic regions, each leaf must be connected to the overall vascular structure of the plant. Accordingly, the main vascular bundle of xylem and phloem present in the stem of a plant bifurcates into **leaf traces**, which are branches of vascular tissue that supply leaves. Each leaf trace further branches into the familiar **veins** that can often be seen along the surface of leaves, and the veins repeatedly subdivide as well. The vascular components, which serve as a basic skeletal structure in addition to functioning in the transport of materials, extend throughout the **mesophyll** so that the xylem and phloem are brought into propinquity with leaf tissues that carry out photosynthesis.

The mesophyll is the mid-section of a leaf, located between the upper and lower epidermal layers. Not only is vasculature found in the mesophyll, but also the ground tissue of a leaf. Ground tissue comprises the bulk of a plant leaf and is generally comprised of a variety of cell types, the predominant of which are parenchyma. Often less specialized than other plant cell types, parenchyma cells are surrounded by thin, flexible primary walls and execute most of the plant's metabolic activities. The parenchyma cells present in leaves contain chloroplasts, which are the sites of photosynthesis.

In Figure 63, the mesophyll is divided into two conspicuously different regions, a characteristic common among the leaves of many dicotyledons. The upper section is termed the **palisade parenchyma** and consists chiefly of elongated columnar parenchyma cells that contain three to five times the number of chloroplasts as the cells that comprise the lower layer, known as the **spongy parenchyma**. The cells of the spongy parenchyma are irregularly shaped, allowing gases to circulate through the numerous air spaces between them to the palisade parenchyma. The stomata, which are particularly important for gas exchange, tend to be surrounded by exceptionally large air spaces.

A small group of **collenchyma** cells are also illustrated in the mesophyll of the leaf section presented in Figure 63. As depicted, collenchyma cells occur in aggregates just beneath the epidermis and possess thicker primary cell walls than parenchyma cells. The thickness of the walls, however, does exhibit notable variation. The main function of collenchyma cells is to provide additional support to the plant, especially in areas of continued growth

7.2. Monocot leaf tissue organization

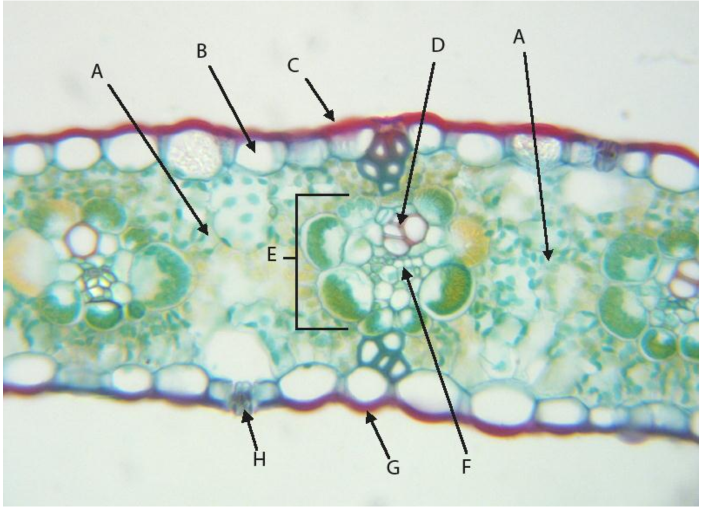


Figure 62: Cross section in leaf of Zea mays A = spongy mesophyll; B =upper epidermis; C = upper cuticle; D = xylem; E = vein; F = phloem; G = lower cuticle; H = guard cell and stoma (Source : www2.sluh.org/bioweb/microscopy/plantanatomy/zeamaysleafplabeled.html)

7.3. Leaf functions

Leaves are primary site of photosynthesis in most plants. Mesophyll cells in leaves use light energy, carbon dioxide, and water to make sugars and a variety of other organic molecules. Transpiration is another function of the plant. Transpiration also benefits the plant by cooling it and by speeding the transport of mineral nutrients through the xylem. Leaf contains chlorophyll which absorbs light. Plants must balance their need to open their stomata to receive carbon dioxide and release oxygen with their need to close their stomata to prevent water loss through transpiration. This section will be developed in plant nutrition.

Activity 7

1. Briefly describe the leaf mesophyll organisation.
2. What are the main leaf functions?

Feedback

This section describes the leaf organization from the upper epidermis to the lower epidermis. Associate functions performed by each part to understand better the leaf organization.

Block summary

This block describes the internal organization of a plant. Meristems divide and give permanent tissues that accomplish different functions.

The dermal tissue system has a protective function and its structure varies depending on the age of the stem or root.

The ground tissue system serves a variety of essential functions for plants. Each type of tissue in the ground tissue system has its role, such as food manufacture and storage or support during and after growth. Filling all the spaces that are not used by the dermal and vascular tissue systems, ground tissue can be found throughout the plant.

Vascular tissues are very important in the transportation of water and nutrients. Vascular plants contain two main types of conduction tissue, the xylem and phloem. These two tissues extend from the leaves to the roots, and are vital conduits for water and nutrient transport. The structure of xylem and phloem tissue depends on whether the plant is a flowering plant (including dicots and monocots) or a gymnosperm. Xylem and phloem tissues are produced by meristematic cambium cells located in a layer just inside the bark of trees and shrubs of dicotyledonous plants. The root, stem and leaf of monocot and dicot are described in detail in this block.

The organs are made up from groups of specialised tissues that have structures suited to the jobs they perform. The table below summarises the main features of these structures and their respective functions.

	Structure	**Function**
Leaves	Thin with a large surface area Cells contain in chloroplasts.	Short distances for gases to diffuse. Large area for absorption of light. Leaves are a plant's food factory. They are the main site of photosynthesis, where sugars are made from water and carbon dioxide, using sunlight energy that has been absorbed by chlorophyll.
Stems	Long and cylindrical. Woody tissues-xylem and fibres (sclerenchyma) - add strength. Contain xylem and phloem	Support the leaves, flowers and fruit. Can bend or resist the wind. Transport water, minerals to leaves and sugars to roots, flowers and fruit.
Roots	Branch extensively through the soil. Root hairs provide huge surface area. Contain xylem and phloem Root tip area of cell division. Root cap covers the root tip.	Provide anchorage in soil. Enable absorption of water and nutrients. Enable transport of water and nutrients. Grow into the soil. Protects and lubricates the growing root.

Answers to activities in block 6

Activity 1

1. Meristems can be found:
   - Near tips of roots and stems. This is called apical meristem.
   - In the buds and nodes of stems.
   - In the cambium between the xylem and phloem in dicotyledonous trees and shrubs.
   - Under the epidermis of dicotyledonous trees and shrubs (cork cambium).
   - In the pericycle of roots, producing lateral roots.
2. The main functions of the ground tissue are photosynthesis, food storage, regeneration, support, and protection
3. No, because a germinating seedling is still undergoing the primary growth periderm cannot be formed as it appears on old stems and roots.

Activity 2

1. Epidermis is generally single layered and covers young plant organs whereas periderm is multilayered and covers old stems and roots
2. Igisura, Isusa
3. They secrete substances used to catch and serve as paths for the absorption of nutrients in the case of carnivorous plants

Activity 3

1.
- Parenchyma: thin walls,
- Collenchyma: thick primary walls;
- Sclerenchyma: tkick secondary walls, usually impregnated with lignin

2. Sclerenchyma cells are usually found associated with other cells types and give them mechanical support

Activity 4

1. The major components of the xylem are xylem vessels, tracheids, fibres
2. Sieve elements are conducting cells with perforated end walls in order to make the sieve tube which transport organic matters from leaves to others organs.

Activity 5

1. Epidermis, cortex, pericycle and vascular tissue.
2. Cells in the quiescent center function as a reservoir to replace damaged cells of the meristem. It is important because it organizes the patterns of primary growth in roots.
3. For example in sweet potato, carrot and cassava root storage function is achieved by the parenchyma tissue. The root is said to be a tuber.

Activity 6

1. Cork, cortex, cork cambium, and phloem
2. The Vascular cambium is present between the xylem and phloem of vascular bundle. This cambium continues to divide and adds secondary phloem on its outer side surrounded secondary xylem on its inner side. The cork cambium is a secondary meristem which develops in the region outside the vascular tissues. This cambium gives rise to cork and secondary cortex towards outer and inner sides respectively. The cork cambium produces periderm.
3. Movement of sugars in the phloem is explained by the pressure-flow hypothesis, which states that sugars are actively transported into sieve tubes. Water is also transpored in by osmosis. Thus, a positive pressure builds up at the source end of the sieve tube. This is the pressure part of the pressure-flow hypothesis. At the sink end of the sieve tube, this process is reversed. Sugars are actively transported out, water leaves the sieve tube by osmosis, and pressure is reduced at the sink. The difference in pressure causes water to flow from source to sink. This water is also carrying dissolved substances with it. Transport in the phloem can occors in different directions at different times.

Activity 7

1. The mesophyll is the mid-section of a leaf, located between the upper and lower epidermal layers. The mesophyll is usually divided into two conspicuously different regions, a characteristic common among the leaves of many dicotyledons. The upper section is termed the palisade parenchyma and consists chiefly of elongated columnar parenchyma cells that contain three to five times the number of chloroplasts as the cells that comprise the lower layer, known as the spongy parenchyma. The cells of the spongy parenchyma are irregularly shaped, allowing gases to circulate through the numerous air spaces between them to the palisade parenchyma. The stomata, which are particularly important for gas exchange, tend to be surrounded by exceptionally large air spaces.
2.
   - Leaves make short distances for gases to diffuse.
   - Transpiration is another function of the plant. Transpiration also benefits the plant by cooling it and by speeding the transport of mineral nutrients through the xylem.
   - They are arge area for absorption of light needed for photosynthesis.
   - Leaves are a plant’s food factory. They are the main site of photosynthesis, where sugars are made from water and carbon dioxide, using sunlight energy that has been absorbed by chlorophyll

BLOCK 7

Plant Growth and Development

Introduction

Growth is an irreversible increase in size (length, volume, mass, dry weight). Development is the coordinated sequence of cell divisions, growth, and differentiations leading to the formation of new organs and tissues.

During development there is a progressive change toward a more specialized (different) state.

In this block the orderly progression from zygote to seedling of a flowering plant will be discussed.

What is in this block?

This block has three sections:

Section 1: Flower development

Section 2: Plant embryo development

Section 3: Germination and seedling development

Section 4: Growth regulation in higher plants

Keywords
Growth
Development
Microsporogenesis
Megasporogenesis
Microgametogenesis
Megagametogenesis
Pollen
Embryo sac
Ovule
Endosperm
Gametophyte
Sporophyte
Zygote

Estimated study time

We estimate that you will need 10 hours to study the content of this block and do all activities.

Learning objectives

At the end of the block, students will be able to:

- explain the flower development process;
- describe sexual reproduction in plants;
- describe the different stages of embryo development in angiosperms;
- describe morphological changes in seed germination and seedling development ;
- discuss regulation of growth and plant development.

Section 1: Flower development

1.1. Differentiation of flower organs

Higher plants have two basic growth modes during their life cycles: vegetative growth and flower and seed growth. The above ground vegetative growth of the plant develops from the **apical meristem**. This vegetative meristem gives rise to all of the leaves that are found on the plant. The plant will maintain its vegetative growth pattern until the apical meristem undergoes a change. This change actually alters the identity of the meristem from a vegetative to an **inflorescence meristem**. The inflorescence meristem produce small leaves before it next produces **floral meristems**. It is the floral meristem from which the flower develops. The floral meristem undergoes a series of developmental changes that eventually give rise to the four basic structures of the flower: sepals, petals, stamens and carpels. Each of these structures is derived sequentially from a whorl that develops from the floral meristem in the following sequence:

Whorl 1 is the first to appear, and it develops into the sepals of the plant (see Fig.66). The second whorl develops into petals. The third and fourth whorls define the stamen (male reproductive organs) and carpel (female reproductive organs), respectively. If you move from the base of the flower upwards and inwards you will encounter the four organs in the same order in which they are developed.

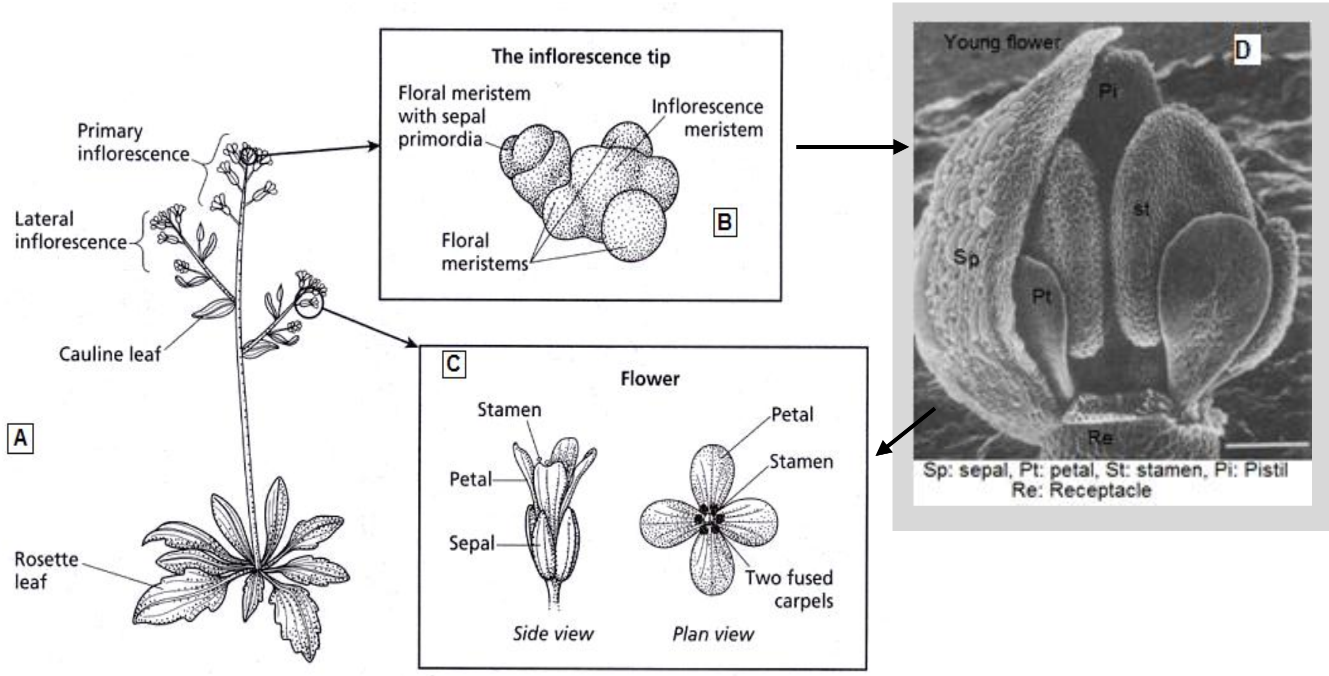


Figure 63: Flower development in *Arabidopsis thaliana.* A: A flowering plant with different developmental stages. B: inflorescence meristem and flower meristem. C: highly magnified flower bud showing the different flower organs in the four whorls. D: Magnification of a developing flower with some sepals removed to show the four whorls. (Source : www2.sluh.org/bioweb/microscopy/plantanatomy/zeamaysleafplabeled.html)

1.2. Development of anther

Each stamen or microsporophyll arises as a small papillate outgrowth of meristematic tissue from the growing tip of the floral primordium. It grows actively and soon gets differentiated into apical broader portion, the anther and the lower slender part, the filament.

Development of microsporangium (pollen sac) and the male gamete (needs to be edited as a title)

In each lobe a few cells in the hypodermal region become differentiated by their large size, radial growth, dense cytoplasm and conspicuous nuclei. They make archesporial cells which divide periclinally forming parietal layer and a primary sporogenous layer. Primary sporogenous cells continue division to give rise to a central sporogenous mass, and consecutive divisions of neighbouring cells result in the formation of three concentric parietal layers: the **tapetum** adjacent to the------ something is missing here or **microsporocytes**, a **middle layer**, and the **endothecium** subjacent to the epidermis. The sporogenous cells undergo few mitotic divisions and give rise to the **microsporocytes** or **microspore mother cells** or **pollen mother cells.**

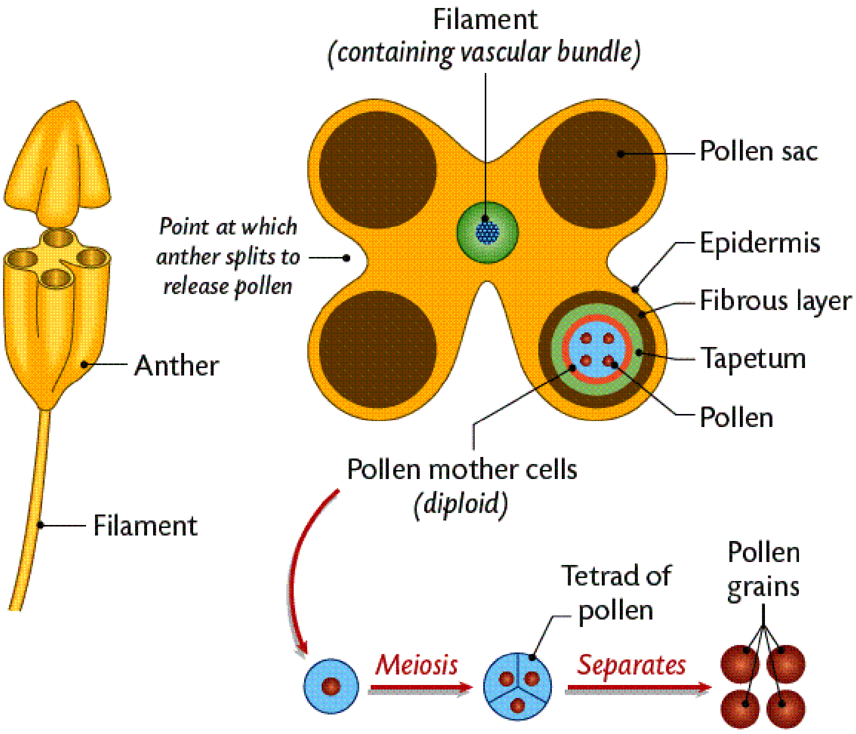


Figure 64: Anther structure and microsporogenesis.
(Source: leaving.bio.net/the structure and functions of flowers(1) html)

The microsporocytes undergo meiosis to give the tetrads of four haploid microspores which soon separate. Each microspore represents the first stage of male gametophyte. Its nucleus divides mitotically to form a vegetative nucleus (tube nucleus) and a generative nucleus; the latter gets surrounded by cytoplasm to become generative cell.

The generative cell divides to give rise to two male gametes before or after the pollen is shed. These pollen grains are, thus, 3-celled at anthesis but the division of the generative cell may occur after the pollen tube germination on the stigma. When the pollen grains are mature, the anther dries out and splits open (a process called **dehiscence**) and the pollen is released.

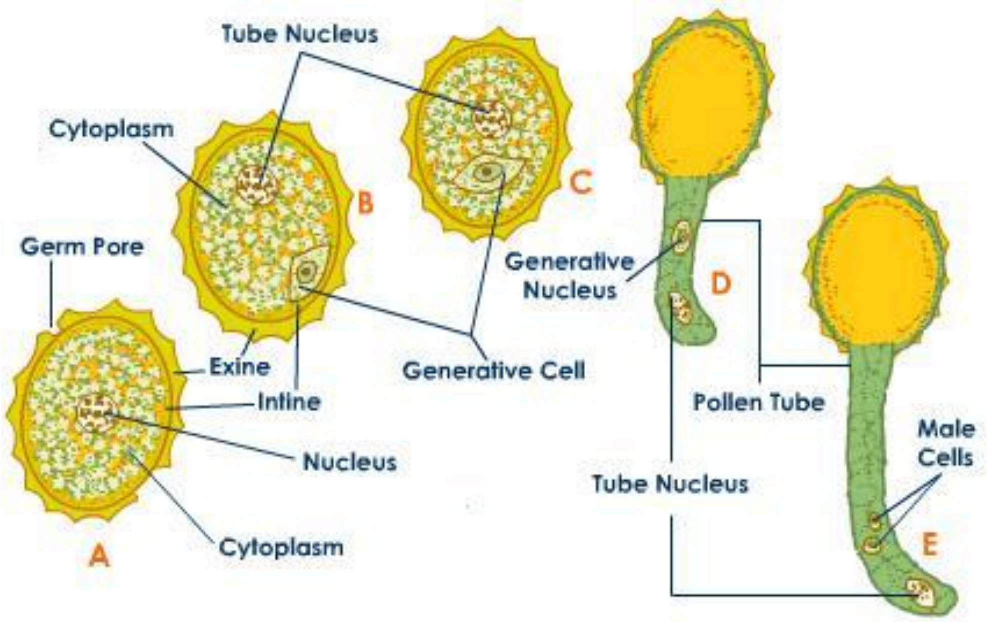


Figure 65: Microgametogenesis
(Source: nickrentlab.siu.edu/PLB400)

1.3. Development of the ovule and female gamete

An ovule or megasporangium develops from the base or inner surface of the ovary. Inside one ovary there may develop one or more ovules. Each ovule begins life as a small projection into the cavity of the ovary. As it grows and develops it begins to bend but remains attached to the ovary wall by a placenta. At the start, the ovule is a group of similar cells called the **nucellus**. As it develops, the mass of cells differentiates to form an inner and an outer **integument**, surrounding and protecting the nucellus within, but leaving a small opening called the **micropyle**. The ovule is considered to an **integumented megasporangium**. In the center of the nucellus is situated the female gametophyte which is known as **the embryo sac**.

During megasporogenesis, a diploid precursor cell in the nucellus, the **megasporocyte** or **megaspore mother cell**, undergoes meiosis to produce initially four haploid cells (**the megaspores**). Three megaspores degenerate and one that is most distant from the micropyle develops into the functional megaspore.

During megagametogenesis, this megaspore becomes larger and its nucleus undergoes mitosis three times until there are eight nuclei. These eight nuclei are then arranged into two groups of four. These groups both send a nucleus to the center of the cell which then becomes **the polar nuclei**. The three cells left at the end of the cell near the micropyle become the egg apparatus with an **egg cell** in the center and two **synergids**. A cell wall forms around the other set of nuclei and forms the **antipodals**. The cells in the center develop into the **central cell**. This entire structure with its eight nuclei is called the **embryo sac**.

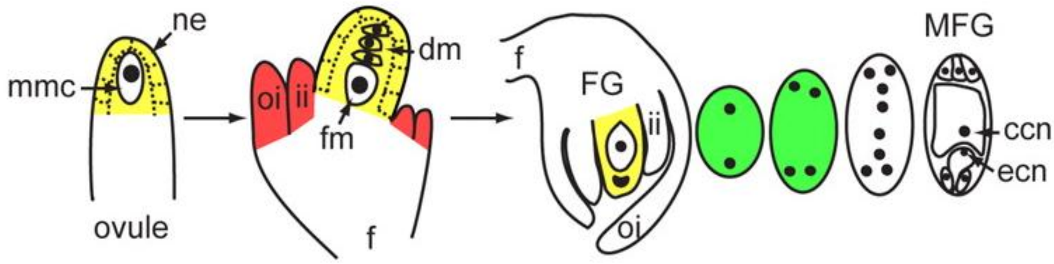


Figure 66: Megasporogenesis and megagametogenesis in *Arabidopsis* ovules. **ccn, central cell nucleus; dm, degenerating megaspores; ecn, egg cell nucleus; f, funiculus; FG, female gametophyte; fm, functional megaspore; ii, inner integument; MFG, mature FG; mmc, megaspore mother cell; ne, nucellar epidermis; oil, outer integument. (Source : www2.sluh.org/bioweb/microscopy/plantanatomy/zeamaysleafplabeled.html)**

Activity 1

1. Explain the development of floral meristems of higher plant.
2. Explain Microspogenesis.

Feedback

This section states on how microspores and megaspores develop and explain the process of gametes production in flowering plants. Read more details in your documentation to understand the whole mechanism.

Section 2: Plant embryo development

Keywords

Double fertilization

Zygote endosperm

Embryo

Cotyledon

Morphogenesis

Maturation

Development of the angiosperm embryo

In the process of **double fertilization** that is unique to angiosperms, the male gametophyte produces two sperm cells that fertilize two cells within the female gametophyte. One fertilized cell becomes the zygote, which develops into the embryo (**new sporophyte**), while the other becomes a unique triploid nutritive tissue (**endosperm**) that provides nourishment for developing embryo. The first fusion involves the sperm- oosphere nucleus. After double fertilization has taken place, the single-celled zygote lies beneath the endosperm nucleus. The triploid endosperm nucleus divides to produce a mass of endosperm tissue surrounding the developing embryo.

The basic body plan of the angiosperm laid down during embryogenesis also begins with an asymmetrical cell division, giving rise to a **terminal (or apical) cell** at the chalazal pole and a **basal cell** at the micropylar pole. The terminal cell gives rise to the **embryo proper**. The basal cell gives rise to the **suspensor**. The **hypophysis** is found at the interface between the suspensor and the embryo proper.

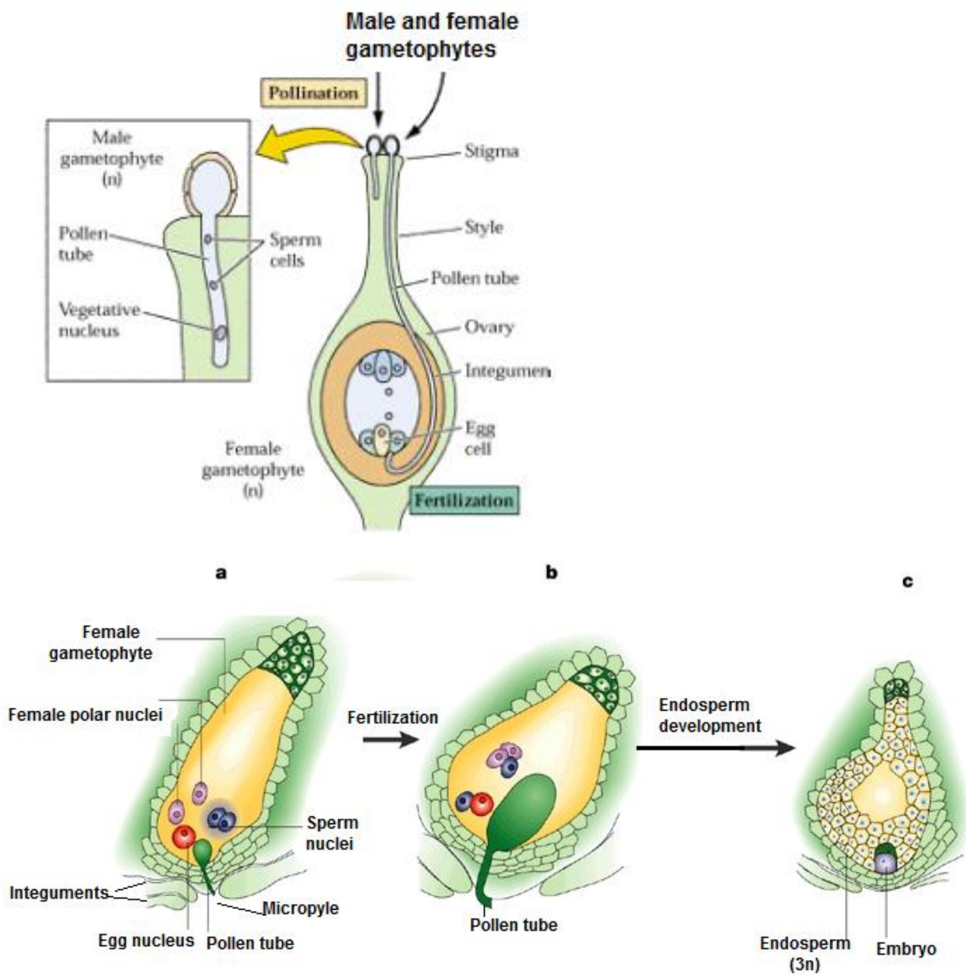


Figure 67: Schematic drawing representing the nuclear fusion in corn: the egg nucleus fuses with one sperm egg to give the zygote; the other fuses with the two polar nuclei and give a triploid endosperm which undergoes division before the embryo. (Source: wikipedia.org/wiki/ Double fertilization)

The embryo development goes through different stages (zygote, globular, heart and cotyledonary stage) as shown in Arabidopsis (Fig. 71). In this plant *Arabidopsis* which is the plant model for plant developmental studies, the zygote divides asymmetrically to produce an apical cell that develops into an embryo proper and a basal cell that generates the hypophysis and the suspensor. The hypophysis will give rise to the root quiescent center and the initials of the central root cap, whereas the suspensor is a transient organ that plays structural and physiological roles in embryo development.

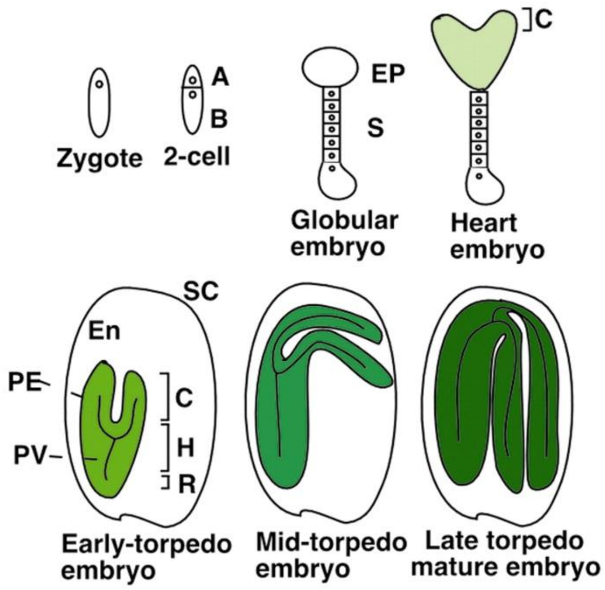


Figure 68: Schematic representation of stages of embryo development in *Arabidopsis*. The zygote divides to from an embryo composed of a filamentous suspensor (S) that maintains contact with maternal tissues, and a terminal embryo proper (EP). The embryo becomes green at the heart stage of development when chlorophyll and chloroplasts first form. The suspensor degenerates during the torpedo stage. A, apical cell; B, basal cell; C, cotyledon; PE, protoderm; PV, provascular tissues; H, hypocotyl; R, radicle; SC, seed coat; En, endosperm

(Source dev.biologists.org/content/129/1261/F_1.expension.html)

At the **cotyledonary-stage**, along the apical-basal axis are the shoot apical meristem, cotyledons, hypocotyl, radicle and the root apical meristem. Along the radial axis, the embryo consists of three primary tissues: the outer protoderm, the middle ground tissues and the inner procambium tissues. Although the basic plant body is formed during embryogenesis, the vast majority of organ and tissue formation occurs post embryonically.

Note: In angiosperms the endosperm develops from the primary endosperm nucleus formed by the fusion of two polar nuclei and a male nucleus thus, giving rise to a triploid tissue.

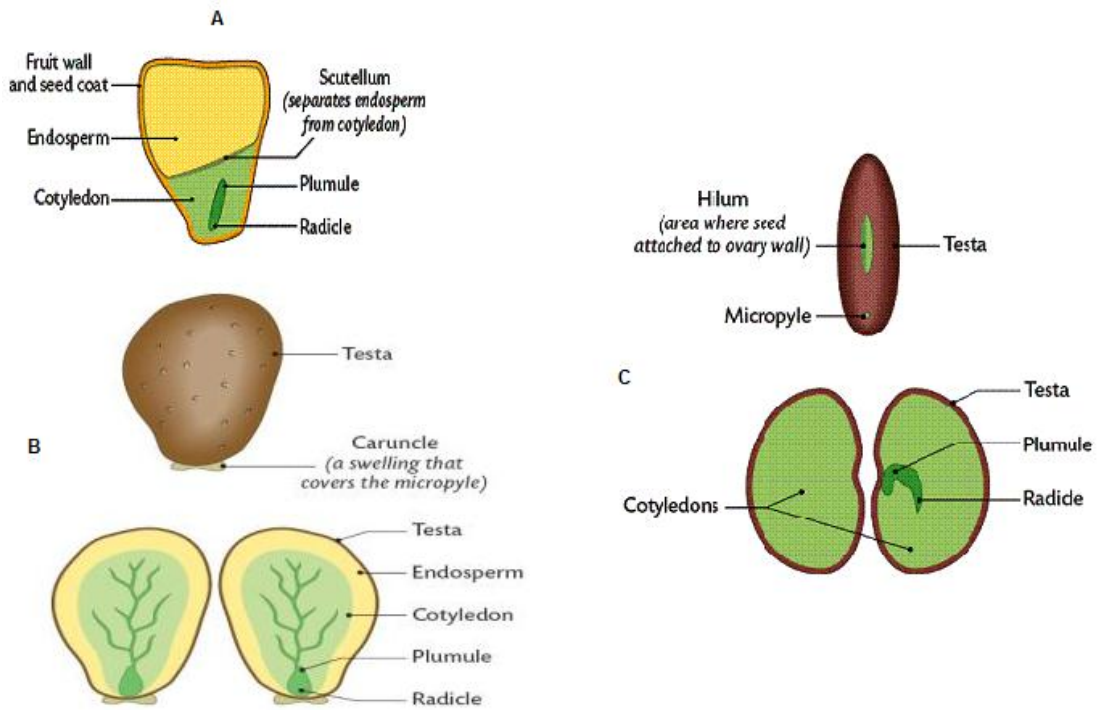


Figure 69: Albuminous seed: A (corn) and B (castor bean). Exalbiminous seed: C (bean) (Source: leavingbio.net/the structure and function of flowers.html)

Globally embryo development in higher plants can be divided into three major phases: **proembryo formation**, **morphogenesis** and **maturation**. Morphogenesis involves the establishment of the embryo's body plan, whereas maturation involves cell expansion and accumulation of storage macromolecules to prepare for desiccation, germination and early seedling growth.

Note: Fruit development is initiated by growth regulating hormones produced by developing seeds. As the ovary grows and matures into a fruit, the fruit may be regarded as matured ovary. However, in many cases the fruit is a result of development of some adjacent tissue exterior to the carpel. Such fruit are called accessory fruit (example: strawberries, apple).

Activity 2

1. What is double fertilization in angiosperms?
2. Describe the basic body plan of an angiosperm embryo.
3. Enumerate the embryo development stages in angiosperms.

Feedback

Embryo undergoes different stages during its development from zygote to mature embryo. In addition to morphological changes there are physiological changes needed to prepare a mature seed that can perpetuate the plant life cycle. Try to get more information in the literature.

Section 3: Germination and seedling development

3.1. Morphology of a seed

A seed is a small embryonic plant surrounded by a protective coat called seed coat which constituted the integument of the ovule. The structure of seeds differs among the major groups of seed plants- angiosperms. Let us consider the bean seed, a dicot exalbuminous seed. Most of the interior of a bean seed is filled by two large, fleshy cotyledons (seed leaves), which are part of the embryo. A mature bean seed has no endosperm as the endosperm was absorbed by the fleshy cotyledons. Between the two cotyledons are the parts that make up the rest of the embryo. The shoot tip along with any embryonic leaves is called the plumule. The epicotyl extends from the plumule to the attachment point of the cotyledons to the radicle or embryonic root. Along the concave edge of the seed, beneath the radicle, is the hilum, which is a scar that marks where the seed was attached to the ovary wall.

3.2. Morphological changes during seed germination:

The part of the plant that first emerges from the seed is the embryonic root, termed the radicle or primary root. The first visible sign of seed germination is the emergence of the radicle. It allows the seedling to become anchored in the ground and start absorbing water. After the root absorbs water, an embryonic shoot emerges from the seed.

- **In dicots** :the shoot comprises three main parts: the **cotyledons** (seed leaves), the section of shoot below the cotyledons (**hypocotyl**), and the section of shoot above the cotyledons (**epicotyl**). The entire root system develops from the radicle. The cotyledons will nourish the seedling for a short time, but will shrink (dry up) and die quickly once true leaves have been formed.

The way the shoot emerges differs among plant groups:

- In **epigeous (or epigeal**): germination, the hypocotyl elongates and forms a hook, pulling rather than pushing the cotyledons and apical meristem through the soil. Once it reaches the surface, it straightens and pulls the cotyledons and shoot tip of the growing seedlings into the air. Beans and papaya are examples of plants that germinate this way.

  Another way of germination is **hypogeous** (**or hypogeal**), where the epicotyl elongates and forms the hook. In this type of germination, the cotyledons stay underground where they eventually decompose. Peas, mango, avocado for example, germinate this way.

- **In most monocot seeds**: the embryo's radicle and cotyledon are covered by a coleorhiza and coleoptile, respectively. The coleorhiza is the first part to grow out of the seed, followed by the radicle. The coleoptile is then pushed up through the ground until it reaches the surface. There, it stops elongating and the first leaves emerge. Most of the root system develops from the lower part of the radicle. Soon after the radicle breaks the seed coat, the shoot begins to grow. The cotyledon of the seed remains underground and transfers nutrient from the endosperm to the growing embryo.

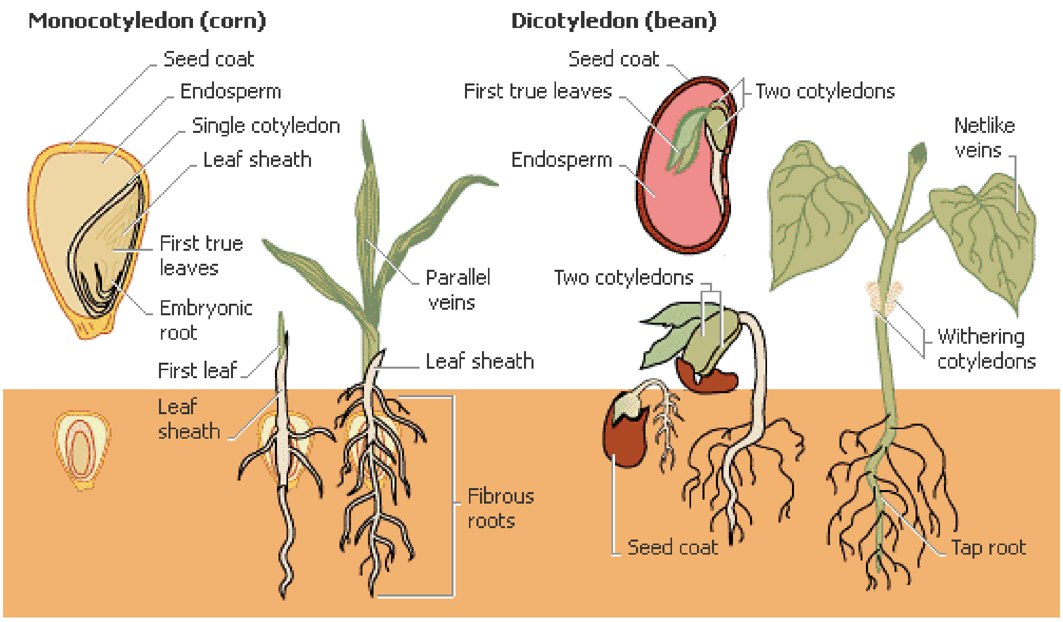


Figure 70: Morphology of a dicot and monocot mature seed and seedling. (Source: biology.unn.edu/counal/Biology-2003/ummaires/flowering-html)

Activity 3

1. Define the following:
   a) hypocotyl
   b) plumule
   c) coleoptile
2. Distinguish between epigeous and hypogeous germination and give examples for each.

Feedback

This section describes the changes observed during seed germination and how the seedling develops after germination. Later on, growth and development will continue to form a mature plant.

Section 4: Growth regulation in higher plants

4.1. Plant growth

The growth may be defined as a permanent irreversible increase in size or volume or mass accompanied by an increase in dry weight. The growth in plant does not occur indiscriminately in all regions but in meristematic regions which are found in the root and shoot apex and in the cambium (apical and lateral apex + intercalary meristems in some monocots).

Growth of the plant body takes place due to addition of new cells which are formed from the pre-existing cells by division. The daughter cells enlarge and divide again or start maturing to obtain a permanent size. In the latter case the thin stretched cell walls grow in thickness and then gradually undergo structural and physiological changes depending on their location in the plant.

Plant growth can be of two types:

- Indefinite or unlimited growth by root, stem and their branches
- Definite or limited growth exhibited by leaves, flowers, fruits, etc.

4.2. Plant growth phases

The growth of a plant or any of its organs follows a definite pattern. In graphical studies on growth, where increase in length of different plants is plotted against function of time, a sigmoid or “S”-shaped curve is obtained. This is generally referred to as growth curve. The analysis of this curve shows three distinct regions, indicating a lag phase, a log phase and a steady phase, which very well correspond to the three regions and phases of growth. During the initial stage, i.e., during the lag phase, the rate of plant growth is slow. The middle region of the curve shows the grand period or exponential period of growth where plants exhibit maximum rate of growth. After some time the growth rate slowly decreases due to limitation of nutrients. This phase constitutes the stationary phase.

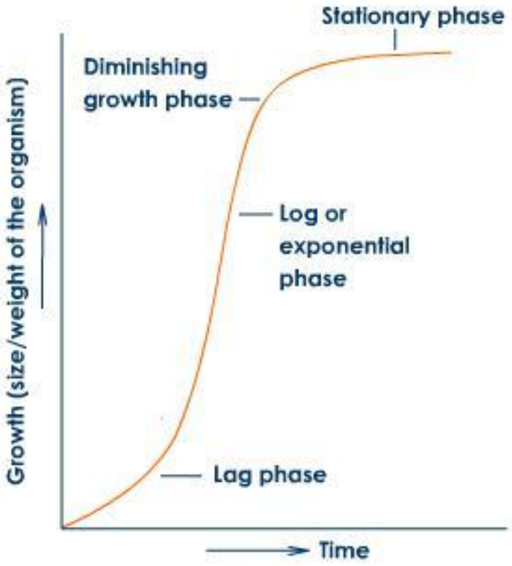


Figure 71: The growth curve with its three phases.
(Source : question ever thing.typepad.com/question everything)

4.2.1. Measurement of plant growth

Plant growth can be measured in terms of increase in length, increase in girth or volume, increase in dry or fresh weight, increase in area, increase in number of cells etc. Of all the indices of growth, measurement of the linear growth of stem has practical significance. Some of the methods of measuring the linear growth include:

- **Direct method:** the rate of growth in length can be measured at intervals using simple scales. This method can be used when long intervals are taken.
- **Auxanometer*:*** an auxanometer is an apparatus for measuring increase or rate of growth in plants. In case of an arc-auxanometer (see Fig. 75), there is a wire fixed with the plant apex on one end and a dead-weight on the other. It passes over a pulley which has a pointer attached to it. When the plant's height increases, the pulley rotates and the pointer moves on a circular scale to directly give the magnitude of growth. Sensitive auxanometers allow measurement of growth as small as a micrometer, which allows measurement of growth in response to short-term changes in atmospheric composition.

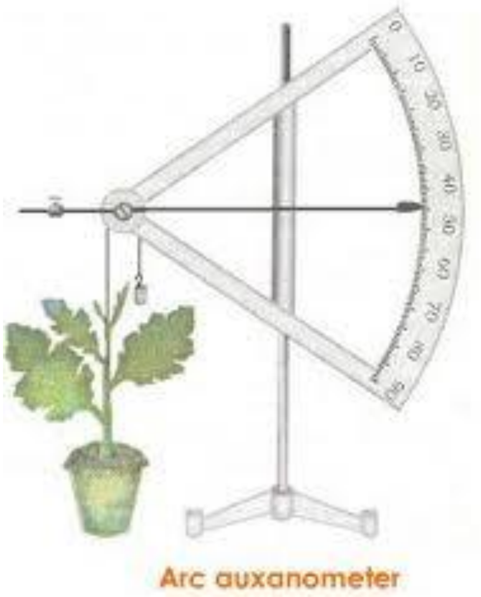


Figure 72: An arc-auxanometer to measure the growing plant size (Source:wwwtutorvista.com/content/biology-iv plant-growth-moment/growth. courve.php)

4.2.2. Factors affecting the plant growth

The rate of growth in plants depends upon several external and internal factors.

- **External factors*:*** The following are regarded as the most important: temperature, moisture supply, and radiant energy, composition of the atmosphere, soil aeration and soil structure, soil reaction, biotic factors, supply of mineral nutrients. Each can be a limiting factor in plant growth. These environmental factors do not act independently. Example: inverse relationship between soil moisture and air, soil temperature affects water and nutrient uptake, etc.
- **Internal factors:** nutrition, genetic factors, hormonal factors, inhibitors. Some other factors can hamper normal growth such as drought, abundance of water, temperature, chemicals, pathogens, radiation etc.

4.2.3. Plant growth regulators

Plant growth regulators are hormone-like chemicals that occur naturally in plants, and play a central role in their growth and development. Five major classes of plant growth regulators have been identified as plant hormones, but scientists believe that there are more waiting to be discovered.

The five growth hormones include **auxins, gibberellins, cytokinins, abscisic acid,** and **ethylene**. Collectively, they regulate many facets of plant growth and development including seed germination, root growth, stem elongation, leaf expansion, flowering, seed development, fruit ripening, and dropping of leaves and fruits.

Many growth regulators are used on ornamental plants. Some are for example used as growth retardants, weed killers or herbicides.

Activity 4

1. Describe the growth curve of a plant.
2. State any five plant growth regulators.
3. What is the commercial application of the growth regulators?

Feedback

Plant growth is regulated by phytohormones but also by many other factors as indicated in this section.

Block summary

Growth is an irreversible increase in size (length, volume, mass, dry weight). Development is the coordinated sequence of cell divisions, growth, and differentiations leading to the formation of new organs and tissues.

Flower development starts when the inflorescence meristem produce small leaves before it next produces floral meristem from which the flower develops. The floral meristem undergoes a series of developmental changes that eventually give rise to the four basic structures of the flower: sepals, petals, stamens and carpels.

In the process of double fertilization that is unique to angiosperms, the male gametophyte produces two sperm cells that fertilize two cells within the female gametophyte. The zygote undergoes division and gives successively the globular, heart, and cotyledonary stages to become a mature seed.

The basic body plan of the angiosperm laid down during embryogenesis also begins with an asymmetrical cell division, giving rise to a terminal (or apical) cell at the chalazal pole and a basal cell at the micropylar pole. Globally embryo development in higher plants can be divided into three major phases: proembryo formation, morphogenesis and maturation.

A seed is a small embryonic plant surrounded by a protective coat called seed coat which constituted the integument of the ovule. The structure of seeds differs among the major groups of seed plants-angiosperms.

The first visible sign of seed germination is the emergence of the radicle. It allows the seedling to become anchored in the ground and start absorbing water. Depending on how the shoot emerges from the soil germination can be epigeous or hypogeous. After germination the root absorbs water, an embryonic shoot emerges from the seed and the seedling develops independently by carrying out photosynthesis. The seedling growth and development into a mature flowering plant is regulated by phytohormones and other factors.

Answers to activities in block 7

Activity 1

1. Whorl 1 is the first to appear, and it develops into the sepals of the plant. The second whorl develops into petals. The third and fourth whorls define the stamen (male reproductive organs) and carpel (female reproductive organs), respectively. If one moves from the base of the flower upwards and inwards you will encounter the four organs in the same order in which they are developed.
2. Microsporogenesis is the formation of microspore (pollen grain) from microsporocyte or pollen mother cells found in the sporogenous tissue.
   Microgametogenesis is the formation of male gametes by mitosis of the generative cell nucleus present inside the microspore (pollen grain).

Activity 2

1. The basic body plan of the angiosperm laid down during embryogenesis also begins with an asymmetrical cell division, giving rise to a terminal (or apical) cell at the chalazal pole and a basal cell at the micropylar pole. The terminal cell gives rise to the embryo proper. The basal cell gives rise to the suspensor. The hypophysis is found at the interface between the suspensor and the embryo proper.
2. The embryo sac ordinarily consists of seven cells and eight nuclei: egg along with two adjacent short-lived synergids near the micropyle opening where the pollen will enter, two central nuclei which will combine with one of the pollen nuclei to form the triploid endosperm nucleus, and three antipodal nuclei at the chalazal end of the embryo sac opposite the micropyle.
3. Zygote, globular embryo, heart-shaped embryo and cotyledonary

Activity 3

1. Definitions:

   a) **Hypocotyl**: the part of the stem of an embryo plant beneath the stalks of the seed leaves, or cotyledons, and directly above the root.

   b) **Plumule:** The shoot tip along with any embryonic leaves

   c) **Coleoptile**: A sheath protecting a young shoot tip in a grass or cereal

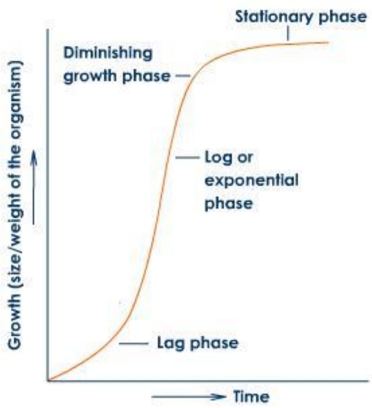
2.

   - In **epigeous** germination, the hypocotyl elongates and forms a hook, pulling rather than pushing the cotyledons and apical meristem through the soil. Once it reaches the surface, it straightens and pulls the cotyledons and shoot tip of the growing seedlings into the air. Examples: beans, papaya

- In is **hypogeous** germination the epicotyl elongates and forms the hook, the cotyledons stay underground where they eventually decompose. Examples: peas, mango, avocado.

Activity 4

1. The growth of a plant or any of its organs follows a definite pattern. In graphical studies on growth, where increase in length of different plants is plotted against function of time, a sigmoid or "S"-shaped curve is obtained. This is generally referred to as growth curve. The analysis of this curve shows three distinct regions, indicating a lag phase, a log phase and a steady phase, which very well correspond to the three regions and phases of growth. During the initial stage, i.e., during the lag phase, the rate of plant growth is slow. The middle region of the curve shows the grand period or exponential period of growth where plants exhibit maximum rate of growth. After some time the growth rate slowly decreases due to limitation of nutrients. This phase constitutes the stationary phase.



2. Five growth hormones: auxins, gibberellins, cytokinins, abscisic acid, and ethylene
3. They can be to improve productivity. They are used as growth inducers, retardants, weed killers or herbicides.

BLOCK 8

Plant nutrition

Introduction

Plant nutrition is the study of the chemical elements and compounds that are necessary for plant growth, and also of their external supply and internal metabolism.

Every organism is an open system connected to its environment by a continuous exchange of energy and materials. In the energy flow and chemical cycling that keep an ecosystem alive, plants and other photosynthetic autotrophs perform the key step of transforming inorganic compounds into organic ones. At the same time, a plant needs sunlight as its energy source for photosynthesis and raw materials, such as CO_2 and inorganic ions, to synthesize organic molecules. The root and shoot systems extensively network a plant with its environment.

This block focuses on how gases are exchanged and how nutrients are transported and used by the plant to manufacture their organic molecules.

What is in this block?

This block is in 3 sections:

Section 1: Transport of water and nutrients in vascular plants

Section 2: Gas exchange and transpiration

Section 3: Photosynthesis

Estimated study time

We estimate that you will need 10 hours to study the content of this block and do all activities.

Learning objectives

At the end of the block, students will be able to:

- explain the mechanism of water absorption and mineral nutrition;
- explain the role of macro-elements and micro-elements of the nutrition of plants;
- explain the mechanism of plant transpiration;
- describe the role that chlorophylls and the other pigments found in chloroplasts play to initiate the light-dependent reactions;
- explain the role of the two energy-carrying molecules produced in the light-dependent reactions (ATP and NADPH) in the light-independent reactions;
- describe the Calvin-Benson cycle in terms of its reactants and products;
- explain how C-4 photosynthesis provides an advantage for plants in certain environments;
- measure physiological processes in plant under given environmental conditions.

Section 1: Transport of water and nutrients in vascular plants

Keywords
Macronutrients
Micronutrients
Mineral uptake
Symplast
Apoplast
Translocation
Transpiration
Photosynthesis
Light reaction
Dark reaction

Plants receive mineral nutrients from the soil, air and water. The 13 most important plant nutrients include macronutrients and micronutrients. They come from the soil, are dissolved in water and absorbed through a plant's roots. Macronutrients are nutrients like nitrogen and calcium which plants require in large quantities. They can be primary nutrients or secondary nutrients. Primary nutrients include nitrogen, phosphorus and potassium. These major nutrients usually are lacking from the soil first because plants use large amounts for their growth and survival. The secondary nutrients are Ca, Mg and S. These can be obtained through lime, or through the decomposition of grass clippings and leaves.

Micronutrients, minor elements or trace elements, are minerals needed for plant growth but in very small quantities. These include B, Cu, Fe, Cl, Mn, Mo and Zn. Fertilizers and recycled grass and leaves can provide these nutrients.

Non-mineral nutrients like hydrogen, oxygen and carbon are obtained through photosynthesis. Some nutrients are able to travel to deficient areas in the plant. For example, mobile nutrients will often move from older, established leaves to new, young leaves, which require additional nutrients in order to grow properly.

1.1. Mineral uptake

One might have expected that minerals would enter the root dissolved in water. But, in fact, minerals enter separately:

- Even when no water is being absorbed, minerals enter freely, mostly through the root hairs.
- Minerals can enter against their concentration gradient; that is, by active transport.
- The root hairs are also the point of entry of mycorrhizal fungi. These transport minerals, especially phosphorus, to the root hair in exchange for carbohydrates from the plant.
- In legumes, the root hairs are the point of entry of rhizobia that will establish the mutualistic partnership enabling the plant to convert atmospheric nitrogen into protein.

The plants absorb their nutrients in inorganic form. For example:

- nitrogen enters as nitrate (NO_3^-) or ammonium ions (NH_4^+)
- phosphorus as PO_4^{3-}
- potassium as K^+
- calcium as Ca^{2+}

Organic matter does play an important role in making good soil texture, but only to the extent that it can yield inorganic ions can it meet the nutritional needs of the plant. Once within the epidermis, inorganic ions pass inward from cell to cell, probably through plasmodesmata. The final step from the cytoplasm of the pericycle cells to the xylem is probably accomplished once again by active transport.

1.2. Transport of water and minerals in plants

Most plants secure the water and minerals they need from their roots. The path taken is: soil -> roots -> stems -> leaves. The minerals (e.g., K^+, Ca^{2+}) travel dissolved in the water (often accompanied by various organic molecules supplied by root cells). Less than 1% of the water reaching the leaves is used in photosynthesis and plant growth. Most of it is lost in transpiration. However, transpiration does serve two useful functions:

1. It provides the force for lifting the water up the stems.
2. It cools the leaves.

Water and minerals enter the root by separate paths which eventually converge in the stele.

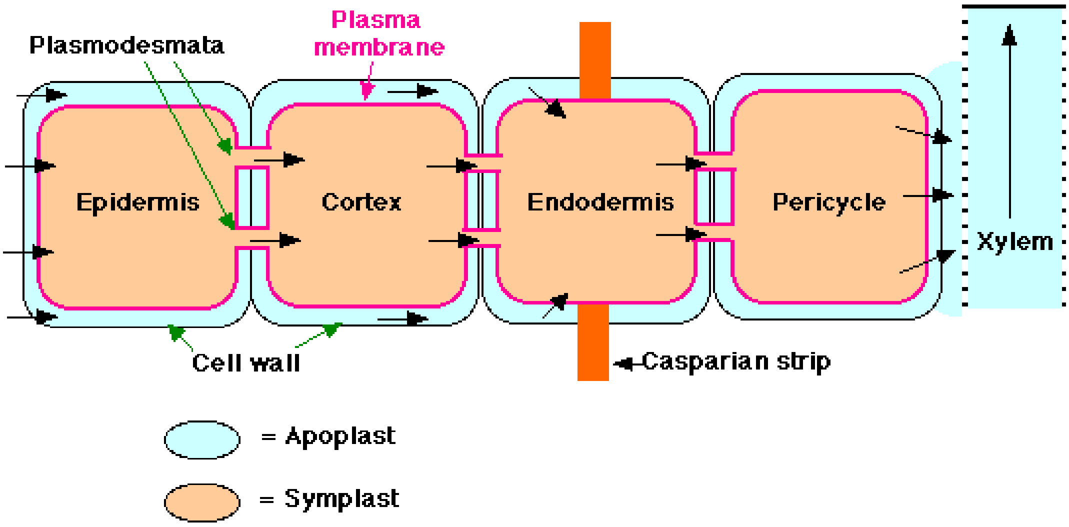


Figure 73: The pathway of water
(Source:users.rcn.com / kimball.ma. ultranet/biologypages/x/xylem.html)

Soil water enters the root through its epidermis. It appears that water then travels in both:

- The cytoplasm of root cells, called the **symplast,** that is, it crosses the plasma membrane and then passes from cell to cell through plasmodesmata.
- In the nonliving parts of the root, called the **apoplast**, that is, in the spaces between the cells and in the cells walls themselves. This water has not crossed a plasma membrane.

However, the inner boundary of the cortex, the **endodermis**, is impervious to water because of a band of lignified matrix called the **casparian strip**. Therefore, to enter the stele, apoplastic water must enter the symplasm of the endodermal cells. From here it can pass by **plasmodesmata** into the cells of the stele. Once inside the stele, water is again free to move between cells as well as through them. In young roots, water enters directly into the **xylem** vessels and/or tracheids. These are nonliving conduits so they are part of the apoplast.

Once in the xylem, water with the minerals that have been deposited in it (as well as occasional organic molecules supplied by the root tissue) move up in the vessels and tracheids.

At any level, the water can leave the xylem and pass laterally to supply the needs of other tissues. At the leaves, the xylem passes into the petiole and then into the veins of the leaf. Water leaves the finest veins and enters the cells of the spongy and palisade layers. Here some of the water may be used in metabolism, but most is lost in transpire.

Activity 1

1. Define a macronutrient and enumerate the primary macronutrients.
2. What is the way traveled by water from the soil to the leaves?

Feedback

This section explains how the water move from the soil to the all the parts of a plant. This water is highly needed by all the organs but especially for photosynthesis in the green parts of the plant.

Section 2: Gas exchange and transpiration

Keywords

Evaporation
Transpiration
Respiration
Stomata
Photometer

2.1. Gas exchange in plants

In order to carry on photosynthesis, green plants need a supply of **carbon dioxide** and a means of disposing of oxygen. In order to carry on cellular respiration, plant cells need **oxygen** and a means of disposing of carbon dioxide (just as animal cells do). Unlike animals, plants have no specialized organs for gas exchange (with the few inevitable exceptions!). There are several reasons they can get along without them:

- Each part of the plant takes care of its own gas exchange needs. Although plants have an elaborate liquid transport system, it does not participate in gas transport.
- Roots, stems, and leaves respire at rates much lower than are characteristic of animals. Only during photosynthesis are large volumes of gases exchanged, and each leaf is well adapted to take care of its own needs.
- The distance that gases must diffuse in even a large plant is not great. Each living cell in the plant is located close to the surface. While obvious for leaves, it is also true for stems. The only living cells in the stem are organized in thin layers just beneath the bark. The cells in the interior are dead and serve only to provide mechanical support.
- Most of the living cells in a plant have at least part of their surface exposed to air. The loose packing of parenchyma cells in leaves, stems, and roots provides an interconnecting system of air spaces. Gases diffuse through air several thousand times faster than through water. Once oxygen and carbon dioxide reach the network of intercellular air spaces (arrows), they diffuse rapidly through them.
- Oxygen and carbon dioxide also pass through the cell wall and plasma membrane of the cell by diffusion.

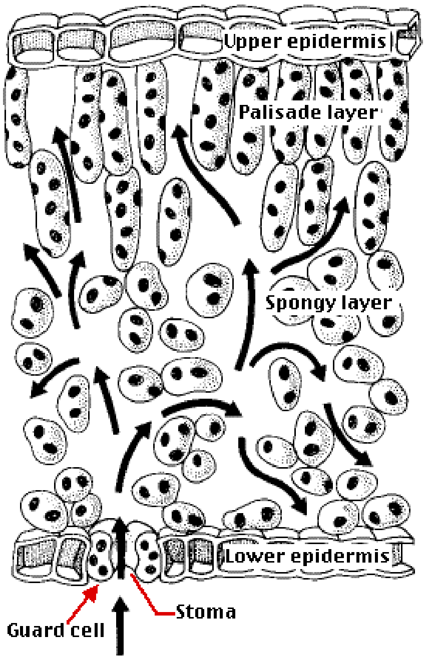


Figure 74: Gases movement in a leaf
(Source:users.rcn.com / jkimball.ma. ultranet/biologypages/G/ bas exchange html.)

2.2. Movement of stomata

The exchange of oxygen and carbon dioxide in the leaf (as well as the loss of water vapor in **transpiration**) occurs through pores called **stomata**.

Sunny, warm, dry, windy weather all increase evaporation. Guard cells control stomata by keeping stomata open during day and closed at night. Normally stomata open when the light strikes the leaf in the morning and close during the night.

The opening and closing of the water-loosing stomata is regulated by guard cells that, in turn, are regulated by uptake of potassium ions. As guard cells change shape, stomata open and close. Greater bowing of the guard cells during turgor increases the size of the stomata opening. As surrounding cells become flaccid, bowing decreases and the stomata closes. Due to radial orientation of microfibrils in the guard cells, the guard cell length increases more than its width during turgor. Changes in guard cell turgor are regulated by the passage of potassium ions across the plasma and vacuolar membranes. This is assisted by the uptake of anions, such as malate and chloride.

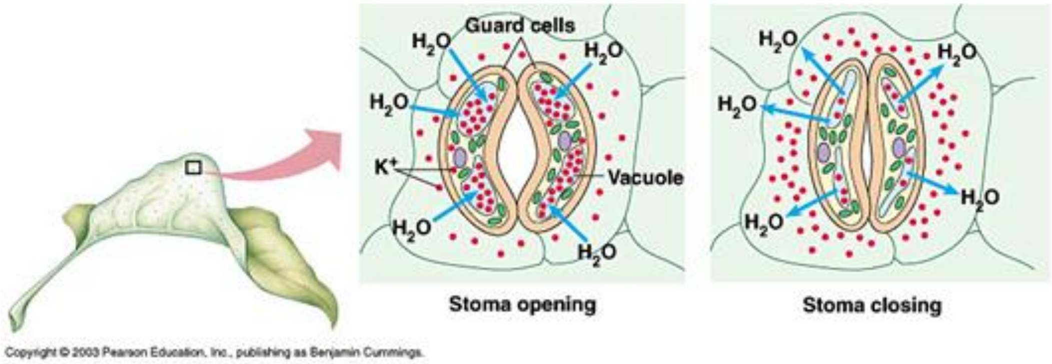


Figure 75: Stomatal movement in a leaf
Source:www.uic.ed/classes/bios/bios100/lectures04am/lect19.html

2.3. Plant transpiration

2.3.1. Mechanisms of plant transpiration

Transpiration is the evaporation of water from plants. It occurs chiefly at the leaves while their stomata are open for the passage of CO_2 and O_2 during photosynthesis. But air that is not fully saturated with water vapor (100% relative humidity) will dry the surfaces of cells with which it comes in contact. So the photosynthesizing leaf loses substantial amount of water by evaporation. This transpired water must be replaced by the transport of more water from the soil to the leaves through the xylem of the roots and stem as shown on Figure 79 and Figure 80 below.

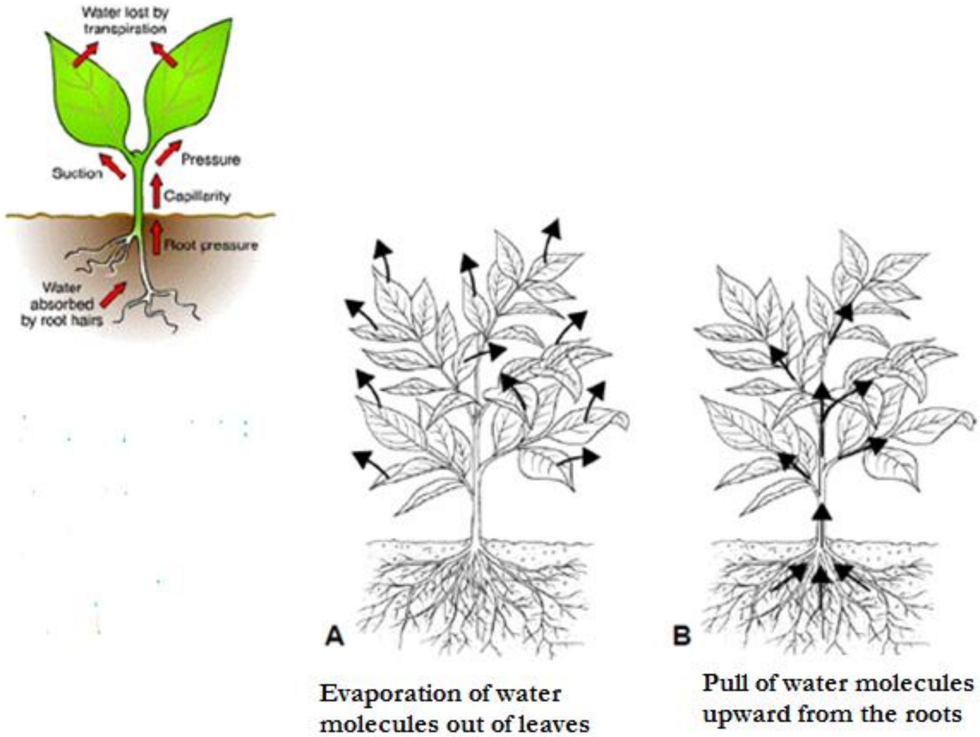


Figure 76: Plant transpiration
(Source: www. meritnation.com/ask-answer/question/explain-ascent-of sap)

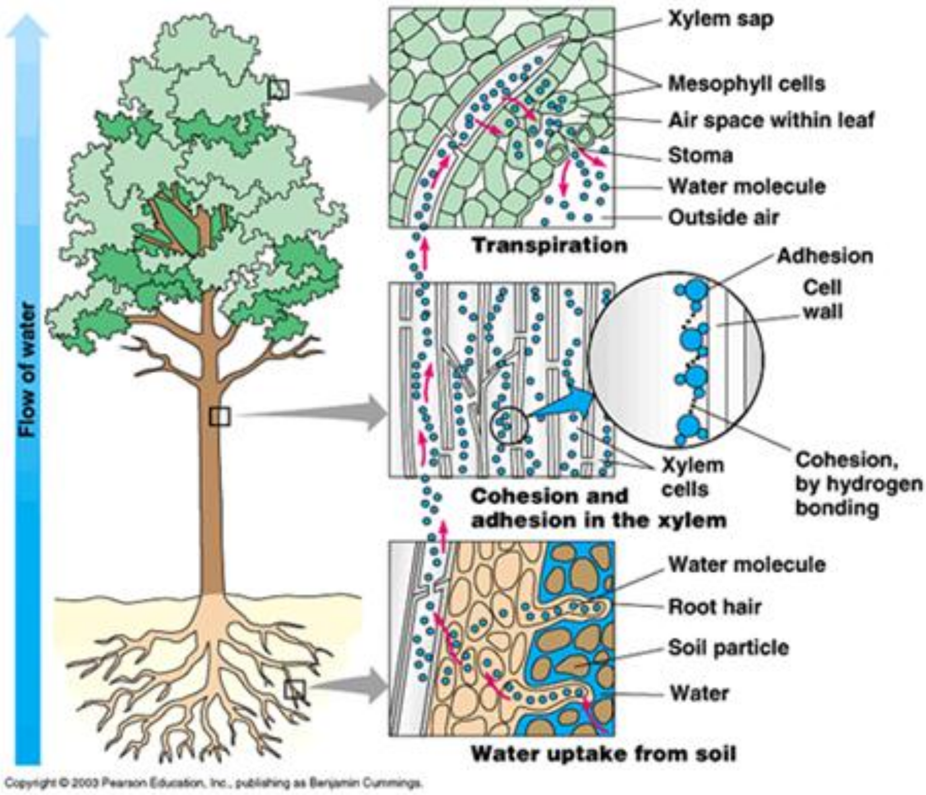


Figure 77: Water flow during plant transpiration
(Source: www. meritnation.com/ask-answer/question/explain-ascent-of sap)

Transpiration exerts an upward pull of water molecules due to diffusion. The "string" of water is held together by cohesion and is helped upward by adhesion. This phenomenon is known as "transpiration-cohesion-adhesion mechanism".

2.3.2. Importance of transpiration

Transpiration is not simply a hazard of plant life. It is the "engine" that pulls water up from the roots to:

- supply photosynthesis (1%-2% of the total);
- bring minerals from the roots for biosynthesis within the leaf; cool the leaf.

2.3.3. Measuring the rate of transpiration

Using a potometer (right), one can study the effect of various environmental factors on the rate of transpiration. As water is transpired or otherwise used by the plant, it is replaced from the reservoir on the right. This pushes the air bubble to the left providing a precise measure of the volume of water used.

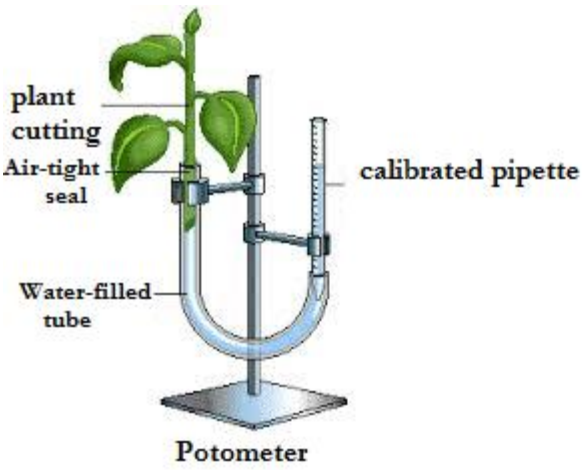


Figure 78: Measurement of transpiration rate by a potometer

2.3.4. Environmental factors that affect the rate of transpiration

- **Light:** plants transpire more rapidly in the light than in the dark. This is largely because light stimulates the opening of the stomata (mechanism). Light also speeds up transpiration by warming the leaf.
- **Temperature:** plants transpire more rapidly at higher temperatures because water evaporates more rapidly as the temperature rises. At 30°C, a leaf may transpire three times as fast as it does at 20°C.
- **Humidity:** the rate of diffusion of any substance increases as the difference in concentration of the substances in the two regions increases. When the surrounding air is dry, diffusion of water out of the leaf goes on more rapidly.
- **Wind:** when there is no breeze, the air surrounding a leaf becomes increasingly humid thus reducing the rate of transpiration. When a breeze is present, the humid air is carried away and replaced by drier air.
- **Soil water:** A plant cannot continue to transpire rapidly if its water loss is not made up by replacement from the soil. When absorption of water by the roots fails to keep up with the rate of transpiration, loss of turgor occurs, and the stomata close. This immediately reduces the rate of transpiration (as well as of photosynthesis). If the loss of turgor extends to the rest of the leaf and stem, the plant wilts.

  The volume of water lost in transpiration can be very high. It has been estimated that over the growing season, one acre of corn (maize) plants may transpire 400,000 gallons (1.5 million liters) of water.

Activity 2

1. What type of environmental conditions would increase transpiration?
2. How do stomata open and close?

Feedback

Transpiration is the process of water movement through a plant and its evaporation from aerial parts especially from leaves but also from stems and flowers. This phenomenon is affected by several factors as shown in this section.

Section 3: Photosynthesis

Keywords

Energy transformation

Photon

Photosystem

Chlorophyll

Accessory pigments

Chloroplast

Thylakoid

RuBisCO

Photorespiration

Photsynthesis is the process by which plants, some bacteria, and some protistans use the energy from sunlight to produce sugar, which cellular respiration converts into ATP, the "fuel" used by all living things. The conversion of unusable sunlight energy into usable chemical energy is associated with the actions of the green pigment chlorophyll. Most of the time,the photosynthetic process uses water and release the oxygen that we absolutely must have to stay alive.

In plants, photosynthesis is used to convert light energy from sunlight into chemical energy (glucose). Carbon dioxide, water, and light are used to make glucose, oxygen, and water. Photosynthesis is not a single chemical reaction, but rather a set of chemical reactions.

The process of photosynthesis is divided into two main parts: **light dependent reactions** and **light-independent or dark reactions**. The light-dependent reaction happens when solar energy is captured to make a molecule called ATP (adenosine triphosphate). The dark reaction happens when the ATP is used to make glucose (the Calvin Cycle).

The overall reaction of photosynthesis is:
$6CO_2 + 12H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

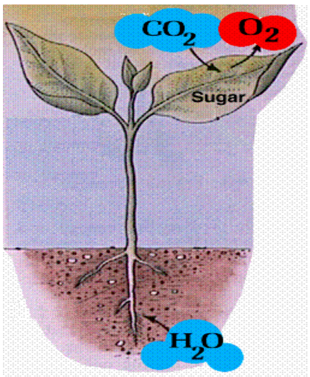


Figure 79: Diagram of a typical plant, showing the inputs and outputs of the photosynthetic process.
(Source: Purves *et al.*)

The reactions for photosynthesis take place in different areas of the chloroplast. The chloroplast has three membranes (inner, outer, thylakoid) and is divided into three compartments (stroma, thylakoid space, inter-membrane space). Dark reactions occur in the stroma. Light reactions occur in the thylakoid membranes.

In plants, photosynthesis usually occurs in the leaves. This is where plants can get the raw materials for photosynthesis all in one convenient location. Carbon dioxide and oxygen enter/exit the leaves through stomata. Water is delivered to the leaves from the roots through a vascular system. The chlorophyll in the chloroplasts inside leaf cells absorbs sunlight.

3.1. Chlorophyll and accessory pigments

A pigment is any substance that absorbs light. The color of the pigment comes from the wavelengths of light reflected (in other words, those not absorbed). Chlorophyll, the green pigment common to all photosynthetic cells, absorbs all wavelengths of visible light except green, which it reflects to be detected by our eyes. Black pigments absorb all of the wavelengths that strike them. White pigments/lighter colors reflect all or almost all of the energy striking them. Pigments have their own characteristic absorption spectra, the absorption pattern of a given pigment.

Chlorophyll is a key molecule for photosynthesis, though other carotenoid pigments (accessory pigments) also participate. There are four types of chlorophyll: a, b, c, and d.

Although we normally think of plants as having chlorophyll and performing photosynthesis, many microorganisms use this molecule, including some prokaryotic cells. In plants, chlorophyll is found in a special structure, which is called a chloroplast.

Accessory pigments are light-absorbing compounds, found in photosynthetic organisms,that work in conjunction with chlorophyll a. They include other forms of this pigment, such as chlorophyll b in green algal and higher plant antennae, while other algae may contain chlorophyll c or d. In addition, there are many non-chlorophyll accessory pigments, such as carotenoids or phycobiliproteins, which also absorb light and transfer that light energy to photosystem chlorophyll. Some of these accessory pigments, in particular the carotenoids, also serve to absorb and dissipate excess light energy, or work as antioxidants.

3.2. The light-dependent reactions

Not all wavelengths of light are absorbed during photosynthesis. Green, the color of most plants, is actually the color that is reflected. The light that is absorbed splits water into hydrogen and oxygen:

H_2O + light energy → ½ O_2 + $2H^+$ + 2 electrons

1. Excited electrons from Photo system I can use an electron transport chain to reduce oxidized P_{700}. This sets up a proton gradient, which can generate ATP. The end result of this looping electron flow, called cyclic phosphorylation, is the generation of ATP and P_{700}.
2. Excited electrons from Photosystem I could flow down a different electron transport chain to produce NADPH, which is used to synthesize carbohydrates. This is a noncyclic pathway in which P_{700} is reduced by an excited electron from Photosystem II.
3. An excited electron from Photosystem II flows down an electron transport chain from excited P_{680} to the oxidized form of P_{700}, creating a proton gradient between the stroma and thylakoids that generates ATP. The net result of this reaction is called noncyclic photophosphorylation.
4. Water contributes the electron that is needed to regenerate the reduced P_{680}. The reduction of each molecule of $NADP^+$ to NADPH uses two electrons and requires four photons. Two molecules of ATP are formed by the energy provided by the movement of protons from inside the thylakoid to the stroma through the ATP synthase complex.

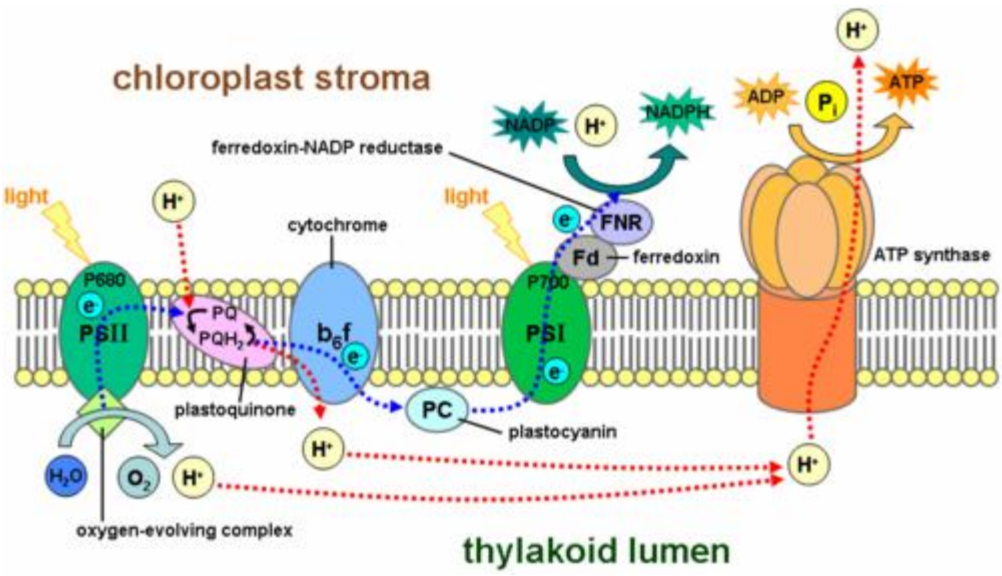


Figure 80: The light-dependent reactions and their output: NADPH and ATP are produced. (Source: http://upload.wikimedia.org/wikipedia/commons/thumb/1/18/Thylakoid_membrane.png)

3.3. The light-independent reactions or dark reactions

Dark reactions do not require light, but they are not inhibited by it, either. For most plants, the dark reactions take place during daytime. The dark reaction occurs in the stroma of the chloroplast. This reaction is called **carbon fixation** or the **Calvin cycle** (see Figure 84).

RibuloseBisphosphate Carboxylase (RuBP Carboxylase) catalyzes CO_2 fixation:

Ribulose-1,5-bisphosphate(RuBP) + CO_2 → 2 copies of 3-phosphoglycerate

Because it can alternatively catalyze an oxygenase reaction, the enzyme is also called RuBP Carboxylase/Oxygenase (**RuBisCO**). It is the most abundant enzyme on earth.

In this reaction, carbon dioxide is converted to sugar using ATP and NADPH. Carbon dioxide is combined with a 5-carbon sugar to form a 6-carbon sugar. The 6-carbon sugar is broken into two sugar molecules, glucose and fructose, which can be used to make sucrose.

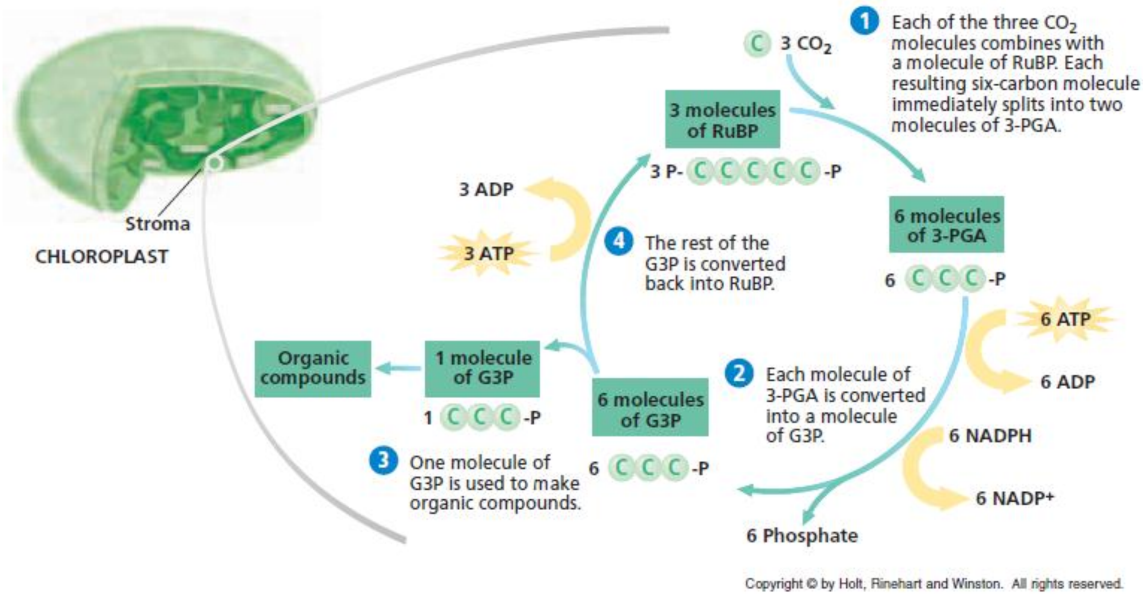


Figure 81: The Calvin cycle in which carbon is fixed into organic compounds takes place in the stroma of the chloroplast.
(Source: Postlethwait and Hopson)

3.4. C4 and CAM plant adaptation

C_4 fixation is an elaboration of the more common C_3 carbon fixation and is believed to have evolved more recently. C_4 and CAM (crassulacean acid metabolism) overcome the tendency of the enzyme RuBisCO to wastefully fix oxygen rather than carbon dioxide in what is called photorespiration. This is achieved by using a more efficient enzyme to fix CO_2 in mesophyll cells and shuttling this fixed carbon via malate or aspartate to bundle-sheath cells. In these bundle-sheath cells, RuBisCO is isolated from atmospheric oxygen and saturated with the CO_2 released by decarboxylation of the malate or oxaloacetate. These additional steps, however, require more energy in the form of ATP. Because of this extra energy requirement, C_4 plants are able to more efficiently fix carbon in only certain conditions, with the more common C_3 pathway being more efficient in other conditions. C_4 plants produce carbohydrates more efficiently than normal C_3 plants, provided the carbon dioxide is limiting and sufficient light is available to support the reaction. C_4 plants thrive in hot, dry climates.

Crassulacean acid metabolism, also known as **CAM photosynthesis**, is another carbon fixation pathway that evolved in some plants as an adaptation to arid conditions. In a plant using full CAM, the stomata in the leaves remain shut during the day to reduce evapotranspiration, but open at night to collect carbon dioxide (CO_2). The CO_2 is stored as the four-carbon acid malate, and then used during photosynthesis during the day. The pre-collected CO_2 is concentrated around the enzyme RuBisCO, increasing photosynthetic efficiency.

Activity 3

1. What are the inputs and outputs of the light reaction?
2. What three events do occur during the light reactions of photosynthesis?
3. What role do NADPH and ATP play in photosynthesis?

Feedback

Photosynthesis is arguably the most important biological process on earth. Directly or indirectly, photosynthesis fills all of our food requirements and many of our needs for fiber and building materials but also provides with us oxygen that we breathe. Read more about this important process.

Block summary

Most plants secure the water and minerals they need through their roots from the environment. Less than 1% of the water reaching the leaves is used in photosynthesis and plant growth. Most of it is lost in transpiration. Transpiration is the evaporation of water from plants. It occurs chiefly at the leaves while their stomata are open for the passage of CO_2 and O_2 during photosynthesis. This transpired water must be replaced by the transport of more water from the soil to the leaves through the xylem of the roots and stem. The volume of water lost in transpiration can be very high. It has been estimated that over the growing season, one acre of corn (maize) plants may transpire 400,000 gallons (1.5 million liters) of water.

In order to carry out photosynthesis, green plants need a supply of carbon dioxide and a means of disposing of oxygen. Photosynthesis is the process by which plants, some bacteria, and some protistans use the energy from sunlight to produce sugar, which cellular respiration converts into ATP, the "fuel" used by all living things. Photosynthesis is also two stage process. The first process is the light-dependent process (light reactions), requires the direct energy of light to make energy carrier molecules that are used in the second process. The second is the light-independent process (or dark reactions) occurs when the products of the light reaction are used to form C-C covalent bonds of carbohydrates. The dark reactions can usually occur in the dark, if the energy carriers from the light process are present. The light reactions occur in the grana and the dark reactions take place in the stroma of the chloroplasts.

The three types of photosynthesis are C3, C4, and CAM. C3 photosynthesis is the typical photosynthesis that most plants use. C4 and CAM photosynthesis are both adaptations to arid conditions because they result in better water use efficiency. In addition, CAM plants can "idle," saving precious energy and water during harsh times, and C4 plants can photosynthesize faster under the desert's high heat and light conditions than C3 plants because they use an extra biochemical pathway and special anatomy to reduce photorespiration.

Answers of activities in block 8

Activity 1

1. Macronutrient: a substance required in relatively large amounts by living organisms. The primary macronutrients for the plants are nitrogen, phosphorus and potassium
2. Water then travels in both symplast and apoplast. The cytoplasm of root cells, called the symplast, that is, it crosses the plasma membrane and then passes from cell to cell through plasmodesmata. In the nonliving parts of the root, called the apoplast, that is, in the spaces between the cells and in the cells walls themselves. This water has not crossed a plasma membrane.

   To enter the stele, apoplastic water must enter the symplasm of the endodermal cells. From here it can pass by plasmodesmata into the cells of the stele. Once inside the stele, water is again free to move between cells as well as through them. In young roots, water enters directly into the xylem vessels and/or tracheids. Once in the xylem, water with the minerals that have been deposited in it (as well as occasional organic molecules supplied by the root tissue) move up in the vessels and tracheids. At any level, the water can leave the xylem and pass laterally to supply the needs of other tissues. At the leaves, the xylem passes into the petiole and then into the veins of the leaf. Water leaves the finest veins and enters the cells of the spongy and palisade layers. Here some of the water may be used in metabolism, but most is lost in transpire.

Activity 2

1. Sunny, warm, dry, windy weather all increase evaporation
2. The opening and closing of the water-loosing stomata is regulated by guard cells that, in turn, are regulated by uptake of potassium ions. As guard cells change shape, stomata open and close. Greater bowing of the guard cells during turgor increases the size of the stoma opening. As guard cells change shape, stomata open and close. Greater bowing of the guard cells during turgor increases the size of the stoma opening. As surrounding cells become flaccid, bowing decreases and the stoma closes. Due to radial orientation of microfibrils in the guard cells, the guard cell length increases more than its width during turgor

Activity 3

1. The three events of the light reactions are: oxidation of water, reduction of $NADP^+$, synthesis of ATP from ADP and P_i
2. The inputs and outputs of the light reaction are respectively ADP, NADP, and sunlight and outputs are ATP, NADPH and oxygen.
3. NADPH provides hydrogen in the photosynthesis process. The hydrogen ions are used to make ATP by the ATP synthase complex. This ATP will be used in the Calvin cycle when carbon is fixed.

Module summary

Plants are complex organisms and are found in all habitats: humid zones, deserts, rocks, water and contribute to form simple or complex ecosystems on Earth.

They are classified and named according to principles established by scientists and the molecular classification system is the most reliable system today. By using the different modern systems of classification, plants are divided into 3 categories: bryophytes, pteridophytes and spermatophytes with several phyla in each group.

Algae have chloroplasts and produce their own carbohydrates by photosynthesis, as plants do. Due to their phylogenetic position, the green algae are considered as ancestors of plants and older classification systems placed Algae in the Plantae kingdom. Currently they are placed in which kingdom???

Bryophytes or **non vascular plants** are small land plants which still display dependence to water availability for their life. The sporophyte of Bryophytes is relatively reduced and is parasitic on the gametophyte issued from spore germination. The gametophyte is very conspicuous and dominates the life cycle. The major groups of Bryophytes include the three phyla Bryophyta (mosses), Hepatophyta (liverworts) and Anthocerophyta (hornworts).

Tracheophytes constitute a large group of land plants with lignified tissues (the xylem) for conducting water and minerals. They also have non-lignified tissue (phloem) to conduct products of photosynthesis and they have roots, stems, leaves and an internal vascular network.

In vascular plants the sporophyte is the dominant phase of the life cycle. In seedless vascular plants (Pteridophytes), the gametophyte is usually a separate small organism quite different from the sporophyte. In seed plants, the gametophyte is a very small parasite in the sporophyte. The gametophytes of seed plants are microscopic.

Tracheophytes can be further divided into two groups, **seedless** and **seed plants**. Seedless plants include the phylum of Pteridophyta and other plants closely associated with them; seed plants include Gymnosperms and Angiosperms. Angiosperms are very important ecologically and economically and constitute the dominant plant group today.

A vascular plant has two organ systems: the shoot system, and the root system. The root system comprises the network of roots in a vascular plant, generally underground, that absorbs water and nutrients. The shoot system is above ground and includes the organs such as leaves, buds, stems, flowers and fruits.

Flowers are divided into three sections: the perianth, the androecium and the gynoecium.

Meristems divide and give permanent tissues that accomplish different functions. The dermal tissue system has a protective function and its structure varies depending on the age of the stem or root. The ground tissue system serves a variety of essential functions for plants. Vascular tissues are very important in the transportation of water and nutrients.

Growth is an irreversible increase in size (length, volume, mass, dry weight). Development is the coordinated sequence of cell divisions, growth, and differentiations leading to the formation of new organs and tissues.

The floral meristem undergoes a series of developmental changes that eventually give rise to the four basic structures of the flower: sepals, petals, stamens and carpels.

In the process of double fertilization that is unique to angiosperms, the male gametophyte produces two sperm cells that fertilize two cells within the female gametophyte. The zygote undergoes division and gives successively the globular, heart, and cotyledonary stages to become a mature seed.

A seed is a small embryonic plant surrounded by a protective coat called seed coat which constituted the integument of the ovule.

Germination allows the seedling to become anchored in the ground and start absorbing water. After germination the root absorbs water, an embryonic shoot emerges from the seed and the seedling develops independently by carrying out photosynthesis. The seedling growth and development into a mature flowering plant is regulated by phytohormones and other factors.

Most plants secure the water and minerals they need through their roots from the environment. Most of the water is lost in transpiration.

In order to carry out photosynthesis, green plants need a supply of carbon dioxide and a means of disposing of oxygen. Photosynthesis is also two stage process: the light-dependent process (light reactions) and the light-independent process that leads to carbon fixation and sugar manufacture.

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Glossary

Aerobic: presence of oxygen

Akinete: cell used for the vegetative reproduction in blue algae when conditions are favorable, resisting to the unfavorable conditions by thickening the cell walls after accumulation of food reserve.

Anaerobic: absence of oxygen

Androsporanges: in general they are sporanges producing male spores.

Androspore: spore formed in the androsporange (male spore)

Antheridium: male reproductive organ producing antherozoids or male gametes

Apothecium: ascogenous or open ascocarp (in Ascomycetes),

Archegonium: female reproductive organ producing oosphere or female gametes

Cambium: embryonic tissue of roots and stems whose cells undergo periclinal divisions in both directions thus producing layers of cells laid out in the radial direction. It can be the vascular cambium or the phellogen.

Carpogonium: female gametocyst formed of a cell supporting a trichogyne

Casparian strip (or band): waxy layer organised on the four faces of the endodermal root cells and which forces water and the aqueous solutions to cross them rather than to circulate between them.

Chlorosis: yellowing of the sheets of a plant following the loss of chlorophyll

Cingulum: transverse hollow (in Dinophyceae) in which one of the two flagella are inserted.

Cladode: very flattened short stem, deprived of terminal bud and leaves.

Cladome: group of filaments with final or subterminal growth

Cleistothecium: closed ascocarp

Coccospore: asexual reproduction spore surrounded by a thick wall to resist to the dessication; it is a dissemination spore in some blue algae

Collateral bundle: bundle having the phloem only on one side of the xylem. A bicollateral bundle has an internal and external phloem laid out on both sides of the xylem.

Collenchyma : supportive tissue made up of more or less elongated live cells and with thick but not lignified cellulose walls, frequent in the parts of the stems and leaves undergoing primary growth.

Columella: sterile tissue located in the centre of the capsule (mosses)

Companion cells: parenchymatous cells in the phloem of angiosperms associated with sifted cells with which they have the same origin.

Cone: male or female inflorescence of Gymnosperms made of an axis around which ovuliferous or sporangiferous scales are arranged

Conidia: dissemination spores in fungi.

Conidiophore: mycelial filament bearing conidia

Cork or suber : protective tissue composed of dead cells with suberised walls, which are made by phellogen. It replaces epidermis in old stems and roots.

Cormophyte: plants having aerial axis including Bryophytes, Pteridophytes and Spermatophytes

Cortex: tissue located between the epidermis and conducting tissues (central cylinder) on the roots and stems level.

Cryptogams: plants with hidden reproductive organs. They are non flowering plants

Dioecious: male and female flowers are beared by different plant individuals

Elaters: dead cells with thickened wall which helps in opening the capsule for spores dispersal (bryophytes)

Embryophyte: Cormophyte

Endoderm : tissue made up of only a single layer of cells and which circumscribes the central cylinder of a root.

Endoprothally: development of the prothallus inside the spore (pteridophytes)

Endothecium: central cell layer of the capsule in mosses producing the columella (central sterile column) and the sporogeneous tissue

Epiphyte: a plant which grows on a plant-host without becoming a parasite

Eusporangiate: a group of ferns whose spores are produced in a sporangium protected by several cell layers

Fibre: sclerenchyma cells elongated with streamlined ends and generally lignified walls and a reduced lumen.

Gametophyte: haploid individual (with n chromosomes) producing gametes

Gonophore: branch carrying carpogone in algae

Guttation: water droplets emission at the end and on the edges of a leaf.

Gynosporophyll: megasporophylls or bracts bearing megasporanges on their axils

Heterocyst: big cell used in asexual reproduction (Cyanophyceae)

Heterosporous: producing different types of spores: microspores (producing male prothallus) and macrospores (producing female prothalli)

Heterotrichous: case of algal thallus with two categories of filaments, some creeping on the substratum and others erect and perpendicular to the creeping ones

Homosporous: plant producing identical spores (one type of spores)

Hormospore: group of cells which encyst and transform into spores (Cyanophyceae)

Hypotonic: of inferior osmotic pressure

Isotonic: of the same osmotic pressure

Laticifer : cell or sequence of cells containing a characteristic substance called latex.

Lenticellate: which is in connection with the lenticels

Lenticels: opening in epidermis or bark of a young stem by which air can penetrate.

Leptosporangiate: refers to a group of ferns whose spores are produced in a sporangium protected by one cell layer

Lumen (of a cell): space delimited by cellular wall.

Macro-element: essential element in high concentration

Macrosporangia or megasporangia: sporangia in which megaspores (or haploid spore cells) produce the female gametophyte in heterosporous plants.

Mastigosome: cavity where flagella are inserted, also called blepharoplast

Megasporange: female sporange producing megaspores which germinate into female prothalli

Megaspore: female spore

Megasporophyll: bract bearing megasporanges in its axil

Meiospores: young spores grouped into tetrad

Meristem : embryonic tissue made up of undifferentiated cells and which constitutes certain zones of growth in plants.

Mesophyll: foliar tissue made up of parenchymatous cells located between the two epidermises.

Metaxylem, metaphloem : part of xylem, primary phloem which differentiates after the protoxylem and protophloem but before the xylem, secondary phloem.

Micro-element: essential element in low concentration

Microglia: neuroglial cell of mesodermal origin that can become phagocytotic.

Micropyle: interruption of the ovule integument which allows the male gametes to penetrate in the ovule

Microsporange: male sporange producing microspores which germinate into male prothalli

Microsporangia : sporangia in which microspores (or mononuclear (?) grains of pollen i.e haploid spores) produce the male gametophyte in heterosporous plants).

Microspore: male spore

Microsporophyll: bract bearing microsporanges in its axil

Moniliforme: in the form of grains

Monoecious: plants having male and female flowers on the same individual

Monostromatic: flattened thallus forming a pseudoparenchyma with a single layer of cells

Nannospore: unicellular and small reproduction spore (blue algae) without cell wall

Nucellus: central tissue of the ovule or macrosporange

Oocyst: oogonium or organ in which the oospheres are produced

Ostiole : opening in the leaves and stems epidermis surrounded by two stomatic cells and used in the gaseous exchange.

Parenchyma : plant tissue less differentiated, found in cortex and pith of stems, in cortex of roots and between the two epidermis of the leaf.

Pentamerous: parts of the flower which are a multiple of 5 (5,10,15,…)

Pericycle : part of stele parenchyma extended between endoderm and phloem, present in roots

Periderm : set constituted by suberophellodermic zone and its tissues (suber and phelloderm).

Perisperm : a reserve tissue in seeds comparable with the endosperm but coming from the nucellus.

Peristome: a membrane made of 32 teeth arranged in two rows situated in the operculum in mosses for the protection of the capsule

Perithecium: ascocarp opened at maturity by an ostiole or even closed

Phelloderm : tissue resembling cortical parenchyma produced by phellogen in a centripetal way in certain stems and roots.

Phloem: plant conducting tissue which channels organic substances.

Phosphorylation: synthesis of ATP

Photolysis: reaction of bonding separation

Photophosphorylation: transformation of the luminous energy absorbed by the chlorophyll pigments in the form of energy directly usable by the cell metabolism

Phycocyanine: blue-green pigment

Phycoerythrine: red pigment

Planocoque: coccospores without flagella moving by sliding or snaking

Planogametes: motile gametes with flagella

Plasmolysis: when the medium has a pressure of suction superior to that of the plant, the cell loses water and reaches minimum volume: this fact is known as plasmolysis.

Pluristromatic: flattened thallus forming a pseudoparenchyma with several layers of cells

Pollen tube: tube formed after the germination of the pollen grain, containing the vegetative and reproductice nuclei (male prothallus)

Procambium : primary meristem or meristematic tissue, which differentiates in primary conducting tissues.

Prothallian tube: tube formed by the germination of the the female cell in *Welwitschia* which fertilises the male nucleus

Prothallus: organ developing from the germination of spores in pteridophytes and spermatophytes

Protoderm : primary meristem or meristematic tissue which gives rise to the epidermis.

Protonema: pluricellular filament developping from the germination of spores in mosses

Protoxylem, protophloem : first elements of the xylem and primary phloem which appear in a plant body.

Punctuation : small cavity in the cellular wall where primary wall is not covered by a secondary one and where communication between xylem conducting elements can take place.

Pycnidium: flash- like fruiting body containing conidia called pycnidiospores

Sclerenchyma : supportive tissue in higher plants made up of generally dead cells and having thick and rigid walls.

Sclerites : sclerenchyma cells of variable form which an not very elongated and having thick secondary walls.

Spermatium: inert male gamete

Spermatocyst: organ producing sperms

Sporocyst: organ producing spores

Sporophyte: individual diploid (with 2n chromosomes) producing spores

Stele: central cylinder of the stem or root or plant conducting system with associated tissues (pericycle, intrafascicular zones and pith).

Stomata: structure belonging to the leaves epidermis and made up of two guard cells (stomatic cells) laid out around the ostiole; the stoma controls the rate of the gaseous exchange.

Suberin : fatty substance that is present in the cellulose wall of the cork cells and in the endoderm band of Caspary.

Tetramerous: parts of the flower are a multiple of 4 (4, 8, 16,...)

thrombin

Tillering: when a plant grows stems on the same tuft or the same foot.

Trachea or perfect vessels: xylem conducting elements made of dead and hollow cells, with rigid walls whose ends disappeared to allow an easy circulation of crude sap.

Tracheid : imperfect vessels of xylem made up of dead and hollow cells, and with rigid walls whose porous ends let the sap circulate.

Trimerous: parts of the flower are a multiple of 3 (3, 6, 9,...)

Turgescence: maximum volume reached by a cell when the osmotic pressure and the membrane pressure are equal.

Xerophyte: plant adapted to dryness

Xylem: conducting tissue of crude sap towards photosynthetic tissues of the plant.