الجمهورية الجزائرية الديمقراطية الشعبية

The People's Democratic Republic of Algeria

وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Scientific Research

جامعة الإخوة منتوري قسنطينة
UNIVERSITE DES FRERES MENTOURI CONSTANTINE

معهد العلوم البيطرية

Institute of Veterinary Sciences

Department : Animal production

Pedagogical Handout

FUNDAMENTAL ELEMENTS OF HERBIVORE DIETS

Intended for the students of: Second Year Doctor of Veterinary Medicine Program

Prepared by: Dr. DJAALAB Imene

Lecturer - Animal Nutrition

University year: 2024-2025

PREAMBLE

This booklet, entitled "Fundamental Elements of Herbivore Diets", is intended for second-year veterinary medicine doctoral students, in accordance with the curriculum established by the National Pedagogical Committee (CPN). Its objective is to provide general and fundamental knowledge essential for understanding plant biology and animal nutrition.

This educational booklet is designed in a simple and accessible manner, supported by illustrations, diagrams, and summary tables, to facilitate easy understanding and effective memorization of the information by the target audience. At the end of the three chapters covered, a terminological glossary is provided to clarify the technical terms discussed and to reinforce the assimilation of the key concepts presented throughout the booklet.

To follow this course effectively, students are expected to have prerequisite knowledge of the different parts of a plant, as well as a general overview of plant anatomy and histology, typically covered during pre-university education.

The objective of this course material is to provide students and interested learners with scientific information that facilitates the understanding of the fundamental principles of plant biology.

At the end of this unit, the learner will be able to:

- Understand the basics of herbivore nutrition through the study of plant structures they consume.
- Identify the main anatomical parts and histological tissues of plants.
- Relate plant tissue structure to its nutritional value for herbivores.
- Acquire a basic scientific vocabulary in botany and plant histology.
- Develop skills in observation, ana

LIST OF FIGURES

LIST OF TABLES

TABLE DES MATIERES

INTRODUCTION

Herbivores rely exclusively or predominantly on plants to meet their nutritional needs. Their diet is therefore based on a wide variety of plant tissues, whose anatomical, biochemical, and functional composition directly influences the quality of the ingested ration. To understand the digestive mechanisms in herbivores and to better formulate appropriate feeding regimes, it is essential to have knowledge of the vegetative structures of plants - namely, the root, stem, and leaf - as well as their anatomical organization.

The plant tissues that make up these organs - particularly the parenchyma, vascular tissues, supporting tissues, and protective tissues - determine not only the nutritional value of plants but also their digestibility. Indeed, the degree of cell wall development, lignification, secondary growth, and the distribution of sclerenchymatous fibers are key factors affecting the efficiency of microbial digestion in ruminants.

This document offers a detailed analysis of plant anatomy and histology in relation to herbivore nutrition, based on classic transverse sections and morpho-anatomical criteria that allow the differentiation of tissues according to their origin (monocotyledon or dicotyledon) and their function within the plant. In addition, the identification and classification of plants within the plant kingdom is essential for structuring botanical knowledge and guiding research in life sciences.

This document, intended for second-year veterinary medicine doctoral students, is designed to be as simple and accessible as possible, while providing a solid foundation in plant anatomy and histology as applied to nutrition.
Its goal is to enhance the understanding of the nutritional and physiological issues related to herbivore feeding, and to deliver all relevant and necessary information for a high-quality veterinary education.

CHAPTER I

CLASSIFICATION AND CELLULAR ORGANIZATION OF PLANTS

The term "botany" comes from the Greek "botanê," meaning "plant," derived from the verb "boskein," meaning "to nourish." However, plants are not only a source of food for humans and animals, but they also contribute to our lives in many other ways. They provide us with fiber for clothing, wood for furniture, shelter, and fuel, paper for books, spices for flavor, medicines for health, and the oxygen we breathe. We are completely dependent on plants. Plants intensely engage our senses, and so our lives benefit from the beauty of the gardens, parks, and natural areas we have at our disposal.

Indeed, botany is the science dedicated to the study of plants. It has several fields that connect it to other life sciences. It is an important scientific discipline with many subdivisions covering different branches, among them:

- **Plant morphology:** Describing the shapes of plant organs or parts.
- **Plant histology and anatomy:** Dealing with internal structures and different types of plant tissues.
- **Plant physiology:** Focuses on plant function and development.
- **Phytography:** Consists of analytical description.
- **Taxonomy:** Description of diagnostic and differential characteristics. Taxonomy compares these units and delimits them to create taxa.
- **Systematics:** Classifies the multitude of taxa by counting in a specific order.
- **Phylogeny:** Study of the origin of plant species, which are considered to have evolved from simple forms.
- **Paleobotany**: Studies the biology and evolution of fossil plants.
- **Genetic taxonomy:** Focuses on the genetic code of species and the DNA concentration of plant species.
- **Cytotaxonomy:** focuses on the study of the cell, especially chromosome numbers.
- **Chemotaxonomy:** focuses on the chemical structure.
- **Palynology:** studies pollen and its resistant cell wall, "sporollenin."
- **Numerical taxonomy:** uses computer methods to observe and determine the most important morphological and genetic characteristics.
- **Ecology:** studies the relationships between organisms and their environment.

- **Genecology or Genetic Ecology :** focuses on mutations and how they occur. These mutations produce phenotypes that are selected by the environment (hence the connection with biogeography).
- **Plant biogeography** (plants and their environment) and plant pathology.

Some disciplines, such as dendrology, specialize in a subset of plants. Detailed knowledge of plants finds applications in the fields of pharmacology, selection and improvement of cultivated plants, in agriculture, horticulture, and forestry.

1. MAJOR KINGDOMS OF LIFE

The first living beings, which appeared on Earth about 3.5 billion years ago, were bacteria without a cell nucleus. From these prokaryotes, more complex beings emerged: eukaryotes. Their essential characteristic is that they possess a cell nucleus that contains DNA, the carrier of genetic information.

Animals and plants are eukaryotes. All living beings are divided into prokaryotes and eukaryotes. Here are some differentiation criteria (Figures 1 and 2) :

1.1. PROKARYOTES

They include Bacteria (unicellular microbes with elongated (bacillus) or spherical (cocci) shapes) and Cyanobacteria. These are bacteria related to blue-green algae (Cyano = blue). Prokaryotes are characterized by:

- The cells are not very evolved
- Glycoprotein cell wall
- The nucleus is individualized
- Absence of nuclear membrane: the genetic material is not located in a nucleus bounded by an envelope but dispersed throughout the cytoplasm.
- Cell division (by fission).

1.2. EUKARYOTES

They are characterized by:

- More evolved cells
- Pectocellulose cell walls (in plants)
- Well-individualized nuclei
- The presence of mitochondria
- The presence of plastids

- Cell division (by mitosis and meiosis)

They are generally autotrophic (as opposed to heterotrophic).

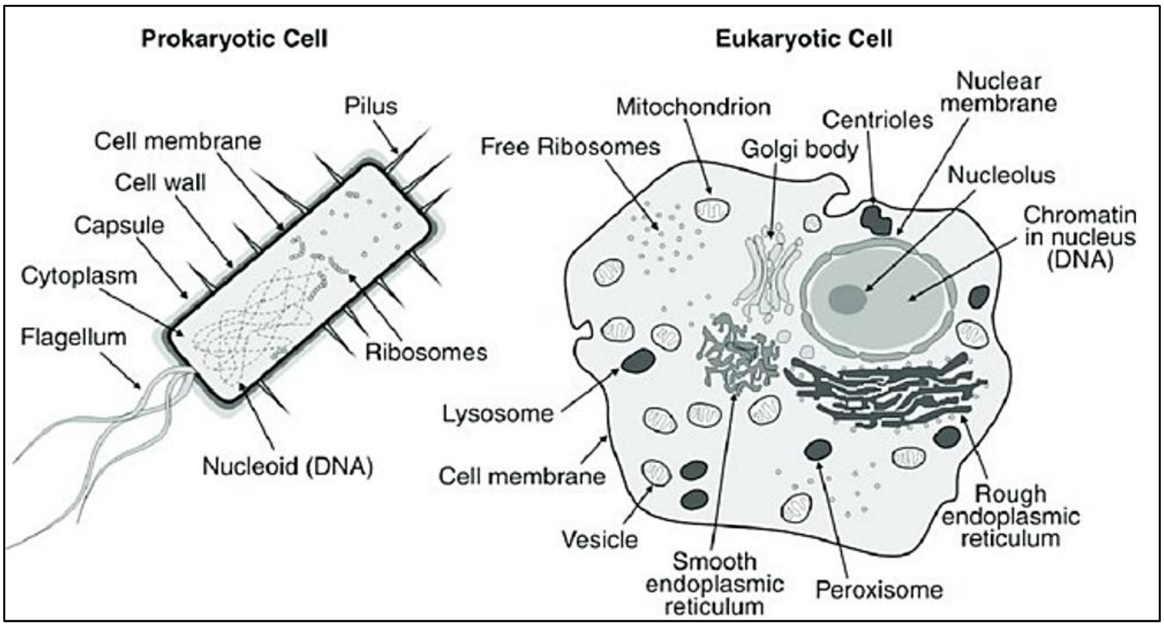


Figure 1: Differences between prokaryotic and eukaryotic cells (Lane, 2009)

Thus, the evolution of living organisms is currently divided into three major domains: Prokaryotes; are organisms without a true nucleus or cell organelles such as Archaebacteria, Eubacteria (true bacteria) and Eukaryotes. The third domain includes all eukaryotic organisms (including a true nucleus and cell organelles) divided into five kingdoms: Monera, Protista, Plants, Fungi and Animals (Figure 2):

• ***Monera,*** which includes all prokaryotic organisms (bacteria and cyanobacteria), i.e., organisms consisting of a cell without a nucleus.

• ***Protists,*** which include eukaryotic organisms that are mostly unicellular (and do not meet the criteria of other kingdoms). Their cell has a nucleus.

• ***Fungi, or mushrooms,*** which include heterotrophic eukaryotic organisms (organisms that cannot produce their own organic matter) and have a cell wall.

• ***Plants,*** which include autotrophic eukaryotic organisms with a skeletal cell wall.

• ***Animals,*** which include heterotrophic eukaryotic organisms without a cell wall.

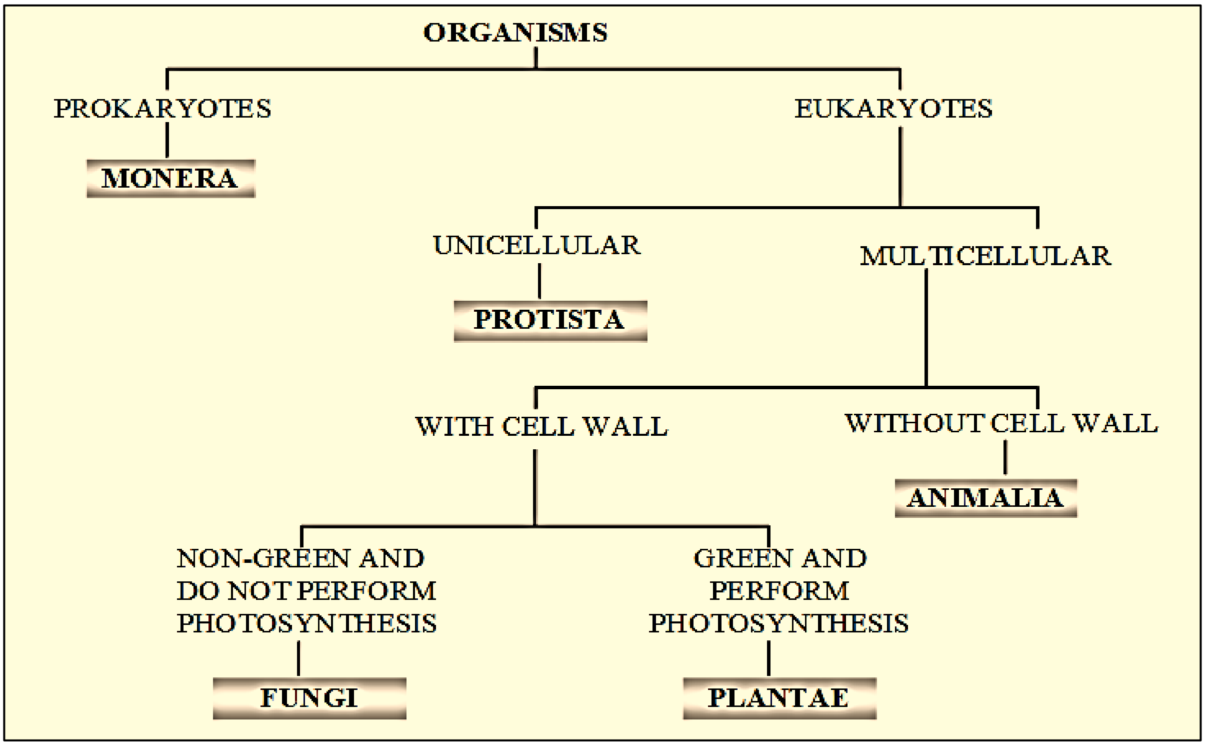


Figure 2: The five kingdoms of the living world (Reynaud, 2011)

2. MAIN CRITERIA FOR CLASSIFICATION OF THE PLANT WORLD

2.1. CYTOLOGICAL CRITERIA

According to the structure of the cell nucleus, cells can be classified into (Figure 3 and Table 1):

2.1.1. Prokaryotes

This class is represented by the most primitive plants whose cells lack a typical nucleus (nuclear apparatus composed of 1 to 2 chromosomes that are free in the cytoplasm). Example: Cyanophytes (blue algae).

2.1.2. Eukaryotes

These plants have a true nucleus with a nuclear membrane, chromatin, and a nucleolus. Example: Spermaphytes (seed plants).

2.2. ORGANIZATION OF THE VEGETATIVE APPARATUS

2.2.1. Thallophytes

Lower plants: the structure of a plant is simple, it has no organs comparable to the roots, stems or leaves of higher plants; the plant body is a thallus which is single or multicellular. This is the case of Algae.

2.2.2. Cormophytes

Higher plants: the vegetative apparatus is called "Cormus", it is composed of a stem, leaves and roots. This is the case of Spermaphytes.

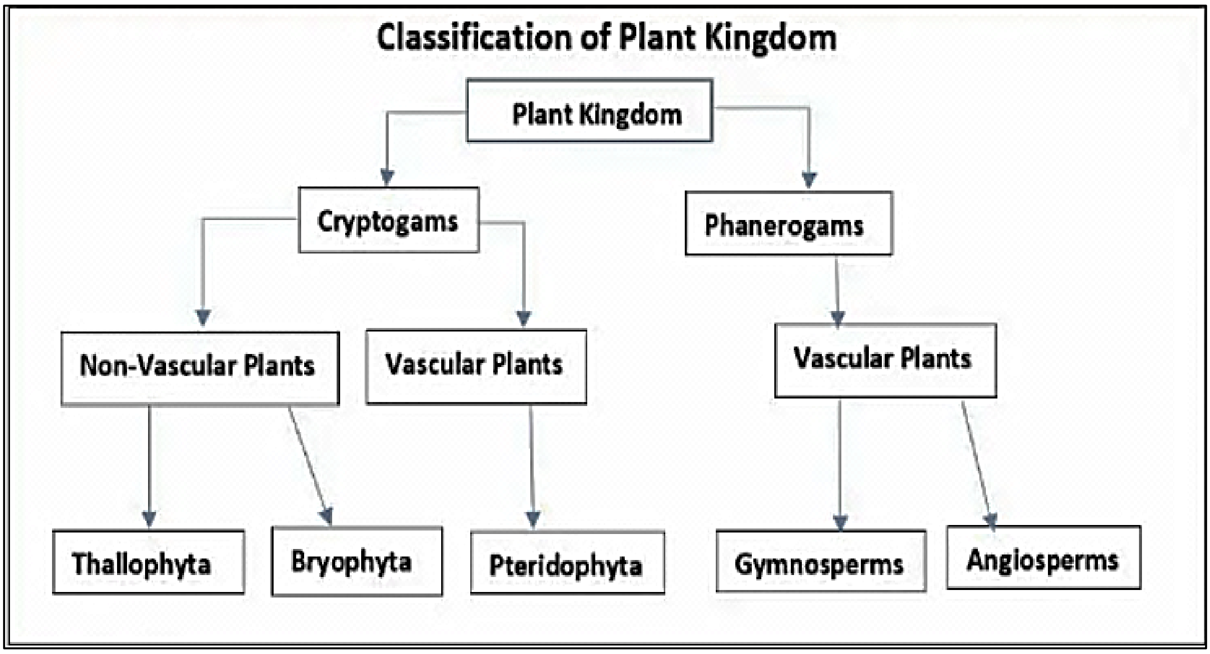


Figure 3: Classification of plant kingdom (Reynaud, 2011)

2.3. ANATOMICAL CRITERIA

2.3.1. Avascular plants

These plants do not have conductive elements and the absorption of water and mineral salts is carried out by capillarity. Example: Bryophytes.

2.3.2. Vascular plants

These are plants that have conductive vessels that transport sap. Example: Pteridophytes.

2.3.3. Structure of the reproductive system

The plant kingdom is classically divided into two large groups or phyla:

A. Cryptogam branch

(Cryptos: hidden; gamos: marriage), that is, plants without flowers, including:

- Algae: studied by algologists,
- Fungi: studied by mycologists,
- Lichens: studied by lichenologists,
- Mosses: studied by bryologists,
- Liverworts: studied by bryologists,
- Ferns (Pteridophytes), studied by pteridologists.

B. Phanerogams branch

(Phaneron: visible; gamos: marriage), that is, flowering plants, divided into two subgroups or subphyla:

- Subphylum Gymnospermae.
- Subphylum Angiospermae; itself comprising two classes: Dicotyledons and Monocotyledons.

Table 1: Botanical Systematics and Morphology **(**Hammiche, 1988)

PHYLUM	**Vegetative organs**			**Anatomical structure**	**Reproductif system**	
	Roots	Stems	Leaves	Vascular elements	Flowers	Seeds
Thallophyta	0	0	0	0	0	0
Bryophyta	Pseudo-foliar vegetative structure			0	0	0
Pteridophyta	+	+	+	+	0	0
Gymnosperms	+	+	+	+	+	+

In practice, ferns are often grouped with Phanerogams because they have individual vessels in common, thus constituting the group of vascular plants, with more than 250,000 species. Then, the large groups are themselves subdivided into increasingly smaller units. The most commonly referred to subdivisions are shown in bold. This principle follows an order established according to the following complete sequence (Figure 4):

Kingdom (plant),

Phyla and subphyla**,**

Classes and subclasses,

Orders and suborders,

Families and subfamilies.

Tribes and subtribes,

Genera and subgenera,

Sections and subsections.

Series and subseries,

Species and subspecies.

Varieties and subvarieties,

Forms and subforms.

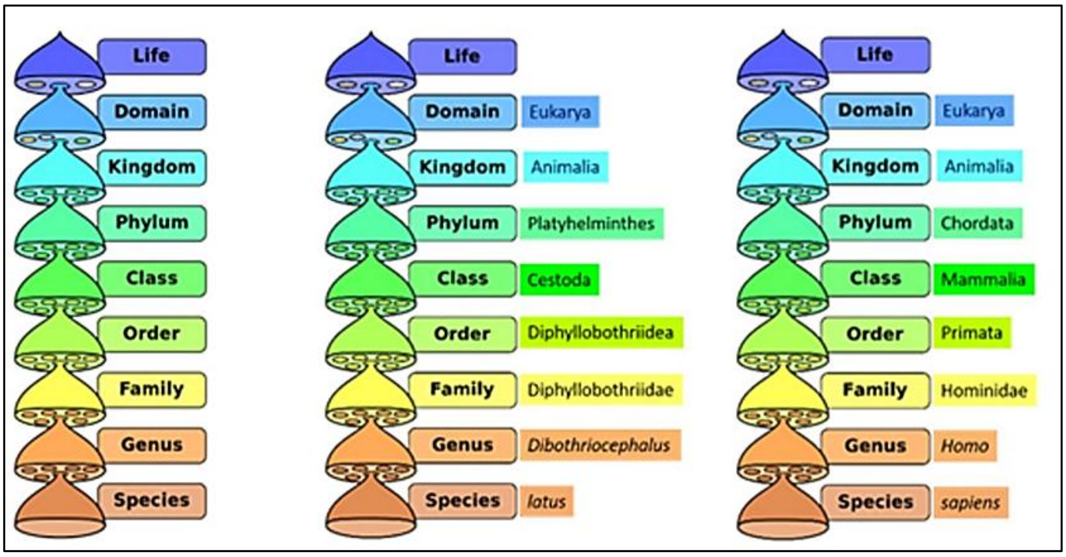


Figure 4: Names of taxonomic classification of organisms (Choudhury, 2024)

3. CLASSIFICATION OF PLANTS

The distinction between the animal and plant kingdoms has existed since the 4th century. Many authors no longer simply compiled earlier works; they proposed their own classification system. Charles Linnaeus (1707–1778) was a Swedish physician and naturalist. At a very young age, he began collecting plants in various regions of Europe (Lapland, Holland). Linnaeus wrote botanical works in which he outlined his concept of systematics.

However, the more recent classification system, called phylogenetic classification, is based on molecular characteristics (DNA, RNA, proteins) and allows for the development of hypotheses on the evolutionary links and relationships between different living organisms (construction of phylogenetic trees or cladograms).

In the division of life into two kingdoms—Animal and Plant—Bacteria and Fungi were traditionally included among the plants (Figure 5 and Table 2). Based on ribosomal RNA sequences, six major groups are now distinguished: Archaea, Eubacteria, Protists, Fungi (including Lichens), Animals and Plants.

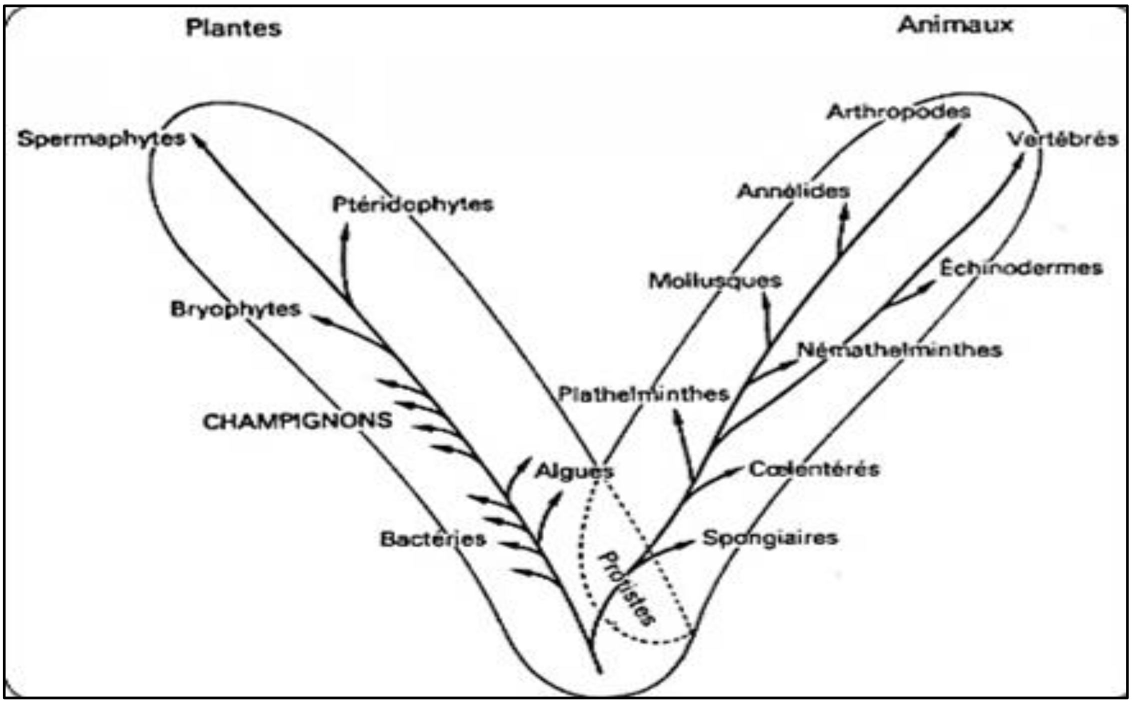


Figure 5: Classification of living beings by Linnaeus's two-kingdom systems in 1735 (Meliani, 2021)

Indeed, the classification of plants is based on several cytological, anatomical and morphological criteria (Figure 6). Thus, the plant kingdom is traditionally subdivided into two large groups based on the structural organization of the plant: presence of a Thallus or a corm. We distinguish between Thallophytes and Cormophytes. Here are the main criteria for identifying these different subdivisions (Table 2).

Table 2: Classification of the plant kingdom (Guignard and Dupont, 2004 ; Laberche, 2004)

<table>
<tr><td rowspan="2">PROKARYOTES
without nucleus</td><td colspan="4">BACTERIA</td></tr>
<tr><td colspan="4">CYANOBACTERIA</td></tr>
<tr><td rowspan="9">EUCARYOTES
with nucleus</td><td rowspan="3">THALLOPHYTES
Thallus</td><td colspan="3">ALGAE</td></tr>
<tr><td colspan="3">FUNGI</td></tr>
<tr><td colspan="3">LICHENS</td></tr>
<tr><td rowspan="6">CORMOPHYTES
Cormus</td><td colspan="3">BRYOPHYTES</td></tr>
<tr><td rowspan="5">RHIZOPHYTES
Tracheophytes
Roots</td><td colspan="2">PTERIDOPHYTES</td></tr>
<tr><td colspan="2">PRESPERMATOPHYTES</td></tr>
<tr><td rowspan="3">SPERMAPHYTES
(Phanerogams)
Seed-bearing plants</td><td>GYMNOSPERMS</td></tr>
<tr><td>CHLAMYDOSPERMS
(Gnetales)</td></tr>
<tr><td>ANGIOSPERMES
(Monocots + Dicots)</td></tr>
</table>

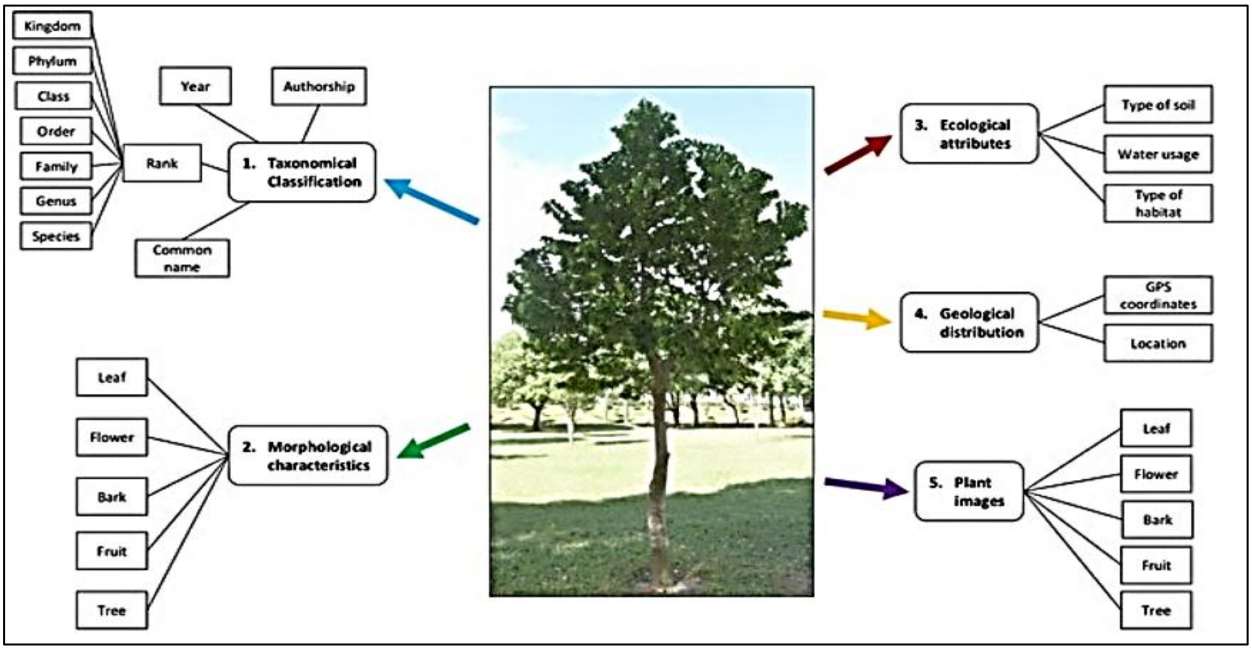


Figure 6: Plant data description. A plant is described with the taxonomical classification, morphological characteristics, ecological attributes, geological distribution and the plant images (Mohamad-Matrol et al., 2018).

- **Prokaryotic Plants**
  - ***Cyanobacteria:*** This category has type A chlorophyll.
  - ***Photosynthetic bacteria***: They have bacteriochlorophyll.
- **Eucaryotic Plants** :
  - ***Thallophytes:*** vegetative apparatus is a thallus;
    - ***Algae***: chlorophyllous thallophytes,
    - ***Fungi***: non-chlorophyllous thallophytes,
    - ***Lichens***: symbiosis between an algae and a fungus,
  - ***Cormophytes:*** vegetative system is a Corm;
    - ***Bryophytes (Mosses):*** simple, non-vascular plants,
    - ***Pteridophytes (Ferns):*** vascular plants without flowers or seeds;
  - ***Spermaphytes (Phanerogams):*** vascular plants with flowers and seeds;
    - ***Gymnosperms:*** plants without true flowers, naked seeds;
    - ***Angiosperms:*** plants with flowers and seeds enclosed in ovaries (*Monocots and Dicots).*

3.1. PROKARYOTES (PROTOKARYOTES)

A plant is a eukaryotic organism that has a double-walled cell, equipped with plastids bounded by one or more membranes, and part of its genetic material is contained in a nucleus. According to this definition, cyanobacteria, photosynthetic prokaryotic organisms without nuclei or organelles, are not plants.

3.1.1 Prokaryotic algae (Cyanophytes / Cyanobacteria)

According to several authors, blue-green algae, also called Cyanophyceae, Schizophyceae, Myxophyceae, or Cyanobacteria, form the Schizophyta (Prokaryotes) phylum with Bacteria. Three characteristics give this phylum its originality: the cells have neither a true nucleus nor a plastid, and there is no sexual reproduction.

Cyanobacteria are distinguished from Bacteria by the presence of chlorophyll A and water-soluble accessory pigments, red (phycoerythrin) and blue (phycocyanin) phycobilins. They also contain carotenoids: β-carotene, echinenone, zeaxanthin, and myxoxanthophyll. Cyanobacteria cells display a homogeneous coloration because they do not have individual plastids. Under the optical microscope (figure 7), however, we can distinguish a colored peripheral zone, the chromoplasm, and a lighter central part, the centroplasm. The latter is not a true plastid, but a chromatoplasm which contains pigments: chlorophyll like other plants and a particular protein: phycocyanin, which gives the blue color.

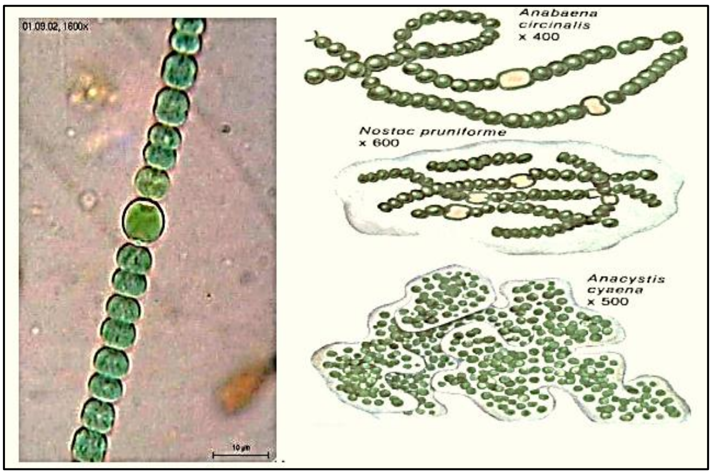


Figure 7: Colony and filaments of Cyanophytes / Cyanobacteria (Ghellai, 2022)

3.2. EUKARYOTES

Knowing that algae are chlorophyll-producing living beings capable of photosynthesis. Their life cycle generally takes place in an aquatic or humid environment (figure 8). Their vegetative apparatus is simple; it is a thallus (without roots, stems, or leaves). They are Thallophytes.

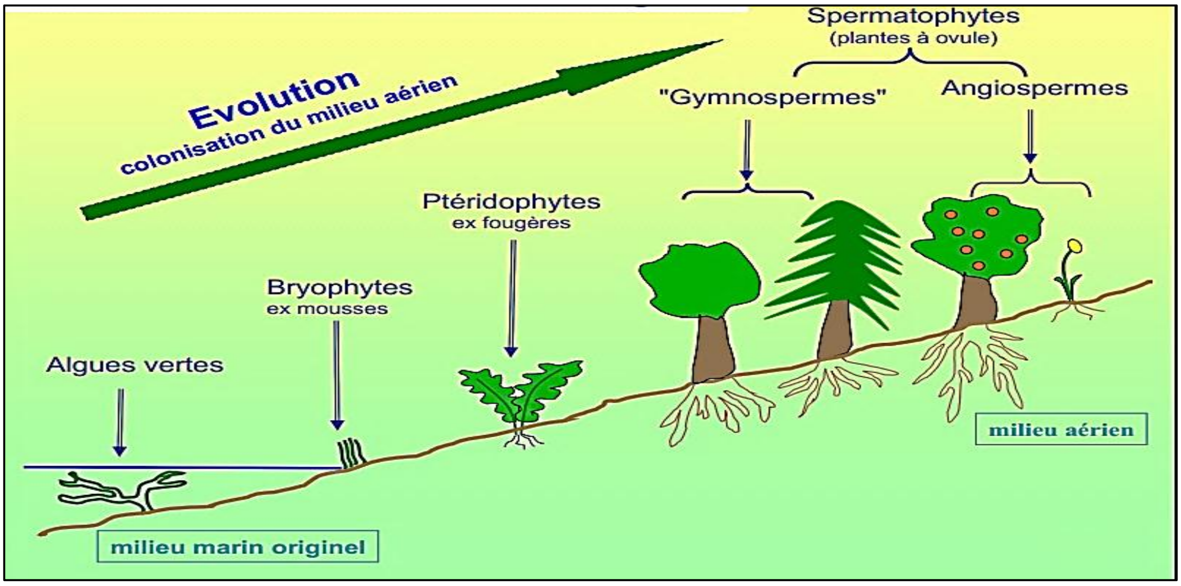


Figure 8: Evolution of the plant world (Reynaud, 2011)

3.2.1. Thallophytes

These are plants with a very simple structure called a thallus. The thallus is composed of similar cells without physiological differentiation, where no roots, stems, leaves, or conducting vessels can be distinguished. They are made up of either isolated cells or filaments (Table 1). Depending on the species, some thallophytes are unicellular, such as cyanobacteria (blue-green algae), and sometimes the thallus has complex, multicellular structures, such as fungi and yeasts. Reproduction occurs through spores or gametes.

The reproductive organs (gametocysts and sporocysts) are formed from a single cell wall, that of the mother cell. The vegetative apparatus, or the thallus, is made up of cells more or less tightly packed together, or more or less tangled filaments of cells (false tissues called plectenchyma).

A. Phycophytes (Algae)

Algae are living beings capable of oxygenic photosynthesis whose life cycle generally takes place in an aquatic environment. They constitute a very important part of biodiversity and the main basis of food chains in fresh, brackish and marine waters. Various species are used for human consumption, agriculture or industry. They are autotrophic organisms (capable of photosynthesis). There are three main groups (Figure 9):

- Chlorophycophytes (green algae),
- Chromophycophytes (brown algae),
- Rhodophycophytes (red algae).

Figure 9: Green (left), Brown (center) and Red (right) algae (Reynaud, 2011)

B. Mycophytes (Fungi)

Organisms that do not contain chlorophyll, live as parasites or saprophytes of organic matter, belong to the Mycophyta phylum (figure 10). Their wall is not cellulose (except for Oomycetes) but based on chitin, their reserves are organic matter and glycogen; probably come from algae after the disappearance of chlorophyll. The Thallus is in the form of a filament and is called mycelium. These are heterotrophic organisms (unable to ensure photosynthesis). Fungi have several forms of life: free, parasitic, symbiotic. They can be associated with higher plants to form mycorrhizae (e.g.: Beetroot) or with algae to form lichens.

Figure 10: Mycophytes (Fungi) (Ghellai, 2022)

C. Lichens

Lichens are formed by the association of algae and fungi; the algae provide organic matter and the fungi provide water and mineral salts. There are approximately 20,000 species, for example: Xanthoria of the walls, these are yellow-orange plates attached to old stones or tree bark (figures 11 and 12).

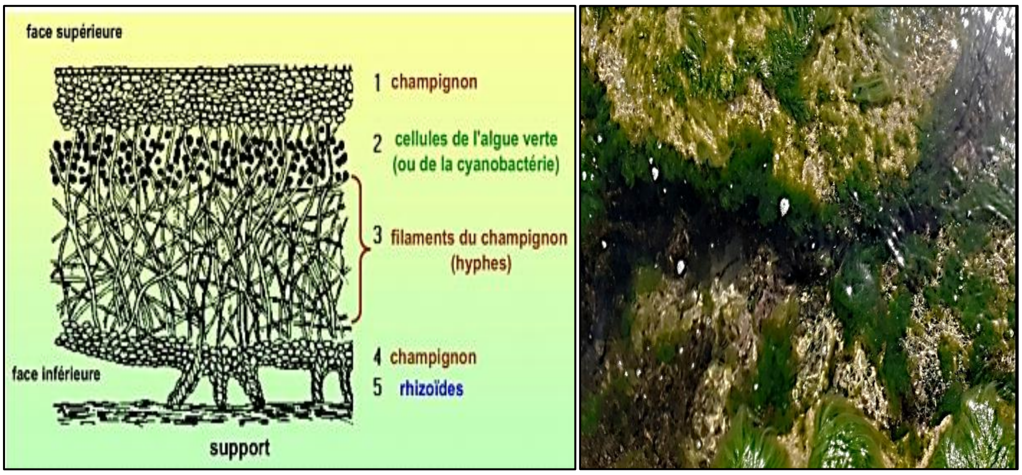


Figure 11: Cross section in a lichen thallus (Reynaud, 2011)

Figure 12: Classification of lichens based on the appearance of the thallus (Belhacini, 2017)

3.2.2 Cormophytes

This group is composed of higher plants with chlorophyll, whose starch is stored in plastids. They are always multicellular organisms whose eukaryotic cells are grouped into tissues that, in turn, form organs much more complex than a thallus called a corm (an upright branch), hence the name Cormophytes. This corm is composed of three fundamental organs: the stem, the leaf, and the root. The physiological functions are well defined (absorption of water and mineral salts by the roots, photosynthesis by the leaves, and reproduction by the stems).

Cormophytes are land plants and are divided into four phyla (Table 2): Bryophytes, Pteridophytes, Prespermaphytes (intermediate fossil plants), and Phanerogams or Spermaphytes (seed plants). These are divided into Gymnosperms (plants with naked ovules) and Angiosperms (ovule located in an ovary). Angiosperms are either Monocotyledons or Dicotyledons (the cotyledon is the first leaf of the embryo, sometimes very thickened by accumulation of reserves).

A. Bryophytes

That is to say, mosses. From the Greek "Bruon": moss and "phytos": plant. They are non-vascular Cryptogams. The plant is formed of sorts of "stems" and "leaves", however, there are no roots and no reproductive conductive tissues are barely or not visible (reproduction in water). They multiply asexually (vegetative) or sexually (gametes) (figures 13 and 14).

Figure 13: Photo of plants belonging to the Bryophyta phylum (Gharabi, 2021)

Figure 14: Bryophytes (mosses on rocks or mosses on tree trunks)
(Reynaud, 2011 ; Benaziza, 2022)

B. Ptéridophytes

These are ferns. The root system and the conducting apparatus appear but there are no flowers and there are no seeds (figures 15 and 16).

Figure 15: The classic fern (Matteucia) (Reynaud, 2011)

Figure 16: The morphology of Pteridophytes (a: Selaginella; b: Horsetail; c: Filicophyte; d: Psilophyte) (Boukhalfoun, 2023)

C. Spermaphytes (Phanérogames)

These are the flowering plants or Phanerogams (from phaneros: apparent and gamos: union). These are the most evolved plants that constitute the majority of terrestrial populations in current nature. The plant has several distinct parts, or organs, each with its own structure and functions. The vegetative apparatus is typically made up of roots, stems and leaves; the reproductive organs are grouped into highly modified branches, the flowers, which lead to the formation of seeds (hence the name Spermaphytes, sperma: seed or grain). This fourth phylum is subdivided into three sub-phyla (tables 1 and 2).

C.1. Gymnosperms

They are trees or shrubs, their leaves have a small surface area or are needle-like (thorns) or scale-like, and are persistent. (Gymnos: naked; sperma: seed), in which the ovules (the beginnings of future seeds) and the seeds themselves are not enclosed in closed envelopes. Most gymnosperms are conifers (Figure 17) such as: firs (Abies), spruces (Picea), larches (Larix), giant sequoias (Sequoia dendron), and pines (Pinus).

Propagation is sexual; they are generally monoecious (male and female flowers are borne on a single plant) or dioecious (male and female flowers are borne on two different plants) species.

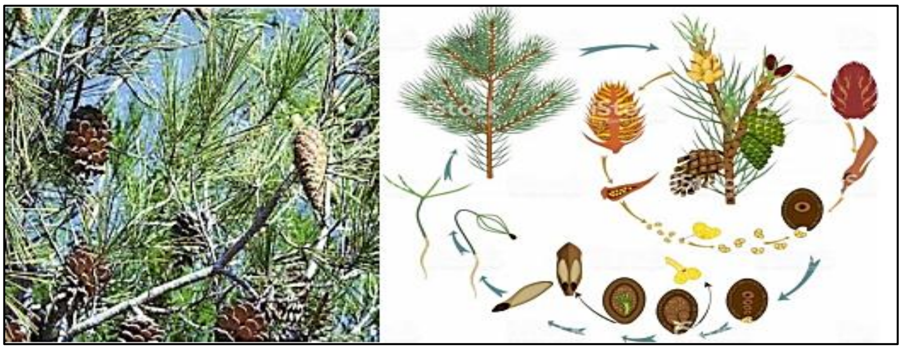


Figure 17: Photo representing a gymnosperm plant in the case of pine (Gharabi, 2021)

C.2. Chlamydosperms

The reproductive organs of Chlamydosperms are surrounded by a simple envelope (Chlamydos: envelope; sperma: seed). These plants are isolated in the current flora and considered to be intermediate between gymnosperms and angiosperms (table 2).

C.3. Angiosperms

Groups together flowering plants, and therefore plants that bear fruit. Angiosperm means in Greek (Angio: cavity or envelope, sperms = seeds) "seed in a container" as opposed to gymnosperms (naked seed). They represent the largest part of terrestrial plant species, with 250,000 to 300,000 species. Angiosperms include Dicotyledons and Monocotyledons. They are characterized by (figure 1):

- The presence of a completely closed ovary in which the ovules are enclosed.
- Plants with a wide variety of growth forms (woody: e.g., palm, and herbaceous: e.g., bean).
- Flowers are unisexual or hermaphroditic; typical stamens with filaments and anthers; the gynoecium can consist of one or more free or fused carpels containing a variable number of ovules topped by styles and stigmas.
- The transformation of the fertilized ovary into a fruit containing seeds.
- A great diversity of species and varieties is found in various environments.
- An initial classification into two major classes: Monocotyledons and Dicotyledons.
  - *Monocots:* (mono = one and cotyledon = lobe) e.g., wheat, corn;
  - *Dicots:* characterized by leaf polymorphism, vein arrangement, and floral type. They are divided into:
    1) Apetals (without petals).
    2) Dialypetals (free or separate petals).
    3) Gamopetals (fused petals).

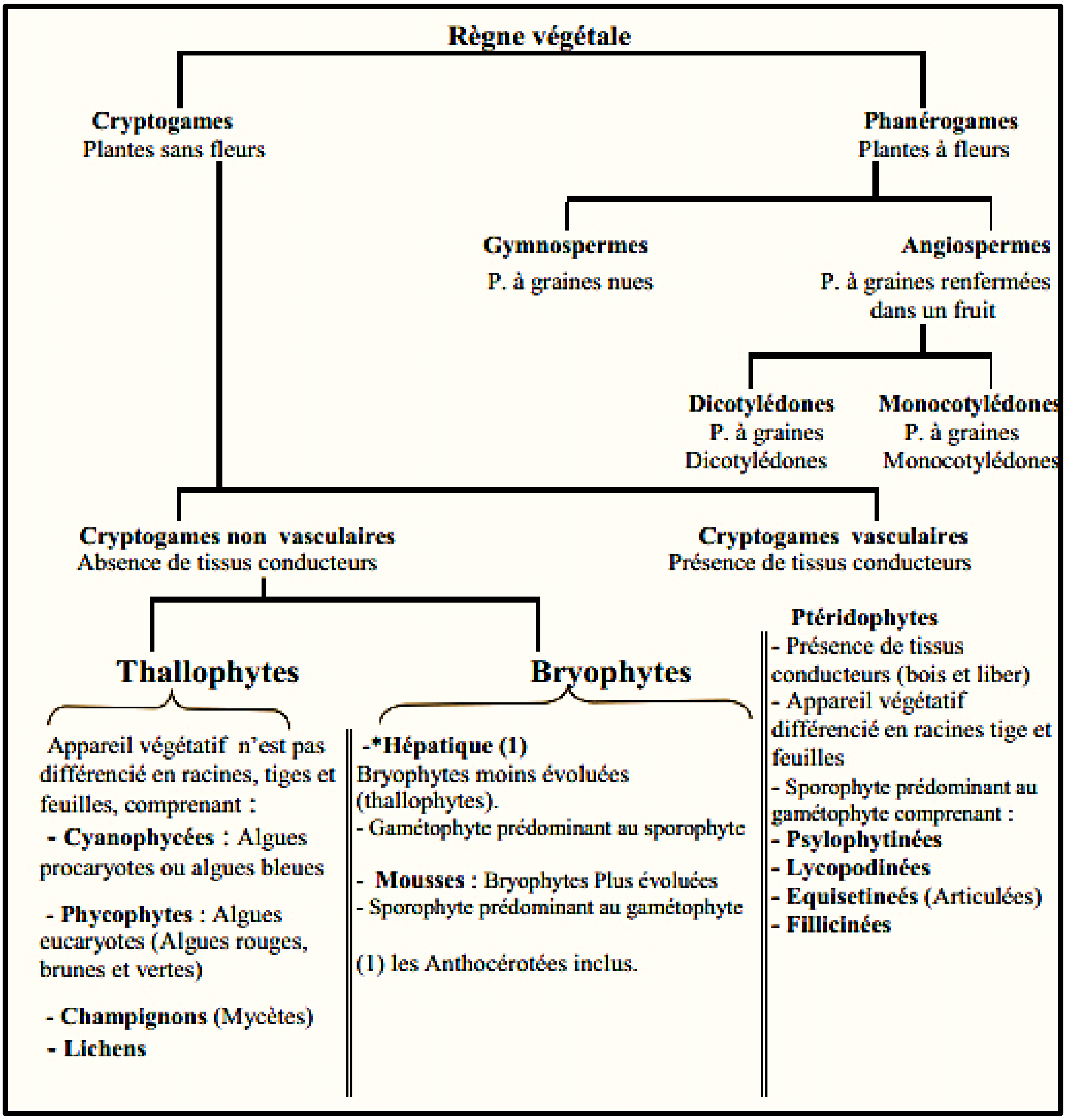


Figure 18: The major groups of the plant kingdom (Zitouni, 2017)

2. CELLULAR ORGANIZATION OF PLANTS

By definition, the plant cell is the basic unit of plant organisms. Angiosperm plant cells generally have a geometric shape because they are surrounded by a rigid skeletal wall of a pectocellulosic nature (Figure 19). The interior of the cell is largely occupied by a vacuole. It also contains cytosomes and organelles called chloroplasts which are specific to it. Higher plants are made up of eukaryotic cells which are distinguished from animal cells by the presence of:

Plastids and assimilatory pigments; Vacuome or vacuolar apparatus; Pectocellulosic wall and Absence of centriole.

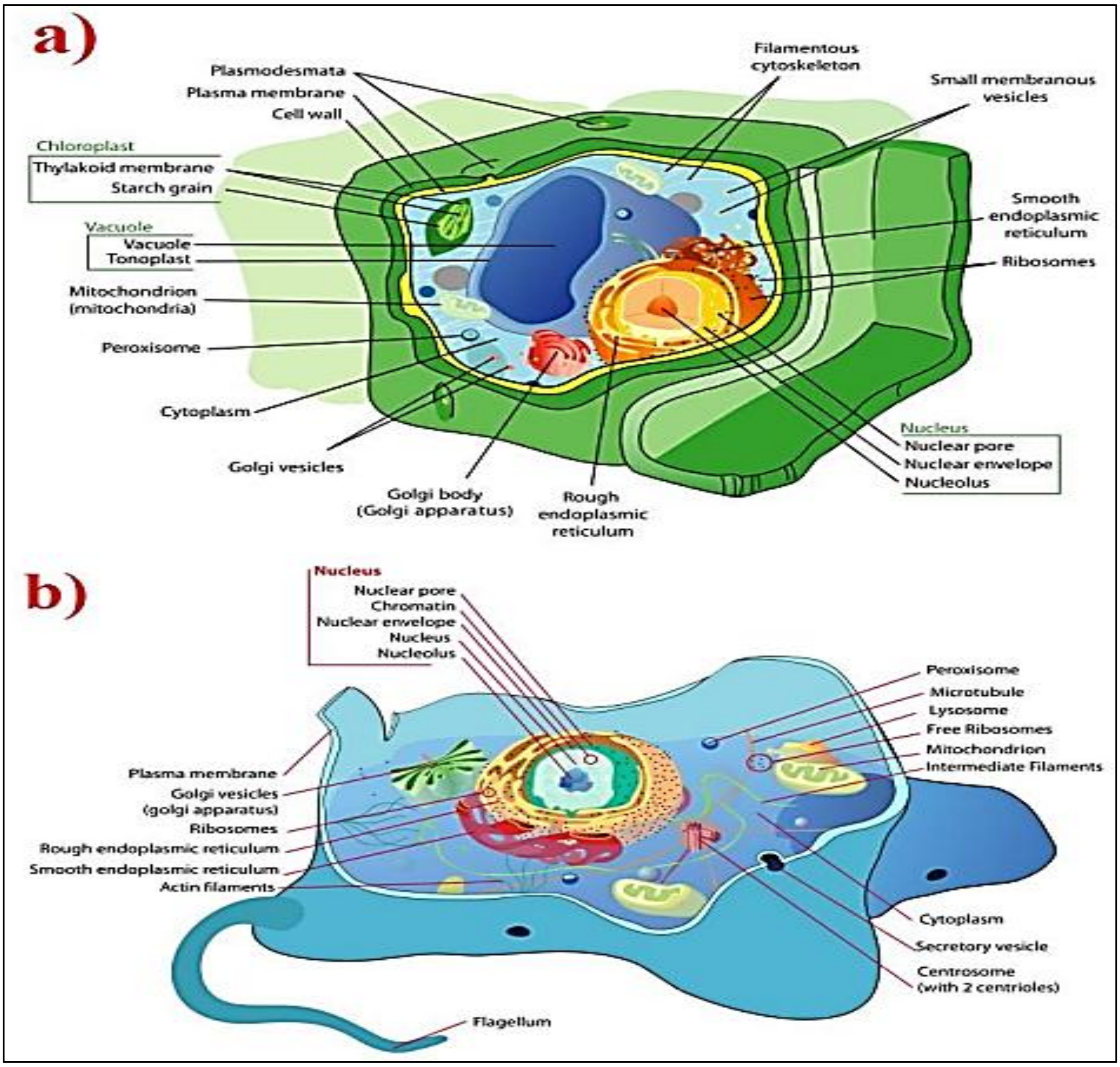


Figure 19: The main difference of cell structures associated with the plant (a) and animal (b) cells (kheyrodin et al., 2022)

Every plant is made up of at least one cell, capable of ensuring the vital functions of nutrition, respiration and synthesis. Each cell is made up of a more rigid envelope "wall", which limits the cytoplasm where the inclusions such as the nucleus, vacuoles, and plastids are bathed and two envelopes surround the plant cell.

2.1. PECTO CELLULOSIC WALL

A unique feature of the plant world compared to the animal world is the presence of a cell wall located beyond the plasmalemma. It ensures the rigidity of the cell without generally preventing water and solutes from crossing it to reach the plasmalemma. It constitutes an extracytoplasmic compartment called apoplasm (figure 20).

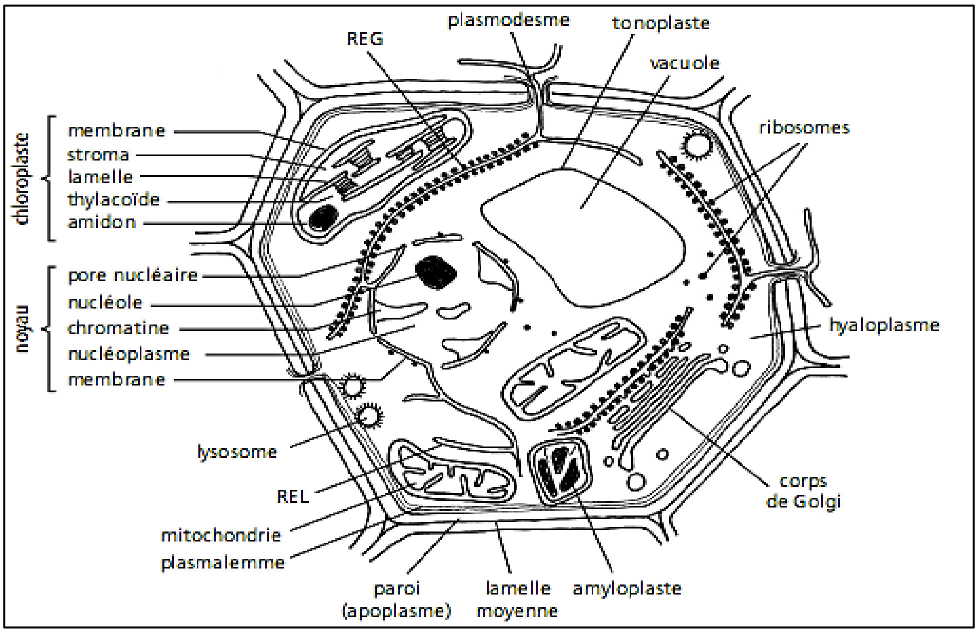


Figure 20: Diagram of the compartments of the plant cell (Laberche, 2004)

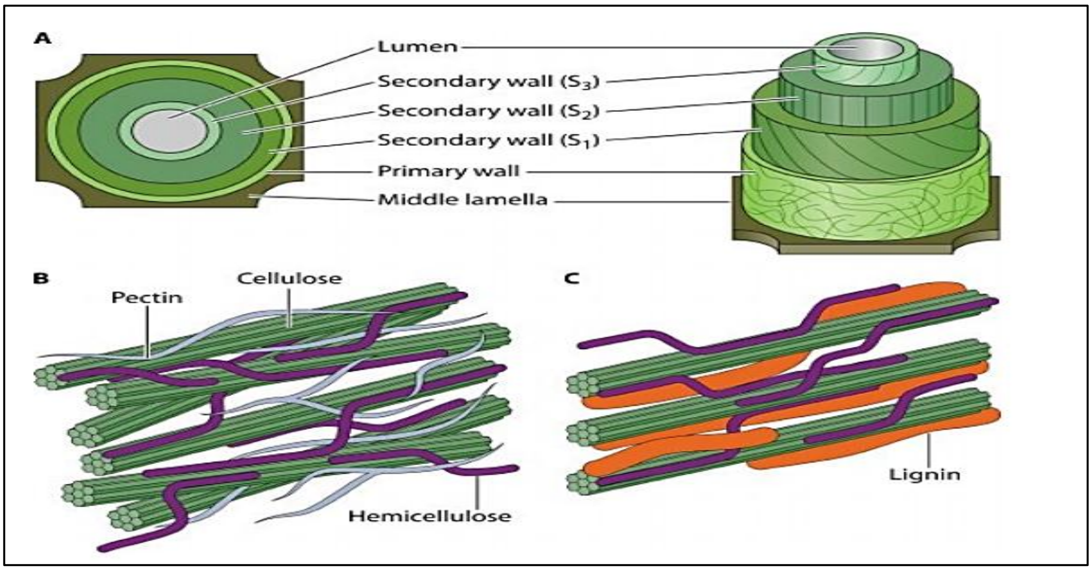


Figure 21: Simplified model of plant cell wall structure. (A) The structure consists of three main layers: the middle lamella and the primary and secondary walls. (A and B) The main polysaccharides and lignin which form the surrounding structure for the plasma membrane are presented in the primary (B) and secondary wall (C). The lignin content in the primary cell wall varies considerably depending on the plant species (Rytioja et al., 2014).

All plant cells have a primary wall consisting of a few cellulose microfibrils and a middle lamella (devoid of cellulose) which constitutes the cement ensuring the junction between the cells of a tissue. Supporting cells, such as sclerenchyma, have an empty central cavity (the cell is dead) and a thick secondary wall. This is generally composed of three cellulose-rich layers oriented differently: horizontally at the periphery and vertically in the middle (Fig. 4.19).

2.1. 1. The Primary Wall

It is the first to be deposited, between the middle lamella and the plasma membrane. 1 to 3 µm thick, it is found in growing and undifferentiated cells undergoing elongation, primarily young parenchyma and meristematic cells.

This primary cell wall is flexible, hydrophilic, and supple. It consists of a network of cellulose microfibrils, pectic compounds, hemicelluloses, structural proteins, and a high proportion of water (up to 60%). These primary cell walls are formed by the cytoplasm and consist of one or more layers. It is the only cell wall of undifferentiated and growing cells.

2.1. 2. The secondary wall

It appears as soon as the primary wall has finished growing, it is rigid, of very variable thickness, formed of several layers of which the most recent are the most internal; it consists of micro fibrils of cellulose arranged in parallel or crossed helical strata, they also contain hemi celluloses and other carbohydrates, it can be impregnated with lignin, silica or suberin (e.g. cork). This wall does not exist in all adult tissues, it is developed by specialized cells.

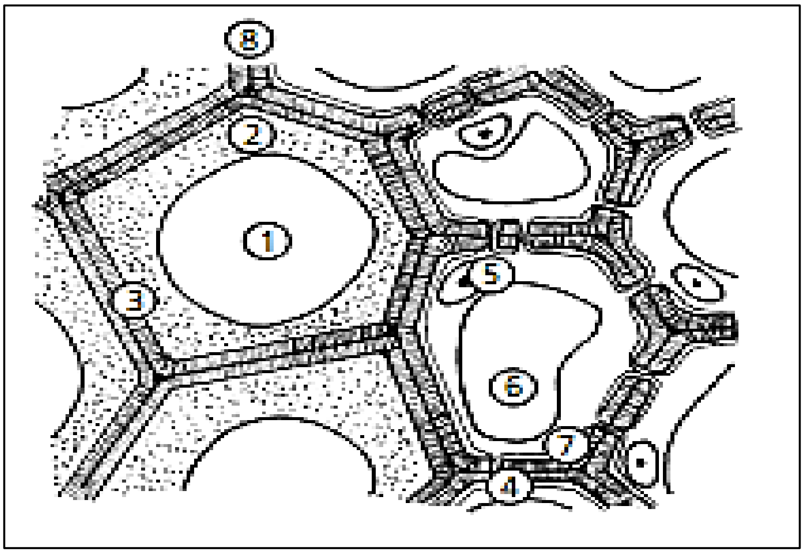


Figure 22: Diagram of the organization of the different walls in cells (1: Empty central cavity; 2: secondary wall; 3: primary wall; 4: plasmodesma; 5: nucleus; 6: vacuole; 7: plasmalemma; 8: middle lamella) (Laberche, 2004).

2.1. 3. Middle lamella

The middle layer between two cells is a cement composed of pectic acids (calcium and magnesium pectates), which are insoluble in water, and therefore provide cohesion between the cells. In older cells, it is impregnated with lignin. Pectic compounds can be hydrolyzed by pectinase enzymes, as is the case in most fruits, and become soluble as the fruits mature.

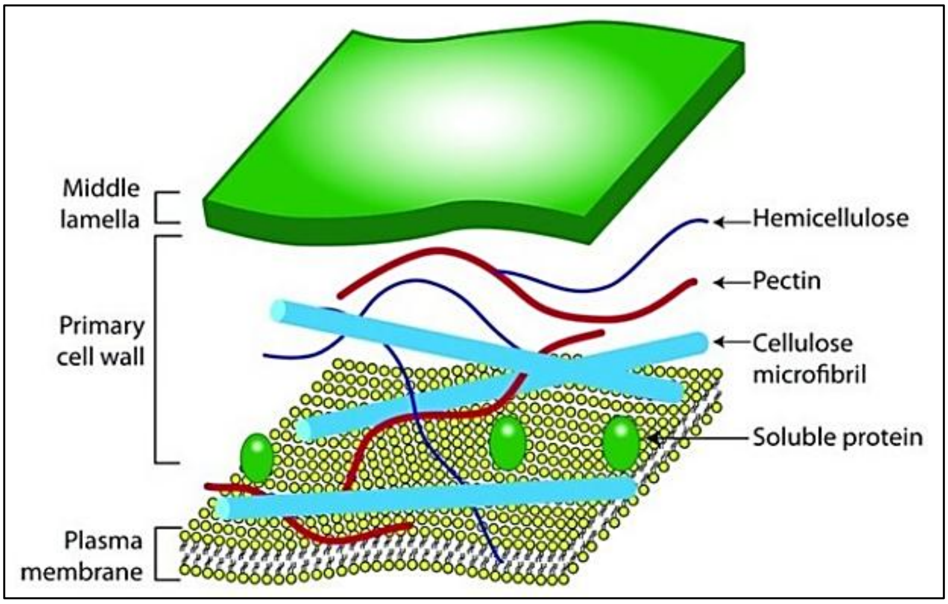


Figure 23: Plant cell wall structure. Diagrammatic representation of the major structural polysaccharide components of a "typical" primary plant cell wall. Plant cell walls consist of cellulose fibrils embedded in a matrix of hemicellulose (xylan, mannan, xyloglucan and β-glucan) and pectin, with lignin also present in secondary walls. Cellulose consists of linear chains of β (1,4)-linked glucose units that form microfibrils through hydrogen bonding (Sjöström, 1993; Harris and Stone,2009; Harry et al., 2012).

The three most important polysaccharide building blocks of plant cell walls are cellulose, hemicellulose, and pectin. Together with lignin, an aromatic heteropolymer, they forma degradation-resistant and functional complex that provides rigidity and structure to the plant and protects the cells from microbial attack (figure 23). The plant cell wall consists of three main layers: the middle lamella and the primary and secondary walls (figure 21, 22). Each of these layers has a unique structure and chemical composition that also differ strongly between plant species, tissues, and the growth phase of the plant.

2.2 CELL MEMBRANES

The most important components of membranes are lipids and proteins. A membrane is formed by a bilayer of phosphoglycerol lipids and cholesterol. Two membranes are particularly important: the plasma membrane and the tonoplast.

2.2.1 Cytoplasmic membrane

The thin, internal membrane that limits the cytoplasm is called the plasma membrane. It limits the cytoplasm of all cells, invisible under a light microscope, and ensures the exchange of water, ions, sugars, amino acids, and proteins.

The plasmalemma is composed of three layers: two dark bands surrounding a light band. This membrane is called the unit membrane or membrane unit. It has the same composition as those of the endoplasmic reticulum, vacuoles (tonoplast), and Golgi bodies; it is doubled in mitochondria and plastids.

These layers are phospholipids, two of which are hydrophilic and one hydrophobic. The light layer is formed by a double layer of phospholipids with opposing molecules, while the dark layer is formed by a layer of proteins, and the hydrophilic portion is phospholipids.

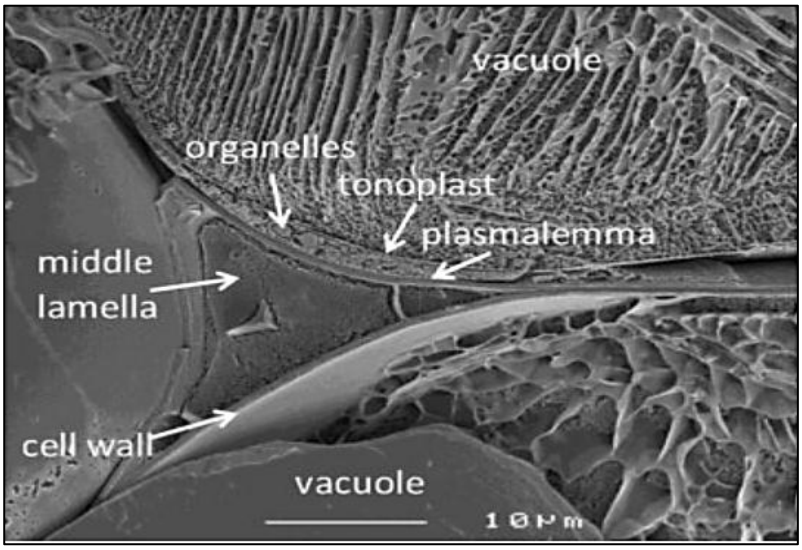


Figure 24: Cryogenic scanning electron micrograph of the interface between 3 different onion parenchyma cells, with various components labeled (Gonzalez and Barrett, 2010).

2.2.2 Tonoplast

The tonoplast is the membrane that separates the vacuole from the cytoplasm of a plant cell (Figure 24). The tonoplast has selective permeability. It plays a role in the osmotic process; it controls the entry and exit of elements stored in the vacuole of the plant cell.

2.3 HYALOPLASM OR BASIC CYTOPLASM

Under a light microscope, it appears as a colloidal, homogeneous, transparent, more or less viscous and elastic substance. Hyaloplasm exhibits:

- A fibrous structure, formed of microfilaments and microtubules measuring 5 to 25 nm
- An organo-mineral composition: 70% to 90% water, decreasing to 10% in mature seeds, 10% to 30% dry matter, which is divided into: 2 to 6% mineral matter, 8 to 24% organic matter. The mineral elements (Ca, P, S, K, Mg, etc.) are partly dissolved salts and ions, and the organic substances are carbohydrates, lipids, and proteins.

When observing cells under a light microscope (Figure 24), the cytoplasm is defined as the space delimited between the plasmalemma and the tonoplast. It consists of the cytosol and organelles. Electron microscope observation of the cytosol does not reveal any structural organization but the presence of a cytoskeleton. The cytosol is the site of many metabolic processes.

2.4 VACUOLES

The vacuome is the collection of vacuoles. Young plant cells generally contain a large number of vacuoles, which are called a vacuome. These small vacuoles, with age, will fuse (during meristematic cell differentiation) to form a large vacuole that can occupy more than 40% of the cell's volume. They are small, numerous, and filamentous.

Vacuoles are regulatory reserves of the plant cell, occupying more than 90% of the cytoplasmic volume and filled with a water-rich liquid: vacuolar liquid.

Variations in cell water content are actually due to variations in the vacuole's water content (turgor or plasmolysis). The vacuole buffers this variation through osmosis. Vacuoles contain mineral elements, organic substances, water, and pigments. The physiological role of the vacuole is to regulate osmotic pressure, pH, and ion concentration.

Vacuolar sap varies from liquid to solid. It contains water (the main constituent), carbohydrates (glucose, fructose, sucrose), organic acids (malic, citric, oxalic acids), tannins, amino acids, colorants (e.g., anthocyanins), mineral salts and ions (nitrates, phosphates), and crystals (e.g., calcium oxalate). In ripe grains, the vacuoles dehydrate (10% water) to form whitefly grains, which are "solid vacuoles." In addition, the tonoplast is the membrane surrounding the vacuole, which stores water, minerals, organic substances, and pigments.

2.5 PLASTES

Plastids are derived from proplastids (organelles or simple, undifferentiated structures located in meristems). They have their own DNA but are semi-autonomous. Plastids are organelles of the eukaryotic plant cell, ovoid to spherical in shape, bounded by a double membrane called the plastid envelope (Figure 25). There are several types of plastids: chromoplasts, leucoplasts, amyloplasts and proteinoplasts.

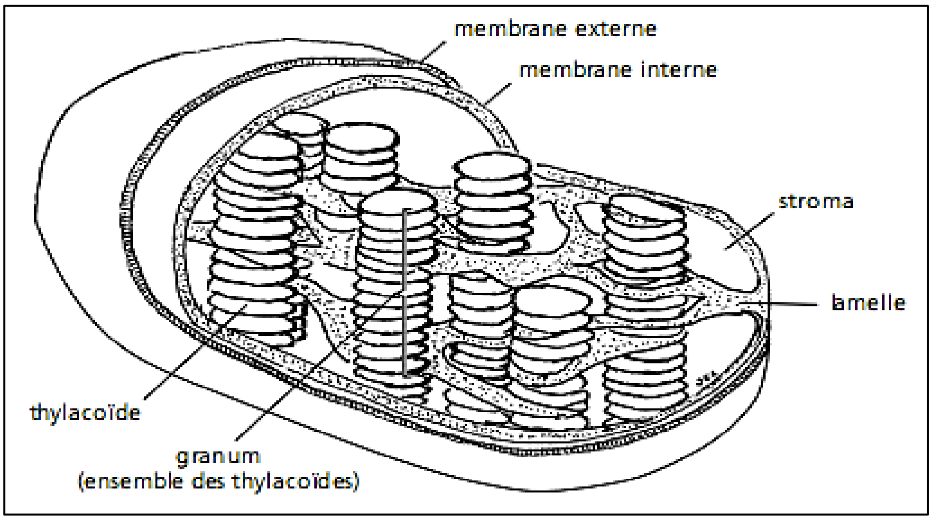


Figure 25: Schematic representation of a chloroplast (Laberche, 2004)

2.5.1 Chloroplasts

They contain chlorophyll pigments. The ultrastructure of a chloroplast shows that it is delimited by a double membrane separated by the intermembrane space, surrounding a stroma that contains ribosomes, circular DNA, starch and lipid droplets in addition to a stack of small saccules called thylakoids (figure below) containing green pigments (chlorophyll) and yellow-orange pigments (carotenoids); the stack of thylakoids forms the granum (several are called grana).

• **Chromoplast:** This is a plastid found in seed plants. They are rich in carotenes, like xanthophylls, which are colored yellow to orange. They are responsible for the color of tomatoes and flower petals.

• **Leucoplasts:** These are non-pigmented plastids located in roots and non-photosynthetic tissues. They specialize in storing reserves of starch (amyloplasts), lipids (oleoplasts), or proteins (proteinoplasts).

• **Amyloplasts:** These are storage organs, as in hypertrophied underground stems such as potato tubers. They are a starch reserve.

• **Oleoplasts:** are organelles in the form of spherical lipid droplets (plastoglobules) specialized in storing lipids.

• **Proteinoplasts:** also called proteoplasts, aleuroplasts, or aleuronaplasts. They contain proteins in crystalline form and are present in certain seeds, for example peanuts.

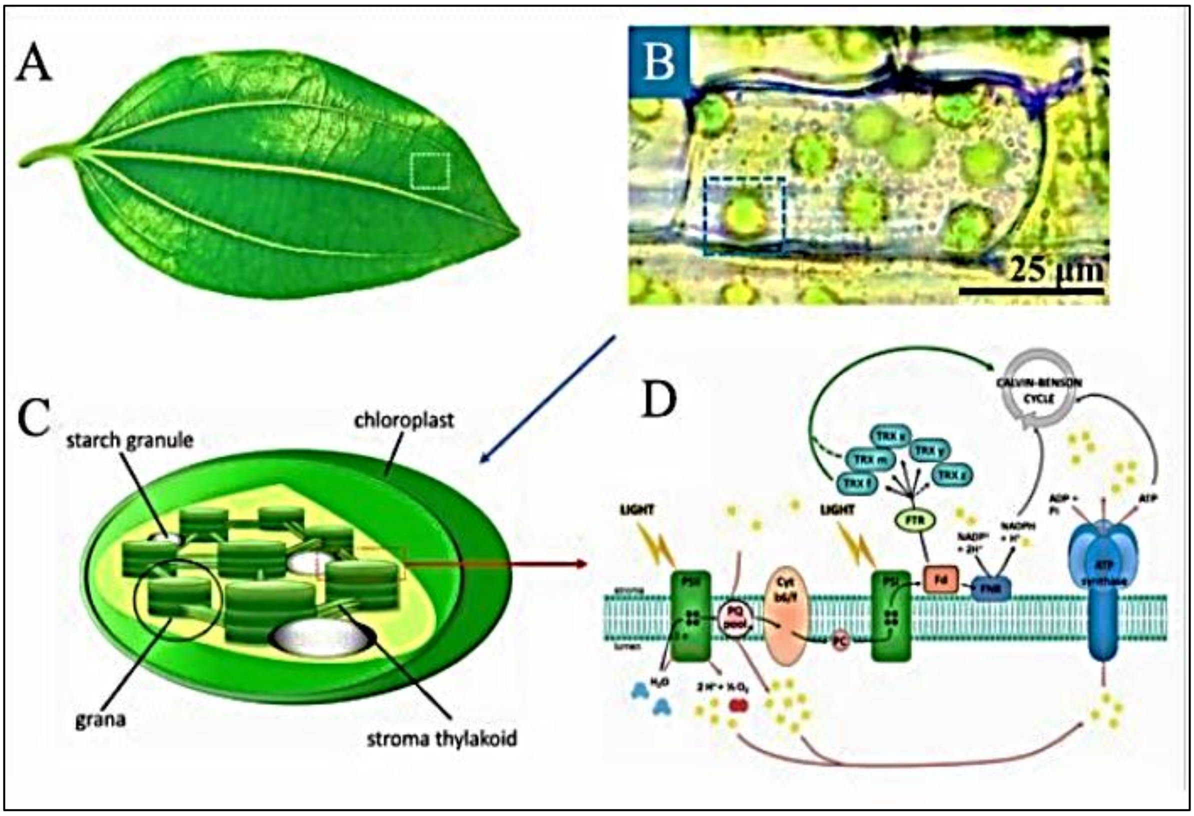


Figure 26: (A) A typical plant leaf. (B) Chloroplasts inside the plant cells. The average size of the chloroplasts is 6 µm (ranging from 3 to 10 µm). (C) Plant cell chloroplast structure. (D) Thylakoid membrane containing photosystem II reaction centers P680 and photosystem I reaction centers P700. On the thylakoid membrane, the natural light-harvesting antenna complexes, photosystem II (PS II, P680) and photosystem I (PS I, P700), capture the photons and regenerate the coenzyme for carbo- hydrates synthesis (D). However, in APS, sunlight is used to create not only the carbohydrates but also other high- value chemicals from abundant resources (Adapted from Michelet et al.,2013 ; Chen et al., 2014).

Plastids can change type (Figure 27); for example, an amyloplast transforms into a chloroplast under the effect of light and a chloroplast can take the form of a chromoplast in citrus fruits; this phenomenon is called the process of interconversion.

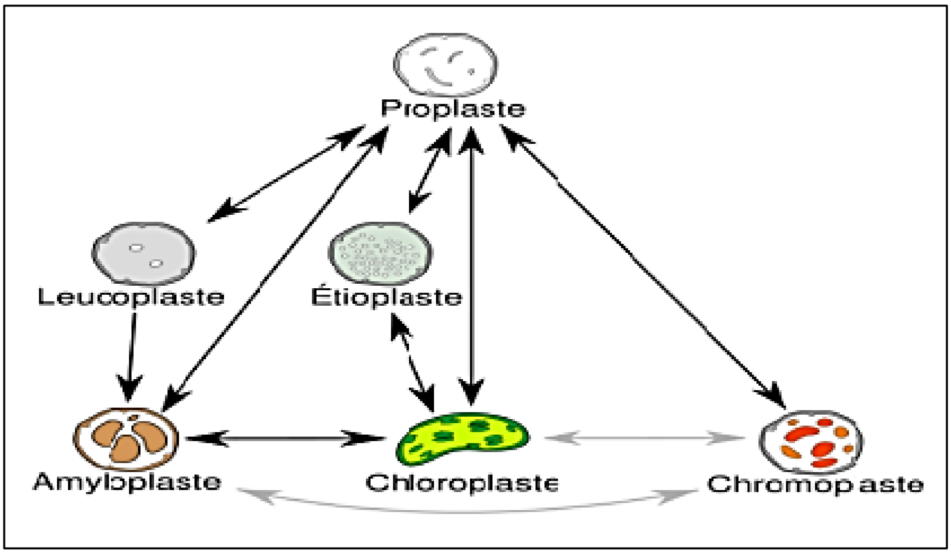


Figure 27: Plastid interconversion process (Gharabi, 2021)

2.6 NUCLEUS (BRAIN OF THE CELL)

It is spherical in shape in young cells (meristems) and often lenticular in plant cells. Its size varies according to the size of the cell and the number of chromosomes. Outside of the division period, the nucleus includes: a nuclear envelope containing the nucleoplasm, chromatin and nucleoli (figure 28).

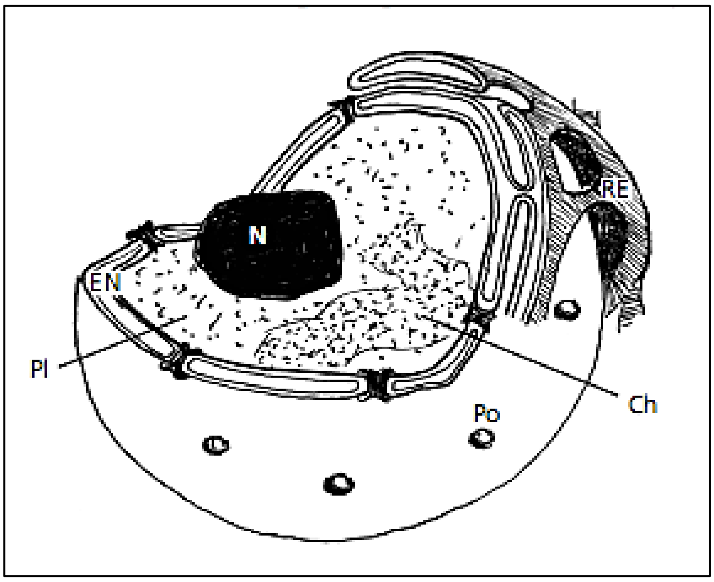


Figure 28: Schematic of the ultrastructure of the nucleus (N, nucleolus; Po, nuclear pores; EN, nuclear envelope; ER, endoplasmic reticulum; Pl, nucleoplasm; Ch, chromatin) (Laberche, 2004)

2.6.1 Nuclear envelope

Double cytoplasmic membrane, punctuated with nuclear pores allowing exchanges with the cytoplasm.

2.6.2 Nucleoplasm

A colorless substance that fills the free space of the nucleus, it ensures turgor, rich in simple proteins and phosphates without nucleic acids or lipids, it has properties close to those of the cytoplasm.

2.6.3 Chromatin

Chromatin is denser than nucleoplasm. It is made up of tangled filaments distributed throughout the nuclear sap. We speak of euchromatin when they are loose and heterochromatin when they are tightly packed. Chromatin is the form of chromosomes outside of periods of division; it is made up of DNA (deoxyribonucleic acid).

2.6.4 Nucleoli

These are nuclear inclusions, spherical in shape; their number varies depending on the species and their shape according to the physiological state of the cells. They are no longer separated from the nuclear sap. They are formed of fibrils and granules that contain RNA (ribonucleic acids). The nucleus is the brain of everything that must be carried out in the life not only of a cell but of the entire individual.

CHAPTER II
PLANT HISTOLOGY

In most plants, the various vital functions are performed by different organs made up of specialized tissues. A tissue is a group of cells with the same embryological origin and which have similarly differentiated in order to perform a certain function.

Unlike the lower plants (Algae, fungi, lichens) and intermediates (Bryophytes and Pteridophytes), tissue formation (histogenesis) and organ appearance (organogenesis) are not ensured by meristematic cells unique to each organ. But in flowering plants (higher plants), histogenesis and organogenesis is ensured by specialized homogeneous regions which are the meristems. The first meristems are usually formed at the end of the future stem and the future root (at the embryo level). The cell divisions in these meristems begin at the time of seed germination and allow the growth in length of stems and roots and even the formation of young leaves.

Thus, the fundamental growth tissue of higher plants is called meristem or embryonic tissue, whose cells are alive and perform all functions at once. This meristematic tissue is at the end of the growing root and stem. All other tissues derive from it by differentiation and specialization. Tissues will form organs such as roots, stems, leaves, and flowers.

According to the physiological function determined, tissues are classified into six main groups:

- The meristems or tissues of cell divisions or growth,
- Parenchyma or fundamental tissue or filling,
- Coating fabrics or protective or surface fabric,
- Support tissues or mechanical tissues,
- Conduction tissues,
- Secretion tissues.

1. MERISTEMS OR CELL DIVISION TISSUES

This meristematic tissue is found at the end of roots and stems and gives birth to all plant tissues. Two types of meristems are distinguished: primary or apical meristems and secondary or lateral (Cambium).

1.1 PRIMARY OR APICAL MERISTEMES

These are tissues made up of groups of embryonic cells, small in size with dense cytoplasm, little or no vacuolized, voluminous nucleus endowed with a great power of division. These meristems are set up during embryogenesis, that is to say, when the embryo is differentiated from the zygote. They are found mainly at the apex of stems and roots (vegetative point) (Figures 29, 30).

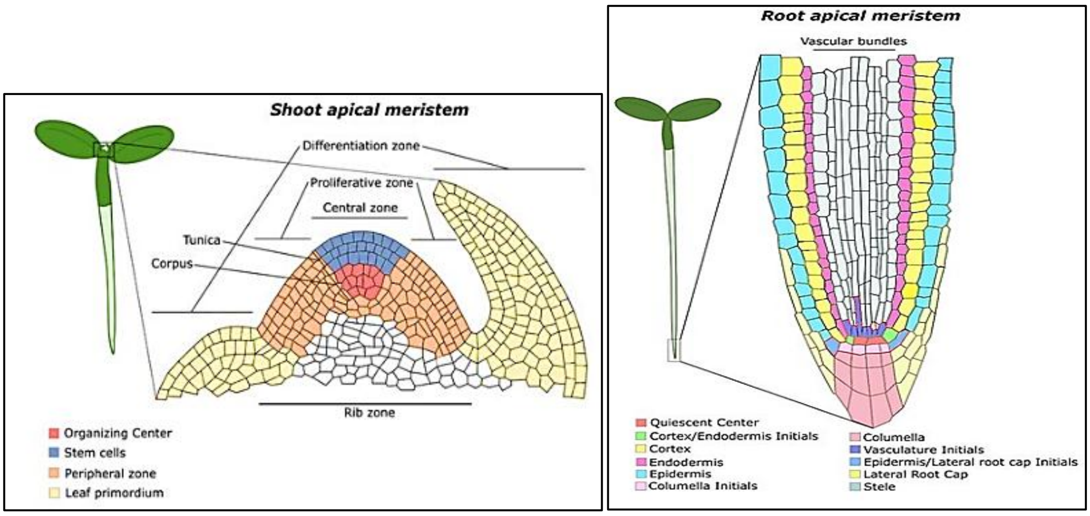


Figure 29: Plant meristem organization - Schematic representation of Arabidopsis Shoot Apical Meristem (SAM) (Di Pietro et al., 2024)

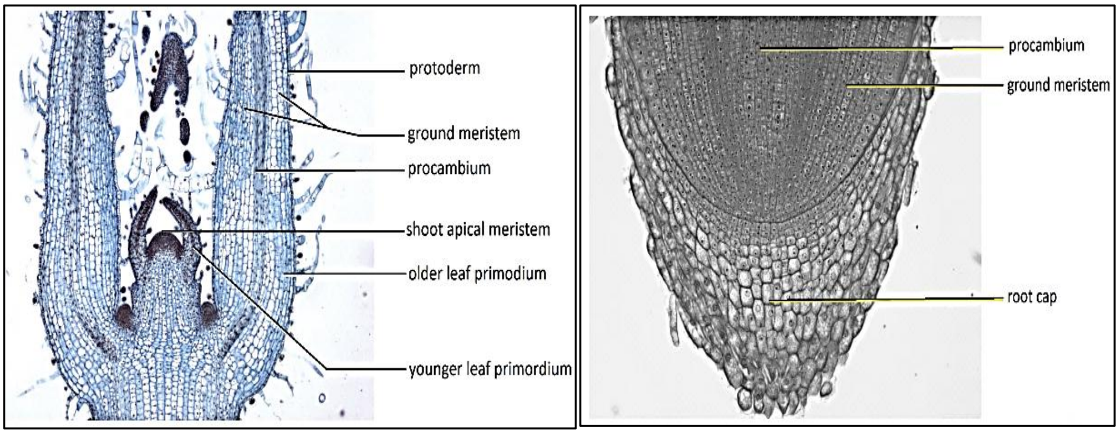


Figure 30: A longitudinal section of the shoot apex of *Coleus* (left) and a longitudinal section of the root tip of corn (*Zea mays*) (right) (Petricka et al., 2012)

The longitudinal section of the shoot apex of *Coleus* includes the shoot apical meristem and the developing leaves (leaf primoridia) that surround it. The three primary meristems are visible in the leaf primordia. The protoderm surrounds the leaf primoridum, the procambium appears as a line running through the center, and the ground meristem fills the rest of the leaf primodium (figure 30 left).

For the longitudinal section of the root tip of corn (*Zea mays*); the large, lighter cells at the bottom form the protective root cap. The remaining visible portion of the root tip (above the root cap) is the **root apical meristem** (zone of cell division). It gives rise to the central **procambium** and the **ground meristem**, which is external to the procambium. The third primary meristem (**protoderm**) is not visible here. It would be the outer layer of the root tip, just above the current view (figure 30 right).

Moreover, the meristems are located at the end of the stems (caulinar meristems) and roots (root meristems) and at the base of the leaves (Figure30). They constitute the primary tissues. The primary meristemic cells are isodiametric, small, their nucleus is, voluminous, spherical, many vacuoles but of very small size and undifferentiated plasts (proplasts). They ensure growth in length.

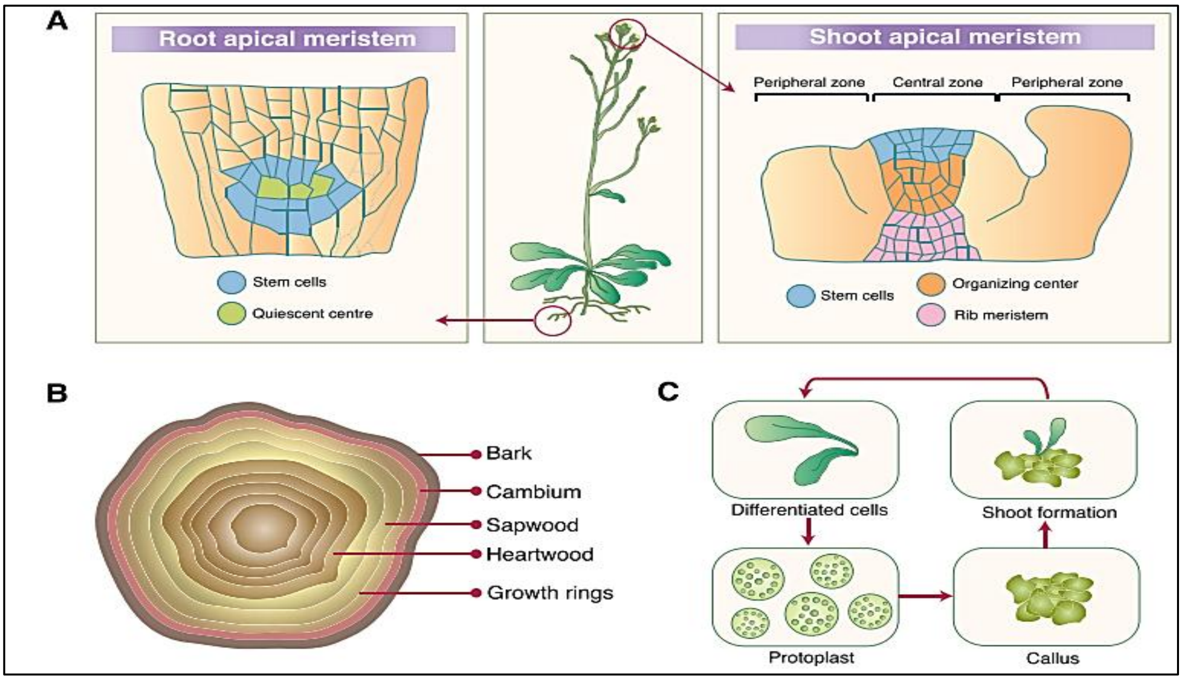


Figure 31: Plant stem cells (Gaillochet and Lohmann, 2015; Dijkwel and Lai, 2019)

The above figure illustrates schematic diagram of longitudinal sections of shoot apical meristem and root apical meristem in Arabidopsis (figure 31 A). Stem cells are organized within the stem cell niche where adjacent cells serve to maintain their pluripotency. Cross section of a tree trunk (figure 31 B). Cambium cell division results in wood and bark formation but can also induce lateral root or shoot formation. Wood and bark consist of cells that have undergone programmed cell death. Largely seasonal plant growth leads to the emergence of growth rings. In plants (figure 31 C), adult structures can dedifferentiate to become cells with stem cell-like properties. Plant mesophyll cells, stripped from their cell walls by enzymatic digestion, are called protoplasts and can dedifferentiate into pluripotent cells.

For this purpose, at the apex (the end of a stem or root) (figures 29, 31), new organs appear through the functioning of meristems, these are the caulinar apical meristems located on the apical region of the stems and the root apical meristems located on the end of the root. They are present in all plants, but work differently. The cells resulting from meristemic mitoses differentiate, thus losing their power of division, ensuring the growth in length of the caulinar and root axes or primary growth.

1.1.1 The root meristem

The root apical meristem is also formed during embryogenesis. It develops the tissues of the root and the cap: it is only histogenic. It does not produce lateral organs and is therefore not organogenic (Figure 32). The lateral roots are formed endogenously at some distance from the apex from the pericycle (cell base located between the bark and the stele). The structure and functioning of the branches are identical to those of the root apical meristem.

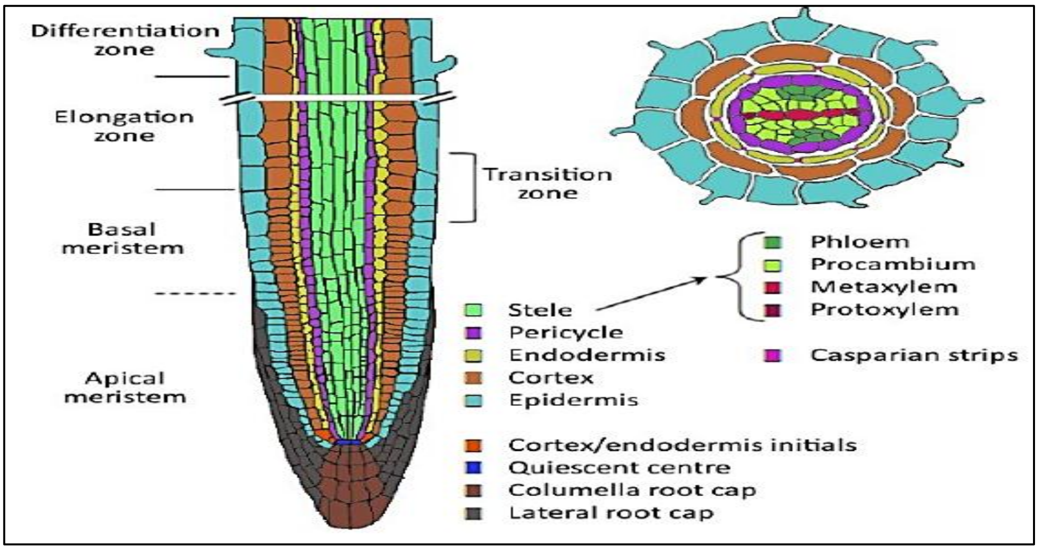


Figure 32: Organization of the Arabidopsis root (Péret et al. , 2009; Petricka et al., 2012; Lee et al., 2012). (Left): Longitudinal section through the root showing apical-basal polarity. Different cell types (each differently coloured) are arranged in cell files, forming concentric single-celled layers surrounding the central vascular tissue. Distinct developmental zones are formed along the growing root. Cell division occurs in the meristematic zone, especially the apical meristem. Cell division rate slows down in the basal meristem and cells start to elongate in the elongation zone. The boundary between meristematic and elongation zone is indicated as the transition zone. Cell differentiation occurs in the differentiation zone; (Right): Radial polarity in on a cross section of the differentiated root zone showing the formation of root hairs and Casparian strips.

1.1.2. The shoot apical meristem

The caulinar (stem) meristem is responsible for building up the aerial part of the plant, from it, cells appear that by multiplying and differentiating will give stems, leaves, apical and axillary buds and floral buds, it is therefore histogenic and organogenic, in a completely repetitive and indefinite way, until the death of the plant.

The caulinar meristem is not a simple stack of cells, but in reality several areas without very clear boundaries. In angiosperms, this meristem forms a dome 0.5 to 3 mm in diameter.

As illustrated in the following two figures (Figure 33, 34), the central section of the caulinar meristem reveals the existence of three regions:

- Z.C. (Central Zone; Axial Zone): Cells rarely divide and give birth to the Z.P. and Z.M.
- Z. (Peripheral Area; Lateral Area; Initial Ring): Cells dividing rapidly to give birth to foliar primordials and a part of the stem.
- Z.M. (Zone médullaire or Meristem Médullaire): sets up the central tissues of the stem.

A. The transformation of the apical meristem into floral meristem

Under the action of processes, which could be linked to proteins, the caulinar meristem is transformed into a floral meristem (figure 33). This change is accompanied by exceptional changes. A system with undefined growth, such as the apical meristem, becomes defined, since, once the floral morphogenesis is finished, the meristem ceases all activity and disappears at the fall of flowers or fruits.

These transformations correspond to a slowdown of activity of the lateral zone (ZL) which will give the sepals, first floral pieces appearing, while the corpus proliferates abundantly setting up what will become the floral receptacle. The tunica T2 will be at the origin of the reproducing floral pieces.

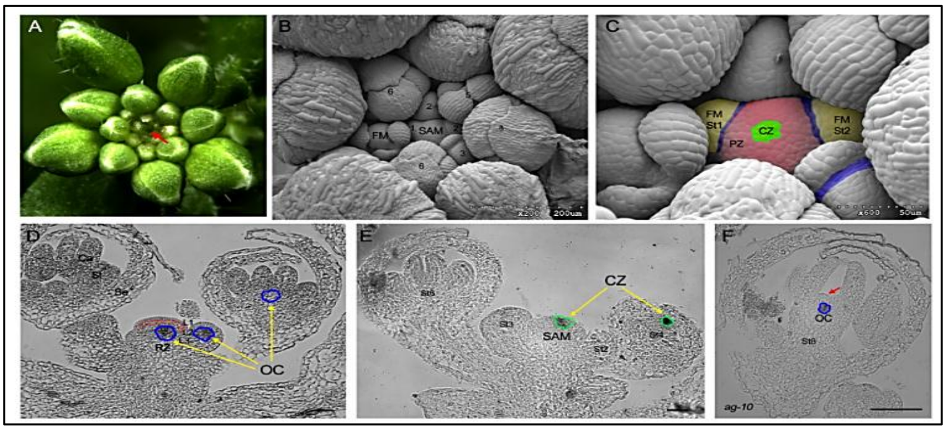


Figure 33: The shoot apical meristem (SAM) and floral meristems (FM) of Arabidopsis (Chang et al., 2020). (A) Top view of the inflorescence. The SAM is localized at the center and marked

by a red arrow. (B,C) Overhead view of the SAM and FM. Numbers indicate the developmental stage of flower. The central zone (CZ) and peripheral zone (PZ) are labeled by green and magenta color, respectively.

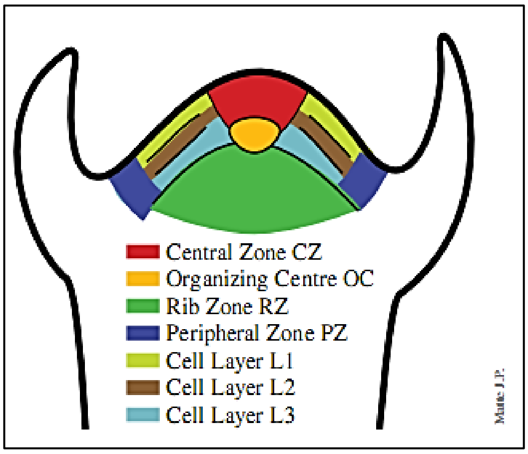


Figure 34: Schematic representation of shoot apical meristem (SAM) layers and domains. Central zone (ZN), organising centre (OC), rib zone (RZ), peripheral zone (PZ), cell layer L1, cell layer L2 and cell layer L3. The SAM stem cell population is localised in layers 1–3of the central zone (Matte Risopatron et al., 2010).

1.2 SECONDARY OR LATERAL MERISTEMS

The secondary meristems are at the origin of the secondary tissues, they consist of generating bases in the form of rings formed by cells able to divide quickly (figure35). These secondary meristem cells differ from the primary meristem cells by their rectangular shape and cell content: a central vacuole and a nucleus that occupies a lateral position.

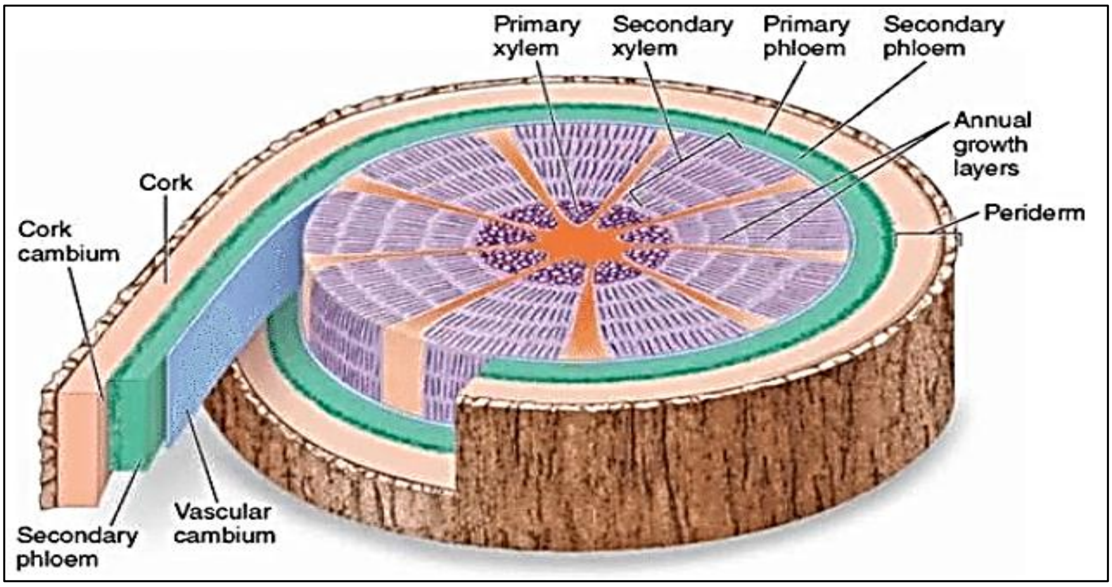


Figure 35: Position of secondary tissues within the plant structure (Wi et al., 2014)

The secondary meristem is a spawning zone that appears later in the plant's maturity. The cells allow a thick growth around the stem and roots of Gymnosperms and Angiosperms Dicotyledons, the Angiosperms Monocotyledones do not possess. Thus, in plants, there are two secondary meristems that differentiate late (Figures 36, 37): phellogene and cambium, appear after the primary meristems. They ensure the growth in thickness and give the secondary tissues that constitute the secondary structure.

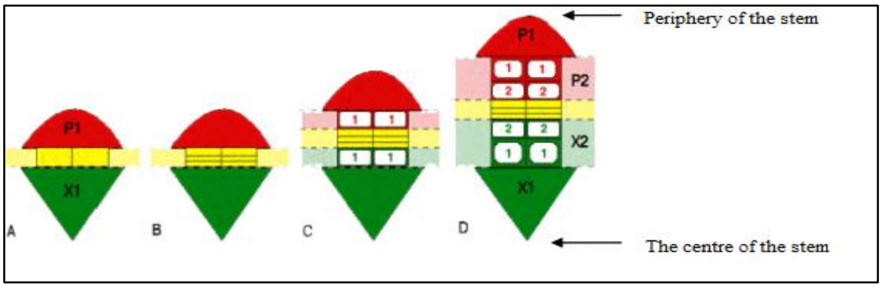


Figure 36: Development of the liberoligous cambium (stem) **(**Raven et al., 2014)

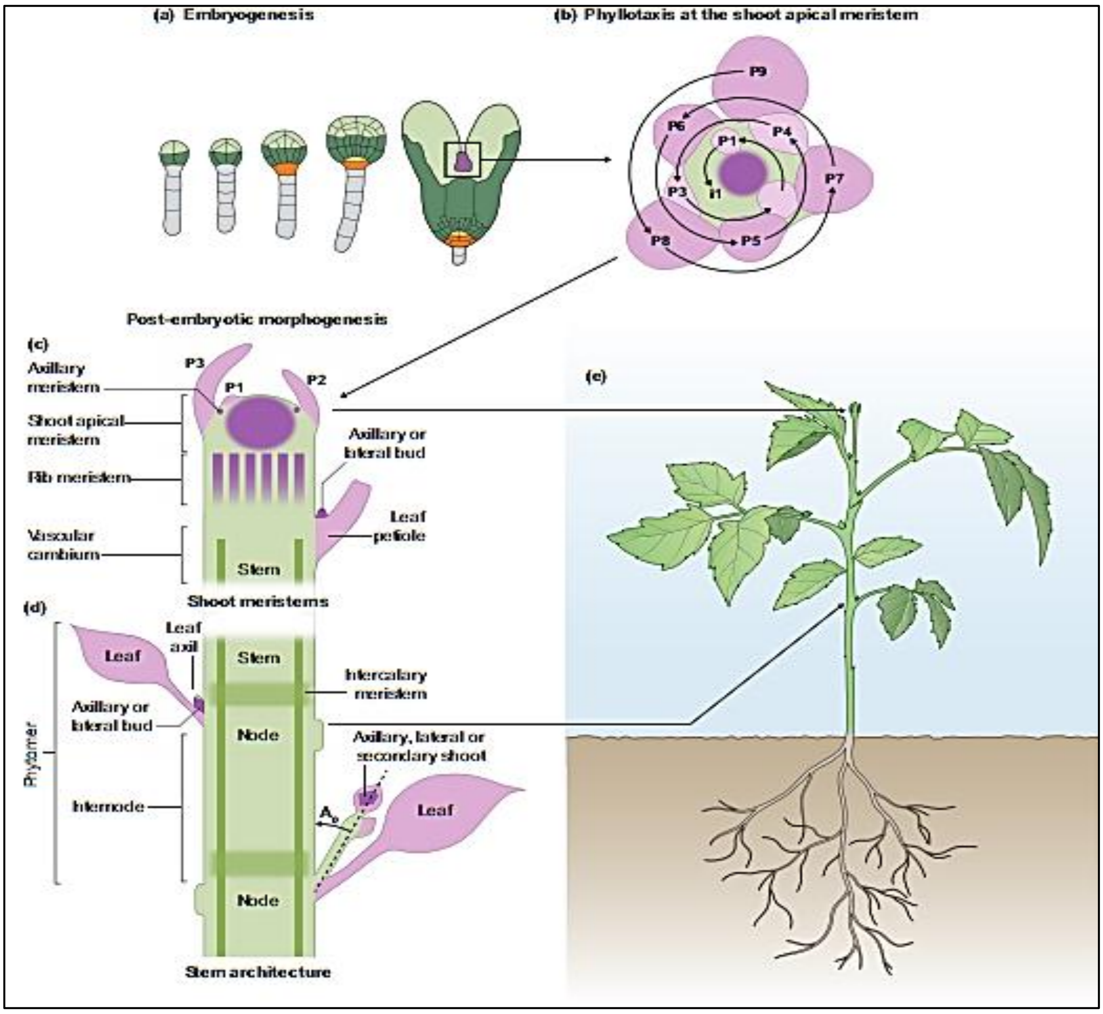


Figure 37: The major stages of early plant development in land Angiosperms. (a) Early embryo development in Arabidopsis thaliana (with the central zone of the shoot apical meristem (SAM)

in purple). (b) Top view of the SAM in Arabidopsis thaliana with the phyllotactic patterning of the leaf primordial. (c) Schematic view of a longitudinal cross-cut of the SAM showing the SAM and leaf primordial. (d) Schematic view of a stem organised into a modular set of segments called phytomers. (e) A typical young dicot with the location of its SAM and phytomers, as well as the onset of branching when an AM becomes active as a new SAM, producing a lateral axis with a insertion angle A_0 (Murray et al.; 2012;_ Radoeva &Weijers, 2014; Wang et al., 2018).

The cells of the primary secondary meristem (cambium) divide radially in such a way as to create secondary xylem or wood inside and secondary phloem or liber outside (Figure 38). The cambium consists of two kinds of cells: long initials or fusiform initials and short initials or radial initials; it is the presence of two systems: the vertical system, containing the long elements specialized in long-distance conduction and the horizontal or radial system, containing short cells or rays. Thus, the cambium allows the enlargement of the central cylinder whereas the phellogene allows the enlargement of the cortex.

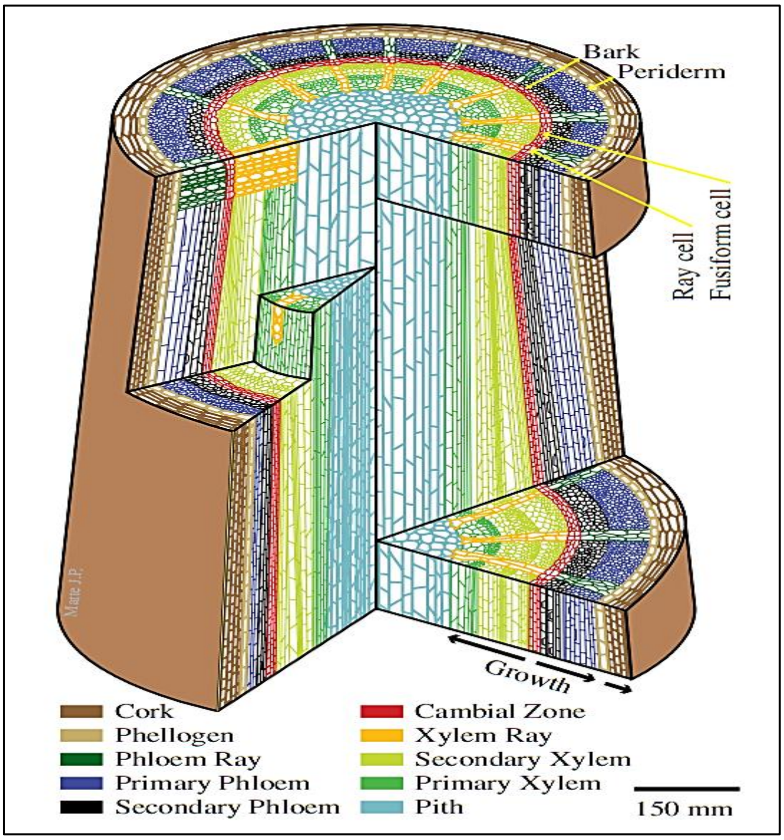


Figure 38: Internal structure of a woody plant stem. The vascular cambium consists of a centrifugal layer of fusiform secondary phloem and a centripetal layer of secondary xylem cells surrounding a central zone comprising phloem and xylem transit amplifying cells with a central uniseriate layer of cambial stem cells. Most angiosperm and gynomsperm tree species also

contain radial files of near isodiametric ray cells that play a role in nutrient transport and storage (Matte Risopatron et al., 2010).

1.2.1 The "Cambium" broad-leaved generating zone

This zone is located between the xylem and the phloem (towards the centre) (figure38), it is responsible for the formation of secondary conductive tissues, it has a mitotic activity directed in the radial direction responsible for the formation of secondary xylem (wood) towards the inside and secondary phloem (liber) towards the outside.

1.2.2 The subéro-fellodermic generating zone «Phellogene»

This zone is responsible for the formation of secondary protective tissues, it is located in the bark (towards the periphery) (figure38), it is responsible for the appearance of cork (suber) towards the outside and from the phelloderm towards the inside.

The following two figures (Figure 39, 40) provide information on the location, organization and functioning of secondary meristers. They form secondary addition tissues determining growth in diameter or secondary growth. There are two types of secondary meristems: the cambium (producing secondary vascular tissues) and the phellogene (producing secondary coating tissues).

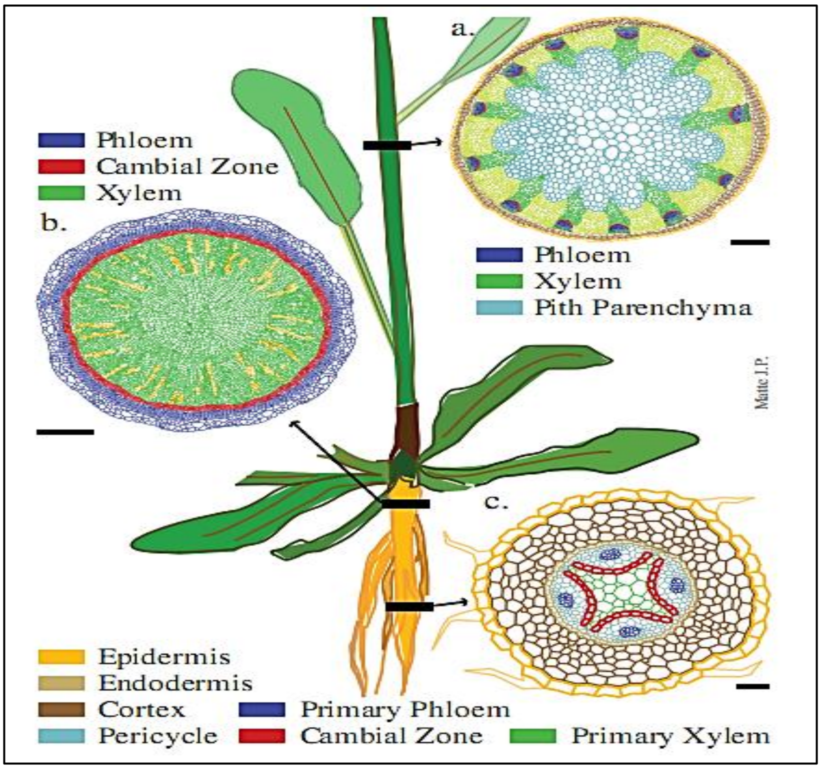


Figure 39: Arabidopsis plant with transverse sections of three tissues used for the analysis of cambial development (a) inflorescence stem showing primary vascular bundles (b), hypocotyl (c) and upper section of main root (c). Bar=200 µm (Matte Risopatron et al., 2010).

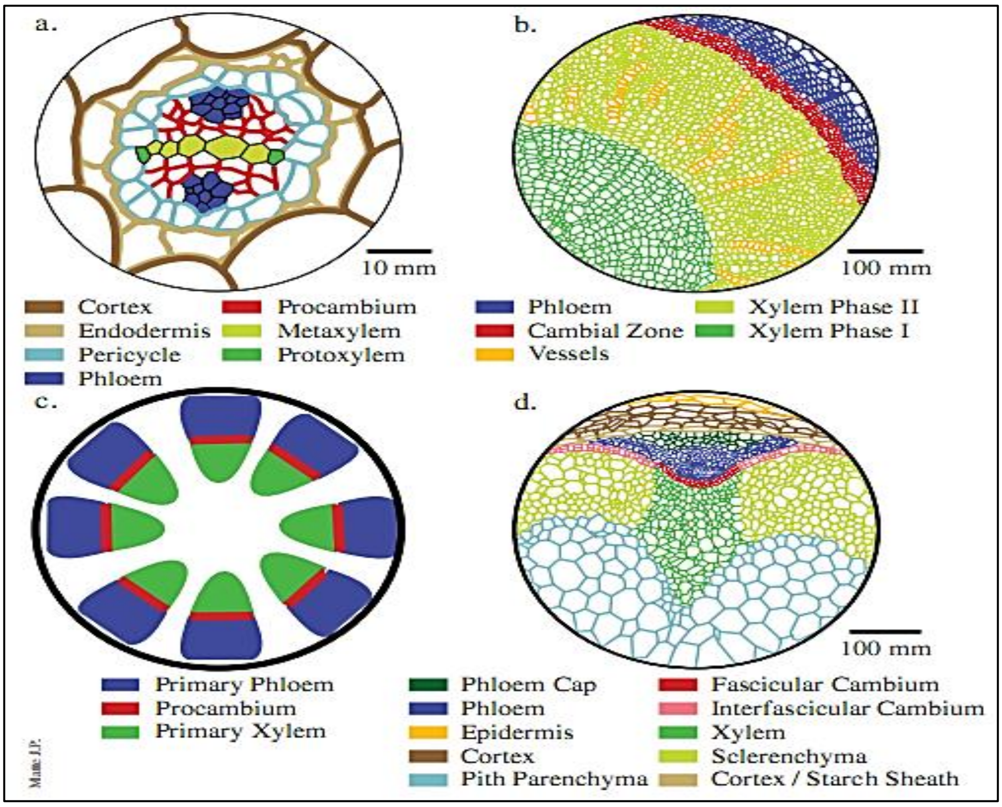


Figure 40: Transverse sections of *Arabidopsis thaliana* showing cellular organisation according at its use in the study of secondary growth. (a) Base of hypocotyl of 10-day-old seedling: an advantage of this tissue is that it is possible to obtain a clear and detailed picture of the cellular organization and any perturbations. (b) Hypocotyls at 8 weeks showing phase I and II of secondary xylem production: with this tissue it is possible to get similar structures as a woody plant (although without ray files). (c) Schematic representation of inflorescence stem showing structure of primary vascular bundles. (d) Base of inflorescence stem at 6 weeks: where it is possible to study the growth of the fascicular and interfascicular cambia, giving a clear model for the characterization of the initiation of secondary growth. Structure in (a) will develop into structure in (b) and structure in (c) will develop into structure in (d) (Matte Risopatron et al., 2010).

2. THE PARENCHYMA OR TISSUE FILLING

Tissue consisting of living cells, vacuolized, little differentiated, usually thin-walled and pecto-cellulosic. This parenchymatous tissue, described as fundamental, is intimately linked to the essential physiological activities of the plant (figure 41). It consists of living cells with thin walls and well-developed vacuole. The filling fabric is of primary origin, it comes from primary meristems.

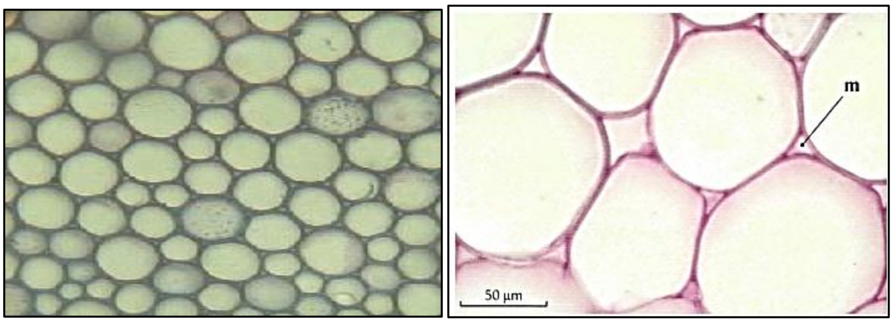


Figure 41: Parenchyma under optical microscope with meats (m) (Boutin et al., 2010)

Classified according to cell shape and tissue function. Parenchyma is divided into the following types:

2.1 CHLOROPHYLLINE OR CHLORENCHYME PARENCHYMA

It is characterized by the abundance of chloroplasts and can be found in any photosynthetic organ. The leaves contain mainly palisade and lacunous or meatic parenchyma.

2.1.1 The palisade chlorophyll parenchyma

It is the tissue that enables photosynthesis. This parenchyma consists of elongated cells, parallelepiped, pressed against each other, forming continuous bases without intercellular spaces (Figure 42, 43). The cells that make up this parenchyma contain many chloroplasts. At the level of the leaves, the palisade parenchyma is on the upper side surrounded by the epidermis and crossed by the ribs.

2.1.2 The lacunous or meatic chlorophyllian parenchyma

Made up of cells of various slightly elongated shapes, more or less rounded or star-shaped with large gaps between them where the gases circulate (Figure 42, 43). This parenchyma is usually found on the lower leaf face, with a reduced number of chloroplasts, participating in gas exchange by the stomata**.**

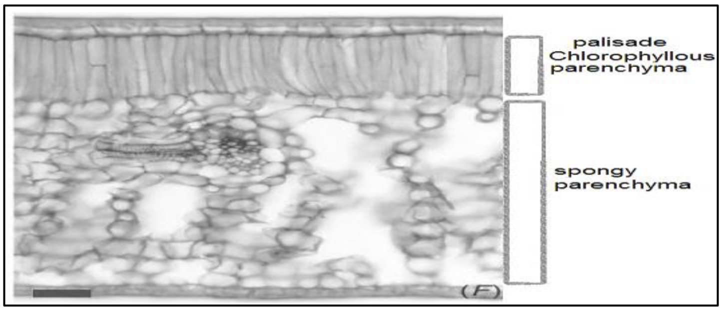


Figure 42: *Blepharocalyx salicifolius,* showing epidermal cells of the adaxial surface with both periclinal walls thickened and palisade parenchyma occupying 25–30% of the mesophyll and compact spongy parenchyma (Cardosoet al., 2009).

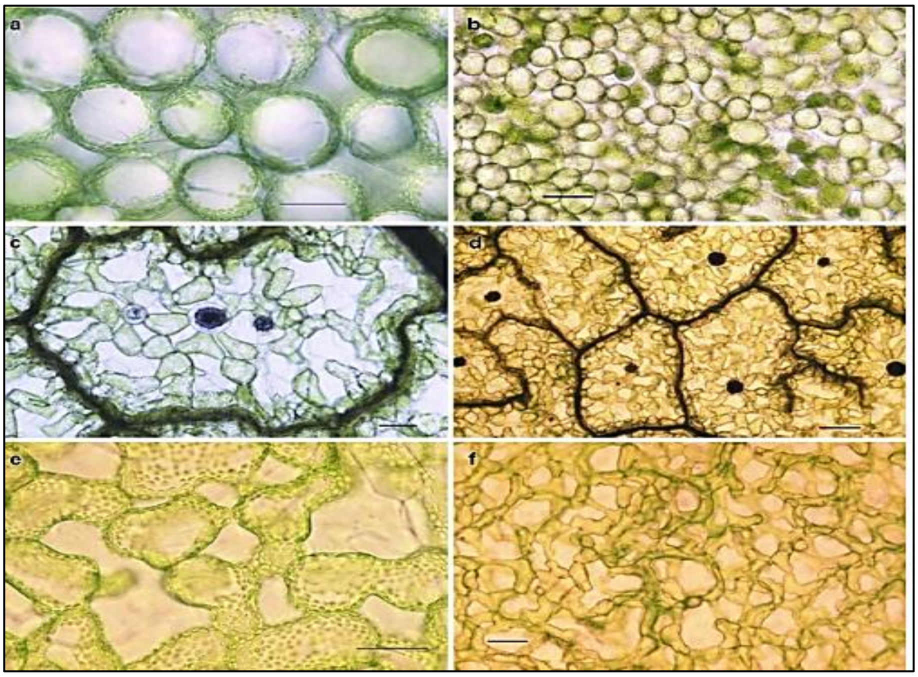


Figure 43: Light microscopic photomicrographs of *Spinacia oleracea* leaf fresh paradermal sections. **a** Palisade mesophyll. Bar equals 50 μm. The image illustrates the chloroplasts localized along the long surfaces of the cells but not at the top of the cells. **b** Some of the palisade mesophyll cells are not perpendicular to the leaf surface, as seen as the darker green. The darker green is also due to attached broken cells. **c** Minor vascular tissue containing specialized palisade mesophyll cells shaped like pears, referred to as pirum mesophyll. **d** The pirum mesophyll cells appear as spokes of a wheel around the idioblasts. **f** Typical spongy mesophyll cells from the lower portion of the spongy mesophyll were curved and tightly connected to one another (Biel et al., 2010)

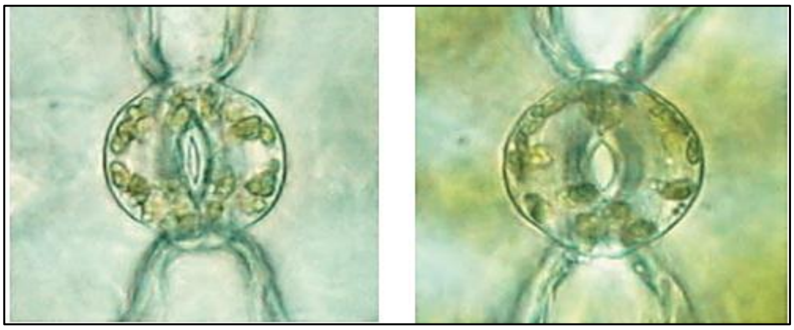


Figure 44: Open stomata (right) and closed stomata (left) (Raven et al., 2003).

Stomata are openings of the epidermis of leaves and stems, consist of two renal cells, called guard cells or stomatal cells, between them have an opening called the ostiole, which allows gas exchanges. In an epidermis, only the stomatal cells have chloroplasts. This image above (Figure

44) illustrates the morphological change in stomatal cells following an entry of water, which causes the ostiole to open.

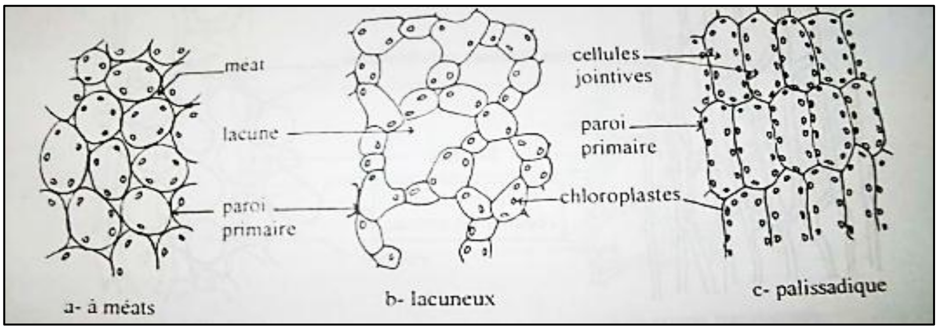


Figure 45: Palisadic parenchyma (c), lacunous parenchyma (b) and meaty parenchyma (a) (Gharabi, 2021)

2.2. RESERVE PARENCHYMA

Inside the stems or roots, there are reserve parenchyms that come in various forms: leucoplasts forming starch grains (insoluble carbohydrate in potatoes). The reserve parenchyma of living cells found in roots, underground stems, fruits and seeds (Figure 46). These reserves are used to maintain plant tissues. They can be in the form of carbohydrates (sugar beets), starch (potatoes), lipids (groundnut seeds) and protides (cereal grains).

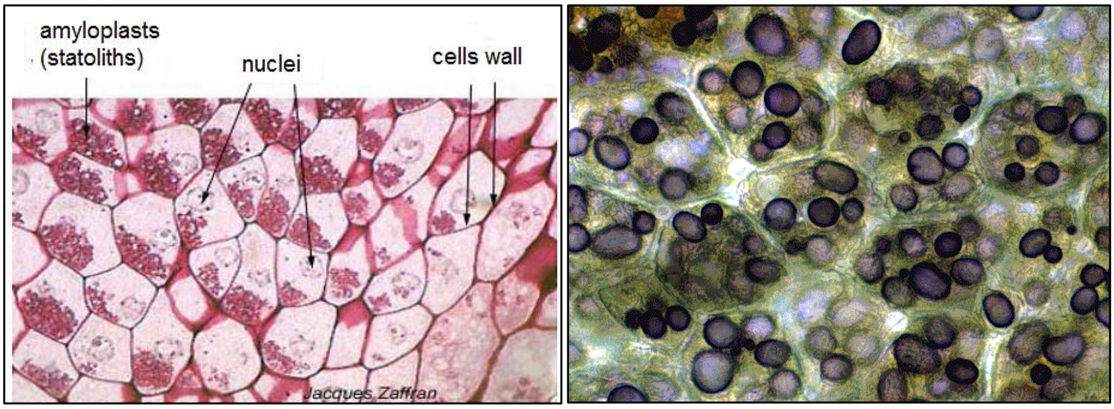


Figure 46 : Amyloplasty parenchyma (left) and white parenchyma or leucoplasty parenchyma (right) (Gharabi, 2021)

The reserve parenchyma also plays a role in tissue regeneration and wound healing. These reserve parenchymas include:

2.3. PARENCHYMA WATER RESERVOIR OR AQUIFER

It is composed of very large cells with reduced cytoplasm and dilated vacuole due to its aqueous content (Figure 47). It is a type of gap tissue where gaps trap air. They are found in aquatic and succulent plants such as Cactaceae.

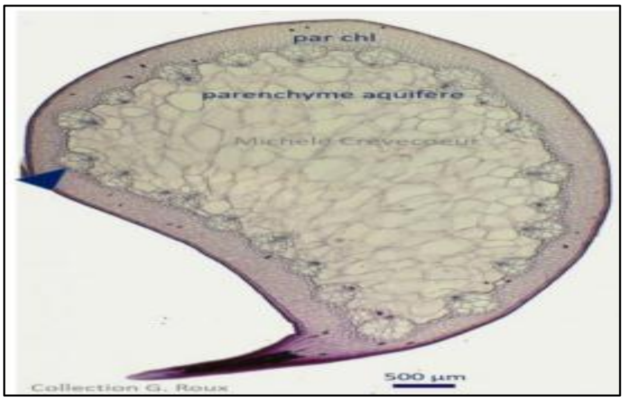


Figure 47: Air parenchyma under optical microscope (Gharabi, 2021)

2.4. AERENCHYMAL PARENCHYMA

It is characterized by large intercellular spaces (Figure 48). It is commonly found in aquatic plants.

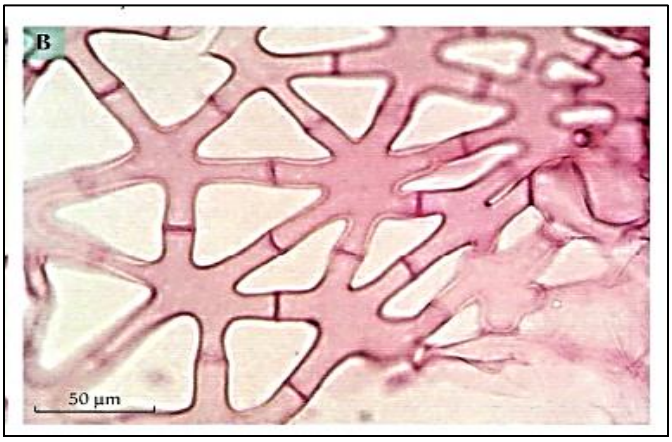


Figure 48: Air parenchyma or airenchyma under optical microscope
(Boutin et al., 2010)

2.5. VASCULAR PARENCHYMA

This type of parenchyma is associated with the vascular system (Figure 49).

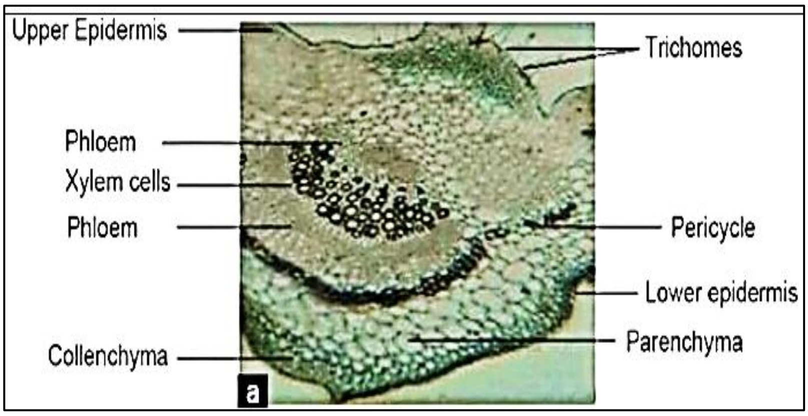


Figure 49: Photograph of transverse sections of *Trichosanthes dioica* leaf showing Bicollateral vascular bundle (Kumar et al.,2012)

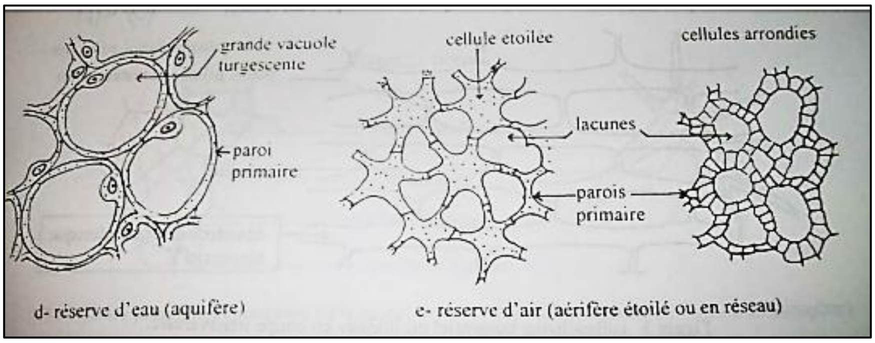


Figure 50: Aquifer reserve parenchyma (b) and aerian (c) (Gharabi, 2021)

3. PROTECTIVE OR COATING FABRICS

In terrestrial plants, parenchymal tissues with thin and permeable cell walls would be rapidly killed by severe dehydration if not separated from the relatively dry outdoor environment by impermeable tissues: The protective tissues.

There are two types of protective tissues: the epidermis (primary formation) and the cork (suber: secondary formation). These tissues are waterproof; they slow perspiration, harmful to the tissues but prevent gas exchanges between the parenchymes and the external environment (respiration and photosynthesis). These exchanges are nevertheless allowed at the level of the existing interruptions within the epidermis and cork, where oxygen and carbon dioxide can be exchanged. Thus, it is surface and covering fabrics that allow the protection of the plant against external aggressions. There are two types of primary protective tissues: the epidermis and the rhizoderm or the piliferous base.

3.1. EPIDERMIS

The epidermis is a tissue that covers the parenchymes of the aerial organs (leaves and young stems), the various floral parts and fruits. It is a primary tissue consisting of a base of living, jointed superficial cells on the surface of the entire plant, sometimes covered with cuticle (Figure 51). It covers the air organs and protects them against desiccation and external aggressions while allowing to regulate the gas exchanges with the atmosphere thanks to the presence of stomata.

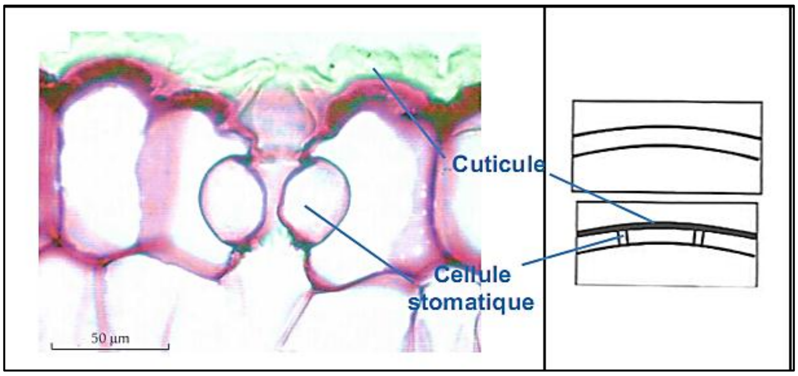


Figure 51: Epiderme et les cellules stomatiques (cellules de Garde) localisé sous de la cuticule (Boutin et al., 2010)

In some plants, the epidermal cells carry hairs that make at least the surface of the stems and leaves more fluffy. The epidermis is interrupted at the level of the stomata in the leaves and sometimes by hair. In the majority of plants, they form a single base of cells forming a simple epidermis and another type an epidermis compound. Many plants have hair of various shapes and structures:

- **Unicellular hairs (papillae):** formed by the extension of an epidermal cell (e.g. petals of roses).
- **Pluricellular hairs:** formed by several cells resulting from the proliferation of an epidermal cell.

3.2. RHIZODERM OR THE PILIFERE ROOT SEAT

Epidermal cells can be replaced at the root level by the piliferous base; it is present at the young roots level at the absorbent region (Figure 52).

The piliferous base contains highly stretched and very permeable cells, which are essential for the assimilation of water and soluble nutrients (salts). Some of these cells are hypertrophied and thus take the form of a hair, called absorbent hair.

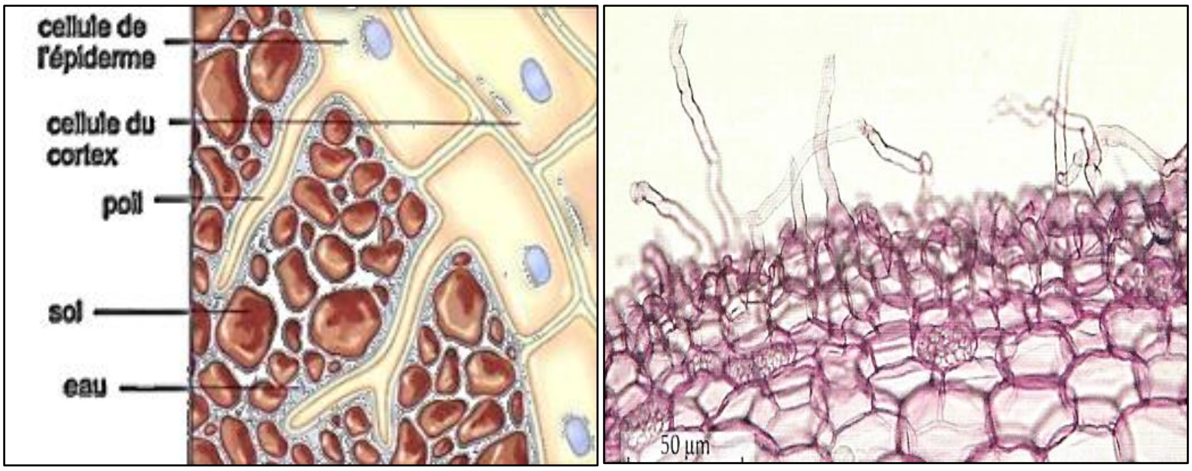


Figure 52: The absorbent hairs on the rhizoderm (Boutin et al., 2010)

2.3. ENDODERM

The endoderm is the deepest base of the bark at the root level. It has a protective role within the plant, and this by sorting the substances assimilated by the plant. In this way, only some of them will be able to migrate to the conductive tissues (Figures 53, 54). The cells of the endoderm present a lignification and suberification, as plants age more the endoderm will lignify. Thus, we observe sub-earic thickening in the form of a frame forming the Caspari frames that prevent transport by apoplasm (permissive) route by forcing symplasm (restrictive) route. This feature allows it to play its filter role.

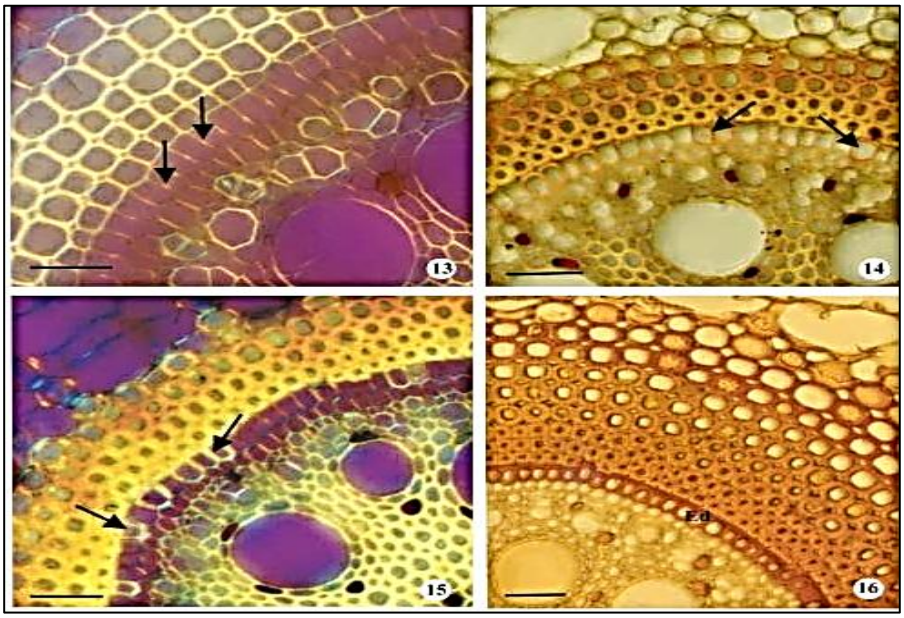


Figure 53: Cross-sections of roots. (13) Polarized light highlighting the Caspian stripes (arrows). (14-15) Polarized light showing the suberin lamella in the endoderm (arrows). (16) Endodermal cells containing phenolic substances. (Ed = endoderm) (Rodrigues et al., 2004).

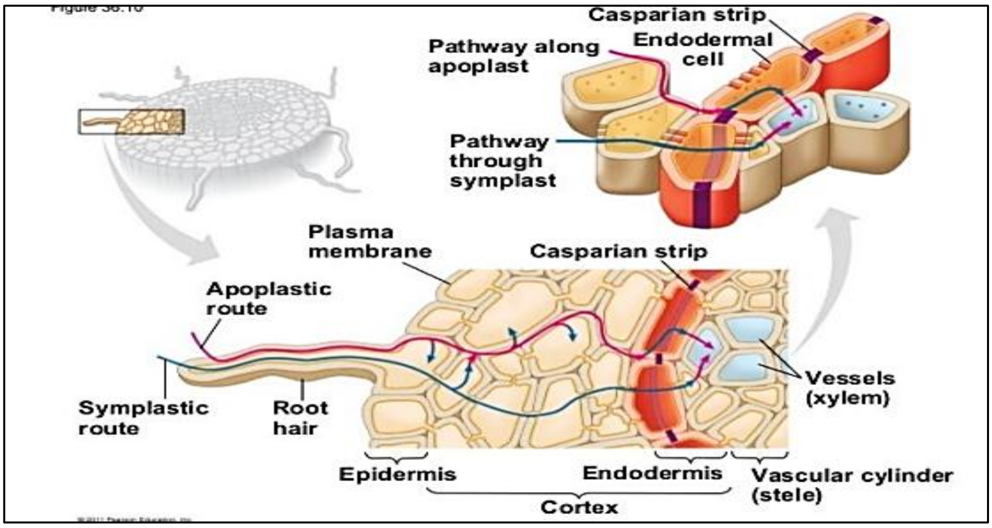


Figure 54: Importance of the endodermis in lateral root transport (Mesnoua, 2016)

According to the figure above, the root hairs (1) absorb water and mineral salts, which move along the cell walls (apoplastic pathway). The minerals and water (2) that cross the plasma membranes of the root hairs enter the cytosol (symplastic pathway). Along the apoplastic pathway (3), some water and minerals are transported into the cytosol of the cells and then move via the symplastic pathway and progress between the cells of the rhizodermis and the cortex. However, they must pass into the endodermal cells due to the presence of the Casparian strip (4). The Casparian strip, a band of waxy material, only allows minerals in the symplast to pass into the vascular cylinder through the plasma membrane of the endodermal cells. The cells (5) in the vascular vessels transport water and minerals throughout the plant.

2.4. THE LIEGE OR SUBER

Commonly called cork, suber is a plant tissue located on the periphery of a stem (or trunk) or root. It is a tissue of secondary origin; it comes from the differentiation of meristemic cells resulting from the functioning of a secondary meristem, the sub-era Fellodermic or Fellogen. It has a protective role. As the cells are waterproof, all cells outside of the suber will die. These dead squamous cells constitute the rhytidome in woody plants, or more simply the bark of trees.

The suberosive base found on the surface of young roots is primary.

The suber is a late tissue coating of adult organs with secondary growth (diameter growth). Yellow-brown in appearance, this protective fabric is derived from the phellogen by centrifugal differentiation. Due to its growth in thickness, it separates the epidermis and cortical cylinder from the rest of the root or stem, and can thus partially or totally replace the epidermis.

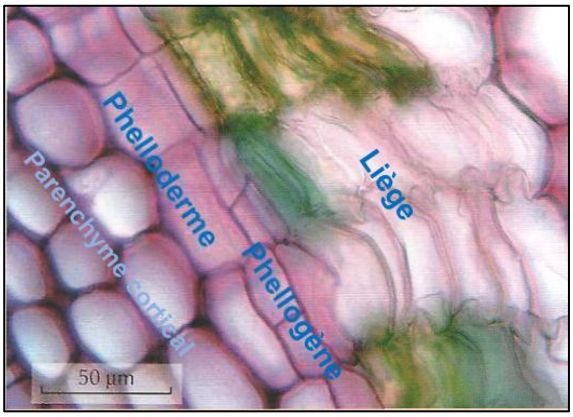


Figure 55: Secondary protective fabric: Cork or Suber (Boutin et al., 2010)

4. SUPPORT OR MECHANICAL TISSUES

The supporting tissues are made up of thick-walled cells giving it a certain rigidity, especially in herbaceous plants, these are the collenchyma and the sclerenchyma.

4.1. COLLENCHYMA

It is a primary tissue under the epidermis (Figures 56), located in the periphery of the aerial parts of young growing organs (stem and petiole). Made of living cells with cellulose walls that allow the plant to continue growing in the area under consideration, no secondary wall therefore no lignin, so the wall is flexible and the cell can lengthen.

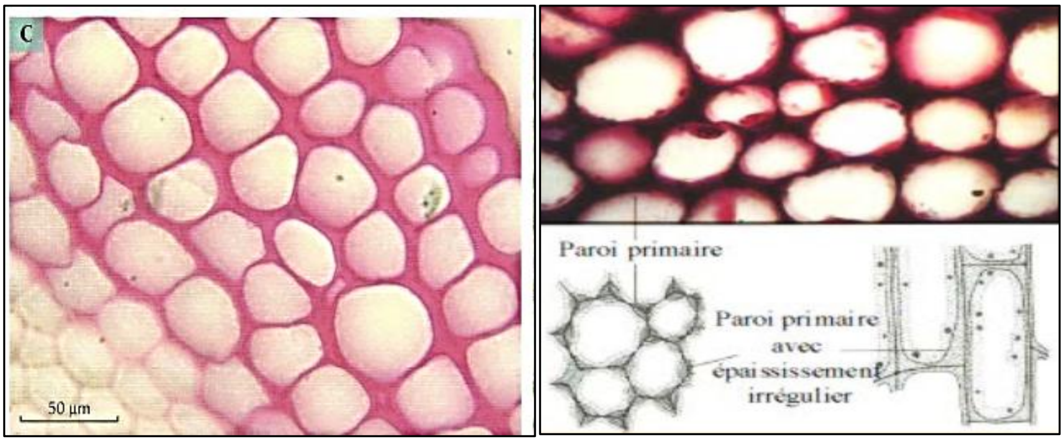


Figure 56 : Collenchyma (Boutin et al., 2010)

4.2. SCLERENCHYMA

The sclerenchyma is also a primary tissue formed of dead cells whose walls are loaded with lignin (thick, rigid secondary wall impregnated with lignin), blocking the plant in its growth in the area under consideration (figure 57). The cells of the sclerenchyma are often grouped in bundles forming vegetable fibers, or when its cells have irregular shapes, they are called sclerites. In plants with important secondary tissues such as trees, the supporting role is no longer provided by the collenchyma or sclerenchyma, but by the secondary conductive tissues.

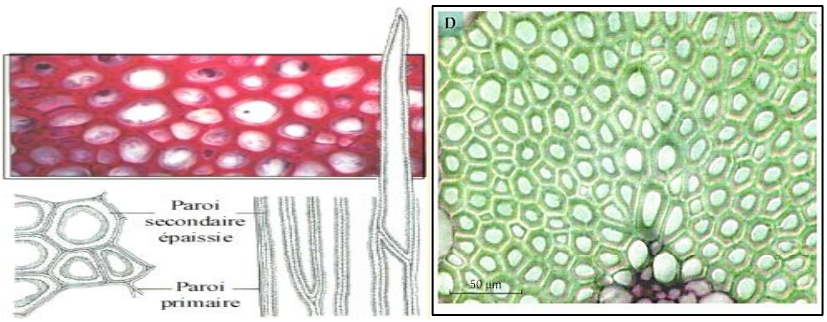


Figure 57: Collenchyma and sclerenchyma (Boutin et al., 2010)

5. CONDUCTIVE TISSUES

All vascular plants (from ferns to angiosperms) have conductive tissues, they allow the transport of water and other absorbed elements as well as the various products of photosynthesis to all parts of the plant. The cells of the conductive tissue are long cells, placed end to end, thus forming long columns (Figure 58). These cells allow the passage of sap throughout the plant organism.

The cells of the conductive tissue are long cells placed end to end thus forming long columns. These cells allow the passage of sap throughout the plant organism. There are two types of conductive vessels (Figure 58): the phloem and the xylem.

By definition, a vessel is a tube distributing sap in the various parts of a plant. On the other hand, a beam is the set of thin and elongated tubes linked together. The crib beam is defined as the whole of xylem and phloem.

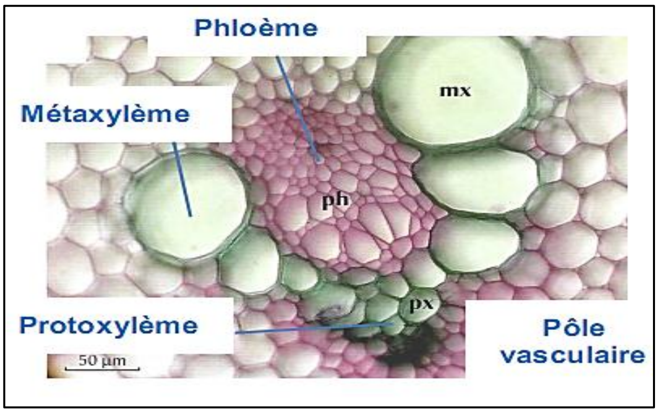


Figure 58: Primary phloem (ph) and primary xylem (px) (Boutin et al., 2010)

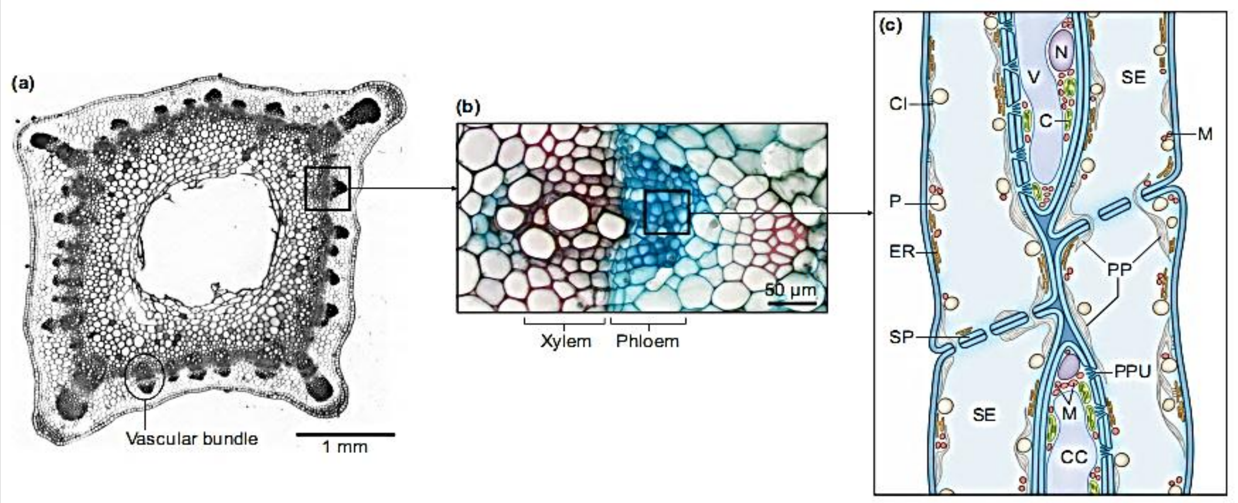


Figure 59: The vascular bundles comprising xylem and phloem with the sieve element/companion cell (SE/CC) complex as the core unit of the phloem. (c) The SE/CC complex forms the core unit of the phloem (Noll et al., 2022).

So, the drawing (figure 59) represents a longitudinal stem section, following the selective autolysis of the immature SE, only a few organelles remain in the transporting, mature SE, including specialized plastids (P) and endoplasmic reticulum (ER), a few mitochondria (M) and structural P-proteins (PP). The organelles are anchored to each other and/or to the SE membrane by small clamps (Cl). Linear arrays of SEs are connected via terminal sieve plates with large pores that ensure mass flow. Each SE is also connected to one or more CCs, which are highly active and supply the SEs via special plasmodesmata known as pore plasmodesma units (PPUs). The CCs contain, among other organelles, a large nucleus (N), the vacuole (V), chloroplasts (C) and numerous mitochondria (M).

Indeed, primary xylem and primary phloem are the two types of primary conductive tissues in herbaceous plants. They are grouped into bundles. In woody plants, between the primary xylem and the primary phloem, an area of poorly differentiated cells with active divisions is established (figure 60). This generating area called cambium libero-lignoso produces cells that differentiate to give the secondary conductive tissues which are the secondary xylem (wood, hence the woody qualifier) and the secondary phloem (or liber).

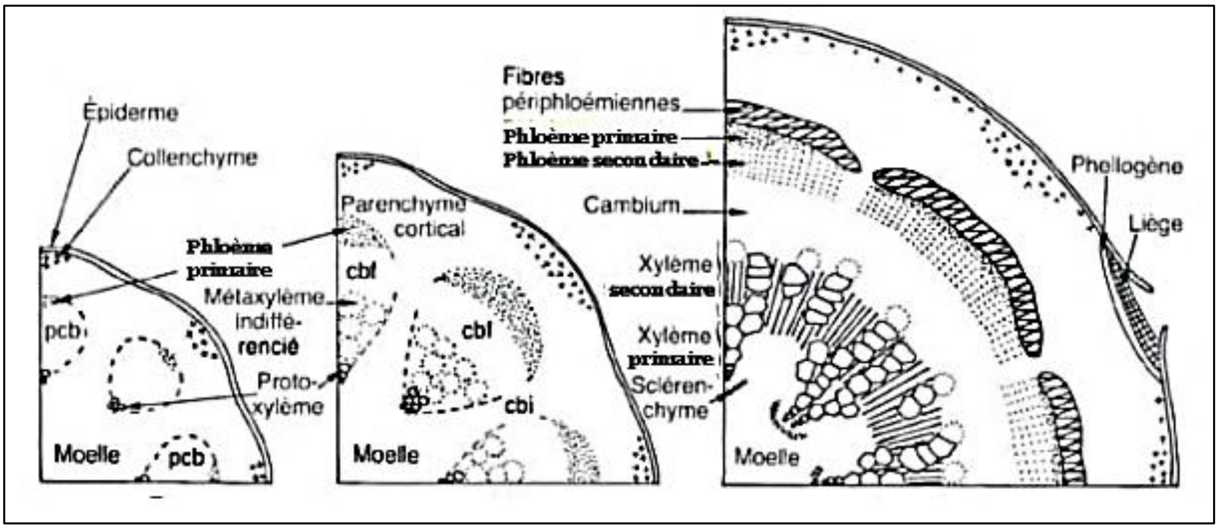


Figure 60: Establishment of the cambium in a stem (Robert and Catesson, 2000)

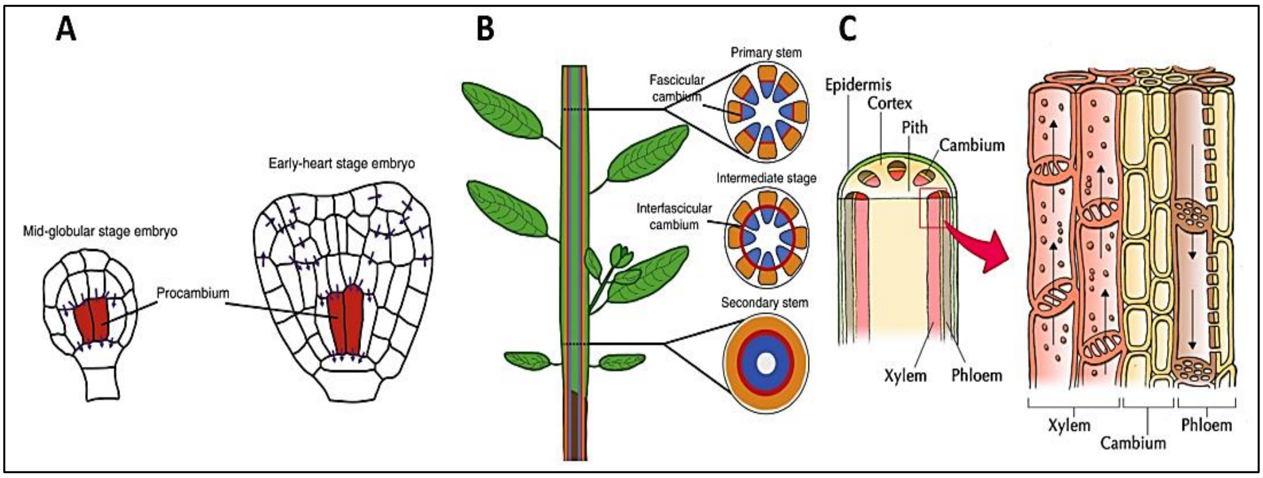


Figure 61: Schematic representation of plant vascular tissue. A schematic representation of two embryo stages (mid-globular and early-heart) showing two and four initial cells of the procambium (A), vascular tissue organization of the stem, showing the xylem (blue), cambium (red) and phloem (orange) (B) and tissue organization of primary stem showing xylem, cambium and phloem tissue from the vascular bundle, showing transport of nutrients indicated by arrows (C) (Jouannet et al., 2015).

5.1. THE XYLEM

The xylem ensures the transport of raw sap (water and mineral salts from the soil) from the roots to the organs responsible for photosynthesis. The xylem consists of highly elongated dead cells with walls thickened by lignin deposits, interrupted in places to allow the passage of raw sap. The xylem contains two types of sap-conducting cells: tracheae and tracheids.

5.1.1. Tracheae (Perfect Vessels)

Also called xylem cells, they are made up of dead cells whose transverse walls have disappeared (heavily reinforced with lignin in their walls). These cells are relatively short, arranged end-to-end and parallel to each other. In higher plants, xylem cells align end-to-end, forming rows of elongated cells along the axis of vascularized organs. The transverse walls eventually undergo lysis, establishing absolute continuity; the resulting structure is a perfect xylem vessel.

5.1.2. Tracheids

They consist of elongated, parallel cells. The ends are beveled, and the cells are less rich in lignin. These cells are more or less similar to tracheae but much shorter, not exceeding 10 nm in length. They are composed of a single cell with a transverse wall. In tracheae, the flow of raw sap is primarily vertical, whereas in tracheids, the presence of a transverse wall causes a zigzag (serpentine) flow pattern.

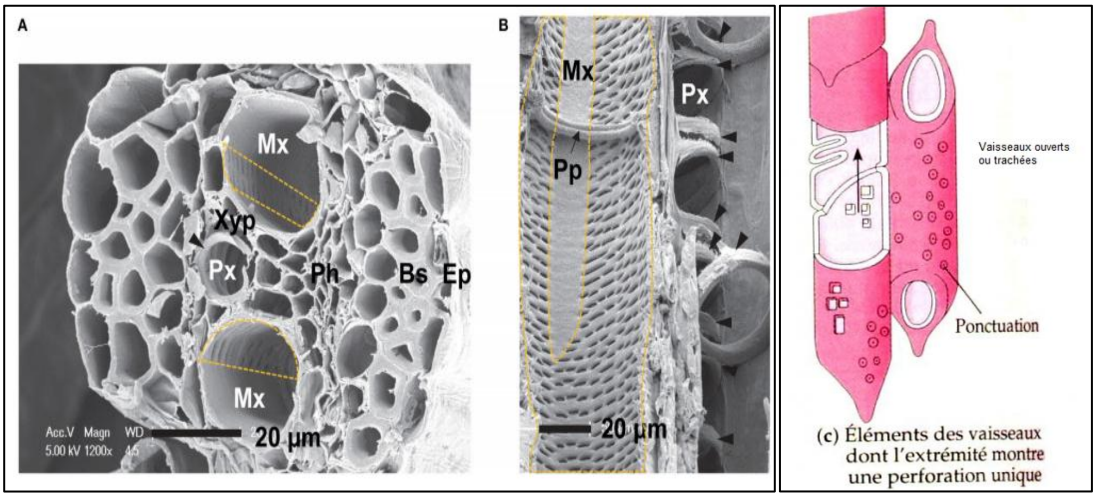


Figure 62: Images of xylem vessels in a vascular bundle of maize (*Zea mays* L.). (A) Transverse section of a maize sheath, showing a protoxylem (Px) vessel with secondary wall thickenings (filled arrowheads) and two metaxylem (Mx) vessels with pits distributed in a nonuniform manner (dashed box). (B) Longitudinal section of a maize leaf, showing protoxylem and metaxylem vessels with a single perforation plate (Pp). Ep, epidermis; Bs, bundle sheath fiber; Ph, phloem; Mx, metaxylem vessel; Px, protoxylem vessel; Xyp, xylem parenchyma cell; Pp, perforation plate (Hwang et al., 2016).

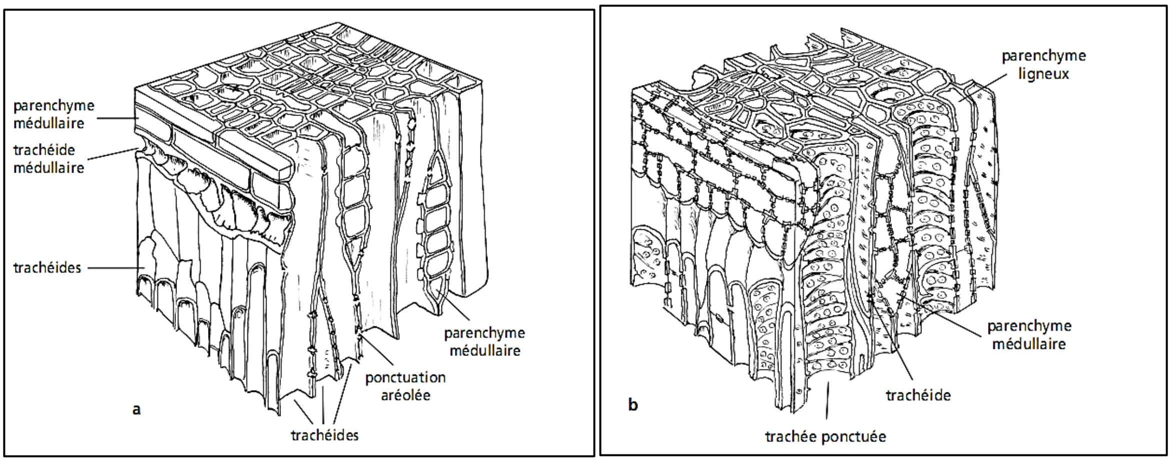


Figure 63: Three-dimensional wood models: (a) Homoxylous in pine, (b) Heteroxylous in linden (Laberche, 2004)

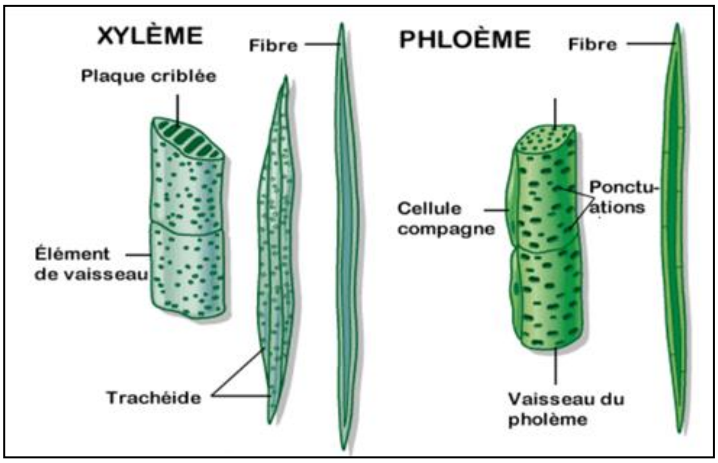


Figure 64: The different types of xylem and phloem cells (Zeghad,2018)

5.2. THE PHLOEM

It is primarily responsible for the transport of elaborated sap (or phloem sap), which is the sap enriched with substances produced by photosynthesis. This conductive tissue consists of sieve tubes and companion cells.

5.2.1. Sieve Tubes

These are living, elongated cells arranged end-to-end along the longitudinal axis, with thick pectocellulosic walls. They lack a nucleus. Their transverse walls are perforated with pores called sieve plates, which allow the sap to flow through.

5.2.2. Companion Cells

These are living, narrow, elongated cells located alongside the sieve tubes. They contain a nucleus and have unperforated cellulosic walls. They play a role in regulating sap flow within the sieve tubes.

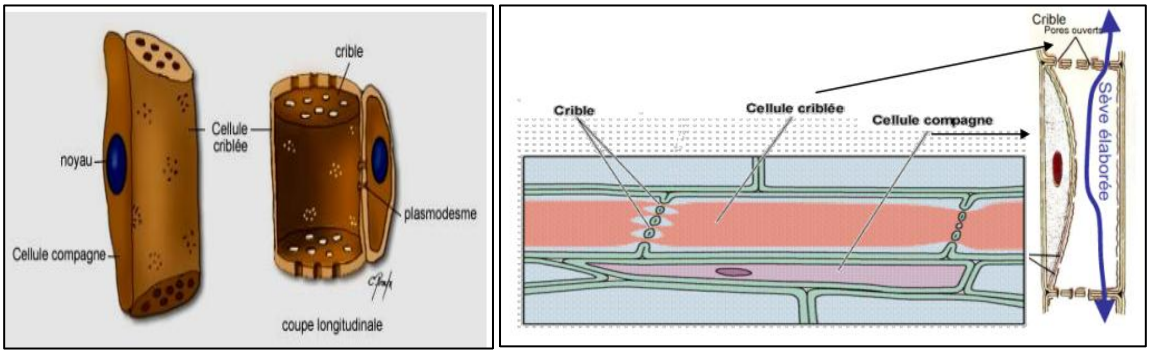


Figure 65: The elements of the phloem. (Bouzid, 2018)

5.3. SECONDARY CONDUCTIVE TISSUES

These secondary tissues will develop and enable the plant's growth in thickness. They become very important. They gradually replace the primary xylem and phloem, ensuring sap transport and providing structural support to the plant (such as the tree trunk). They originate from the vascular cambium (or simply "cambium"), which is composed of short cells and long cells (Figure 66).

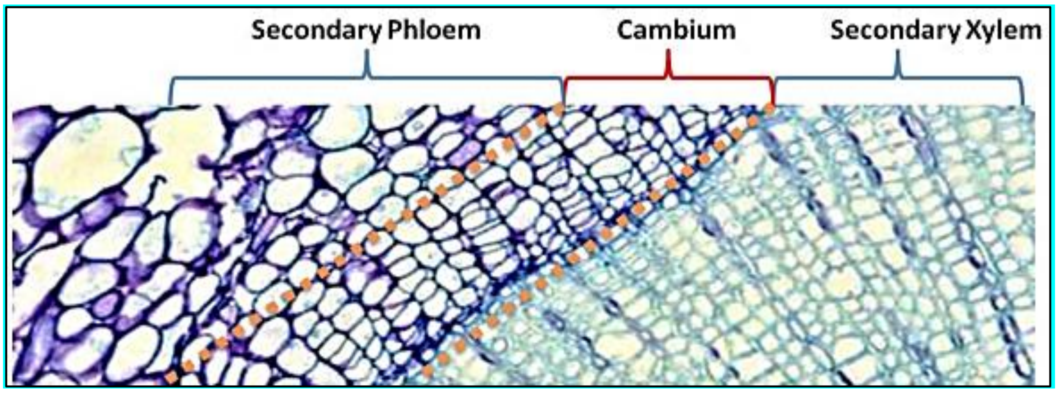


Figure 66: Transverse section of hybrid aspen (*Populus tremula* × *Populus tremuloides*) stem, showing the organization and regulatory components in cambium and secondary xylem and phloem (Ursache et al., 2013).

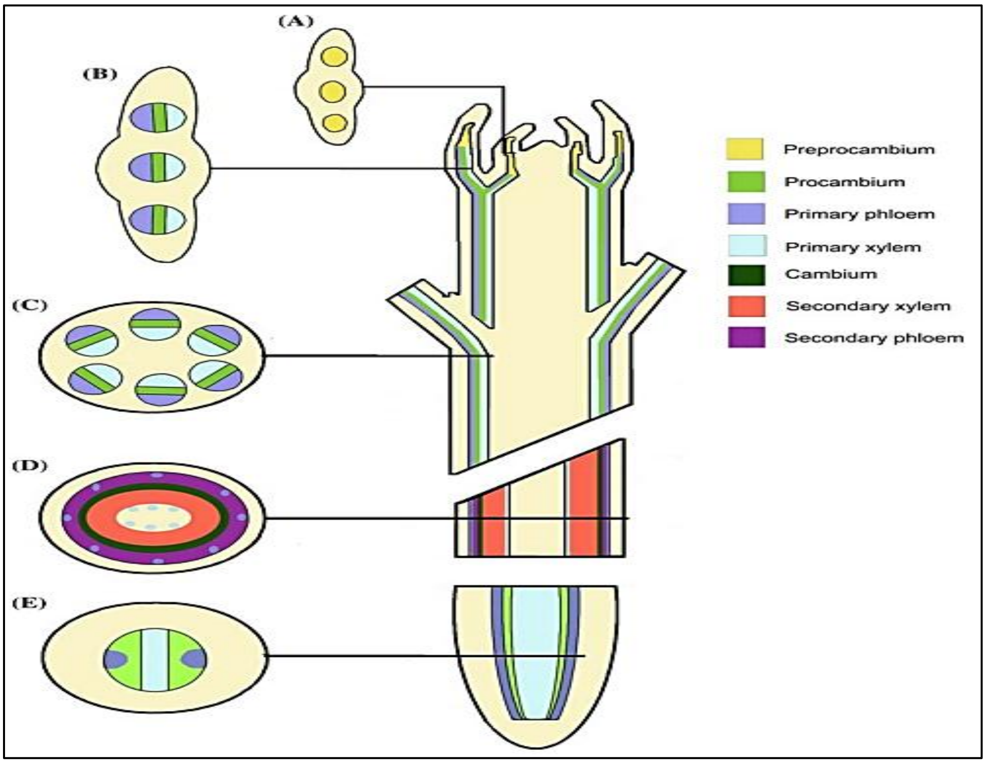


Figure 67: Organization of the vascular tissues during the primary and secondary developmental phases in higher plant, schematic view. (a) Cross section of early developing leaf. Preprocambial cells precede the vascular development. (b) Cross section of leaf. Within the vascular strands primary xylem and phloem tissues differentiate asymmetrically from the procambium. (c) Primary development shown in stem cross section. (d) Organization of vascular tissues during the secondary phase of vascular development. During this phase cambial cells proliferate and secondary xylem and phloem are formed. (e) Cross section of root tip showing vascular organization during primary development. Later during development root vascular tissues proceed also into the secondary development phase (Dettmer et al., 2009).

5.3.1. The Phloem

It is arranged outward. Its formation, centrifugal, is rhythmic and produces thin concentric layers of flattened cells (Figure 68). These layers resemble the leaves of a book, hence the name phloem (from liber = book).

5.3.2. The Wood (Xylem)

It develops inward. It has a centripetal rhythmic growth, synchronized with the seasons (Figure 68). Thus, it forms annual rings.

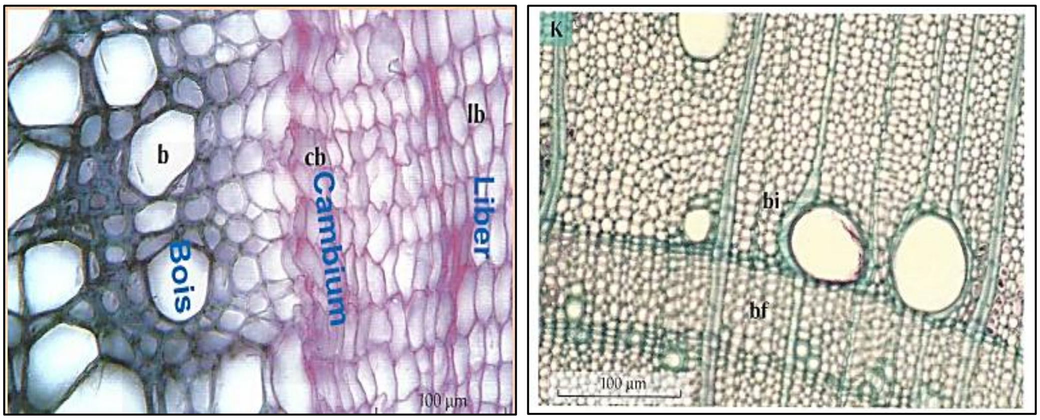


Figure 68: Microscopic cross-section showing the structural features of secondary conductive tissues (on the right: Secondary Xylem or Wood, and on the left: Secondary Phloem or Bast). (Boutin et al., 2010).

6. SECRETORY TISSUES

These are tissues specialized in the synthesis and secretion of certain substances (essential oils, latex, etc.). They consist of secretory ducts or hairs, secretory cells, storage pockets, or parenchyma. They are highly diverse in both form and release mechanisms and can be located in all types of tissues (Figure 69).

Some cells, either isolated in the parenchyma or grouped into pockets or tubes, synthesize substances. They may either store the products or secrete them into plant organs, such as volatile essential oils, which produce the fragrances of certain plants (rose petals, thyme, rosemary, etc.).

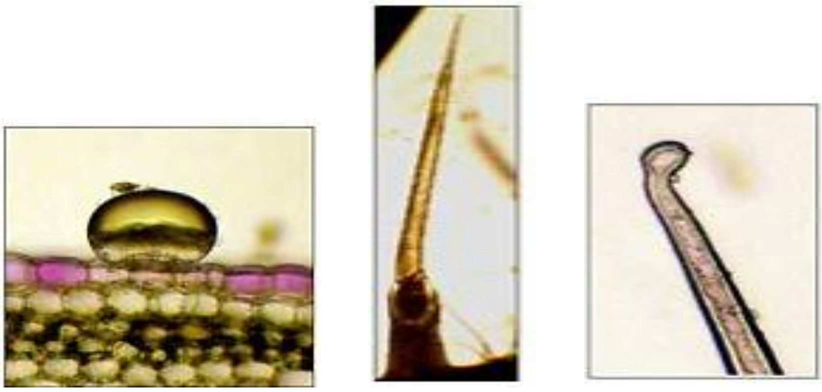


Figure 69: Epidermal hair of sage (on the left) and Epidermal hair of nettle (In the center and on the right (Bouzid, 2018)

Thus, a tissue is a group of similar cells that share the same embryological origin and perform a specific physiological function. The following tables (Tables 3, 4, and 5) summarize the different types of plant tissues, along with their cellular and wall characteristics, as well as their location.

Table 3: Characteristics and localization of different types of plant tissues (Gorenflot and Foucault, 2005 ; Boutin et al., 2010)

<table>
<tr><th></th><th colspan="2">Cell characteristics</th><th>Characteristics of their walls</th><th>Localization</th></tr>
<tr><td colspan="5">PARENCHYMES : tissus fondamentaux des végétaux supérieurs</td></tr>
<tr><td>Parenchyma
The site of
all the elaborative functions of the plant</td><td>Living,
often poorly differentiated</td><td>Isodiametric or elongated cells, rounded at the angles</td><td>Only a thin and flexible primary wall, pectocellulosic with pectic cement.
Often with intercellular spaces and lacunae, particularly in leaf lacunary parenchyma and aerenchyma (air-filled parenchyma)</td><td>Chlorenchyma: Chlorophyllous parenchyma found in leaves, the cortex of photosynthetic stems, and aerial roots.
Storage parenchyma: Present in roots, tubers, rhizomes, bulbs, fruits, and seeds, storing various reserves.
Aquiferous parenchyma: Found in succulent plants.</td></tr>
<tr><td colspan="5">COVERING TISSUES: cover organs in contact with the external environment</td></tr>
<tr><td>Epidermis</td><td>Alive</td><td>Generally, a single cellular layer.
Aeriferous or aquiferous stomata.
Often various hairs</td><td>Thickened outer wall, more or less impermeable due to the deposition of cutin (cuticle of variable thickness) and sometimes wax.
No intercellular spaces</td><td>Aerial epidermises without chlorophyll, except for Pteridophytes and Orchidaceae.
Aquatic epidermises with chloroplasts</td></tr>
<tr><td>Rhizodermis</td><td>Alive</td><td>Some cells or all extend into an absorbing hair.
No stomata.</td><td>Thin wall.
No cuticle</td><td>Piliferous layer of the root</td></tr>
<tr><td colspan="5">CONDUCTING TISSUES OF SAP: Xylem or woody tissue (ascending raw sap)</td></tr>
<tr><td>Tracheids (conduction)</td><td>Dead at the end of differentiation</td><td>Each tracheid is an elongated cell, longitudinally tapered at the ends, arranged end-to-end and parallel to one another</td><td rowspan="2">Rigid wall, but relatively thin (relatively large lumen).
Primary cellulose wall.
Lignified secondary wall with rings, spirals, transverse bands, or interrupted lignin coating at the level of pits.
Transverse secondary wall: With pits (tracheids), multiple pores (imperfect vessels), or a single large perforation (perfect vessels).
No intercellular spaces.</td><td rowspan="4">Deep localization in vegetative or reproductive organs</td></tr>
<tr><td>Vessels (conduction)</td><td>Dead at the end of differentiation</td><td>A vessel is made up of fairly short cells, arranged end to end and parallel to one another.</td></tr>
<tr><td>Fibers (support)</td><td>Dead at the end of differentiation</td><td>Elongated, narrow cell with tapering ends</td><td>Wall much thicker than that of tracheids and vessels (small lumen), lignified. Few pits. No intercellular spaces.</td></tr>
<tr><td>Parenchyme vertical
Cellules de contact
Cellules à réserves</td><td>Living cells
Diverse storage compounds</td><td>Relatively short cells, in longitudinal rows</td><td>Wall more or less lignified, with or without a secondary wall. No intercellular spaces. Pits communicating with the conducting elements</td></tr>
</table>

Table 4: Characteristics and localization of different types of plant tissues (rest 1)
(Gorenflot and Foucault, 2005 ; Boutin et al., 2010)

	Cell characteristics		Characteristics of their walls	Localization
CONDUCTIVE TISSUES FOR DESCENDING ELABORATED SAP: Phloem or sieve tissue				
Sieve tubes	Short life, becoming anucleated	Longitudinally extended, arranged end to end	Thick, pectocellulosic; the transverse walls oblique and pitted	Deep localization in all vegetative or reproductive organs
Bast fibers (Support)	Dead	Always elongated cells	Thick (with a narrow lumen), pecto-cellulosic or lignified; the secondary [wall] with pits.	
Vertical parenchyma Contact cells **Storage cells**	Living Core Bulky Reserves Diverse	From 1 to 3 narrow, elongated cells along a sieve cell Various shapes	Cellulosic, thin, non-sieve elements Secondary or not **Plasmodesmata** communicating with sieve tubes Cellulosic walls thinner than those of sieve elements	
SUPPORT TISSUE				
Collenchyma	Living Poorly differentiated Starch rare or absent	Tapered collenchyma cells at the ends Transverse septation	Thickened primary wall, cellulosic, flexible and hydrophilic. No secondary wall. Intercellular spaces rare	Herbaceous plants and petioles of woody plants.
Cellulosic fibers	Alive	Up to 50 cm in length	Presence of a secondary wall	Extraxylary stem fibers (Flax, Ramie)
Sclerenchyma	Dead	Considerable elongation parallel to the organ axis. Tapered ends. Several centimeters in length (fibers) or less elongated cells with irregular shapes (sclereids).	More or less lignified, thick, inextensible wall. Secondary wall	Aerial organs, more rarely in roots. Fibers: in bark (cortex) and pith Sclereids: isolated or in clusters, or forming a continuous layer (in leaves, fruits, seeds)
SECRETORY TISSUE				
Secretory cells	Alive	Fairly isodiametric. Accumulated products in the vacuoles	Pectocellulosic wall	Epidermes, hairs, cortical and medullary parenchyma of stems, and leaf parenchyma
Secretory hairs Nectaries	Alive	Varied forms Volatile essences produced and accumulated in the cytoplasm	Cellulosic wall with a thin cuticle through which essential oils evaporate (or by rupture of this cuticle	Stems, leaves, and floral parts

Table 5: Characteristics and localization of different types of plant tissues (rest 2) (Gorenflot and Foucault, 2005 ; Boutin et al., 2010)

	Cell characteristics		Characteristics of their walls	Localization
SECRETORY TISSUE				
False laticifers	Alive	Laticifers made up of numerous end-to-end cells; branched or unbranched: cytoplasmic latex	Primary wall composed solely of cellulose. Transverse walls either perforated or even resorbed. Anastomoses between laticifers	In all tissues and all parts of the plant
True laticifers	Alive, with a great many nuclei	Each laticifer is a single cell that elongates significantly during plant growth (several meters). Branched or unbranched cell. Vacuolar latex	Primary wall only cellulosic	
Pockets and channels	Alive	Processed products rejected into pockets and ducts bounded by excretory cells.	Cellulosic wall Pockets and canals originate, at least initially, from the enlargement of an intercellular space (meatus)	

CHAPTER III

ANATOMY AND MORPHOLOGY OF THE VEGETATIVE SYSTEM

Plants are multicellular eukaryotic and autotrophic organisms, capable of synthesizing the organic nutrients necessary for their survival using light and inorganic mineral elements absorbed from the soil.

The vegetative system of plants comprises roots, stems, and leaves. This system performs crucial and specific functions. At first glance, plants exhibit a relatively simple structure:

- **Roots:** Anchor the plant to the soil and absorb water and nutrients essential for its functioning.
- **Stems:** Provide support for photosynthetic organs.
- **Leaves:** Act as photosynthesis factories, where solar energy is converted into chemical energy.

1. MORPHOLOGICAL CHARACTERISTICS OF MONOCOTYLEDONOUS AND DICOTYLEDONOUS PLANTS

Among angiosperms, or flowering plants, monocotyledons comprise species whose typical seedling bears only one cotyledon on the embryo. In addition to this primary characteristic, they also exhibit the following features (see table 6 and figures 70, 71):

Table 6: Morphological characteristics of monocotyledonous and dicotyledonous plants (Godinot et al., 2010)

Plant	Monocotyledonous	Dicotyledonous
Root	Root system often fasciculated: unbranched roots	Taproot system, fibrous roots
Stem	No formation of secondary wood and absence of a true trunk, even though some monocots (such as palms and banana trees) have a tree-like habit, this class does not include true trees in the strict sense	Presence of cambium allows the formation of secondary wood inward and phloem outward.
Leaves	Characterized by parallel veins	Reticulated veins
Flowers	Fundamentally trimerous; 3 sepals, 3 petals, 2×3 stamens, 3 carpels	4 or 5 whorls (sepals, petals, stamens, and carpels)
Pollen	Pollen grains typically having a single aperture (a weakened area allowing the passage of the pollen tube)	3 apertures

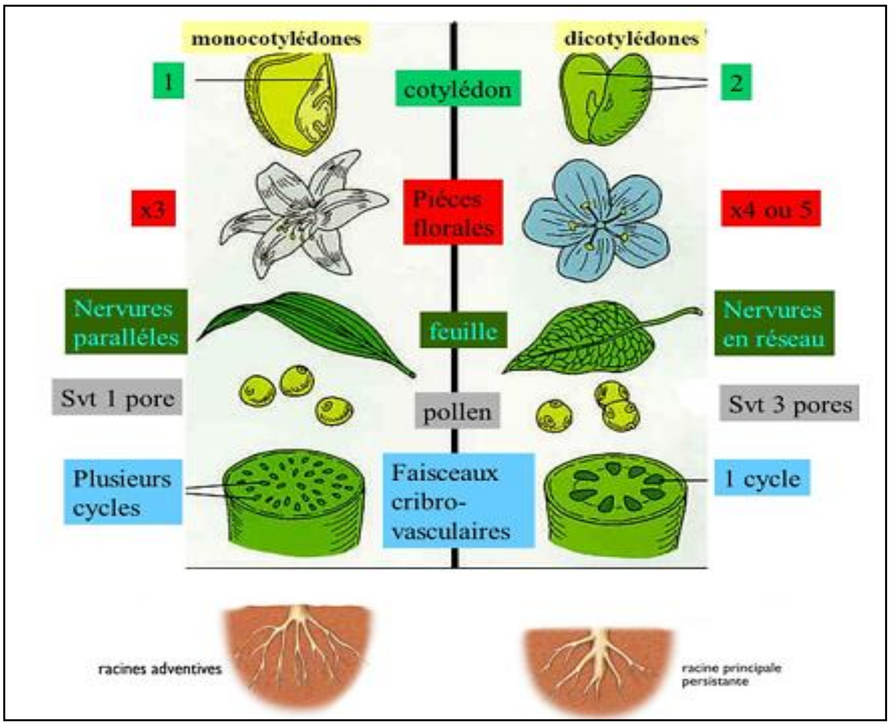


Figure 70: Morphological comparison between monocotyledonous and dicotyledonous plants (Zeghad, 2018)

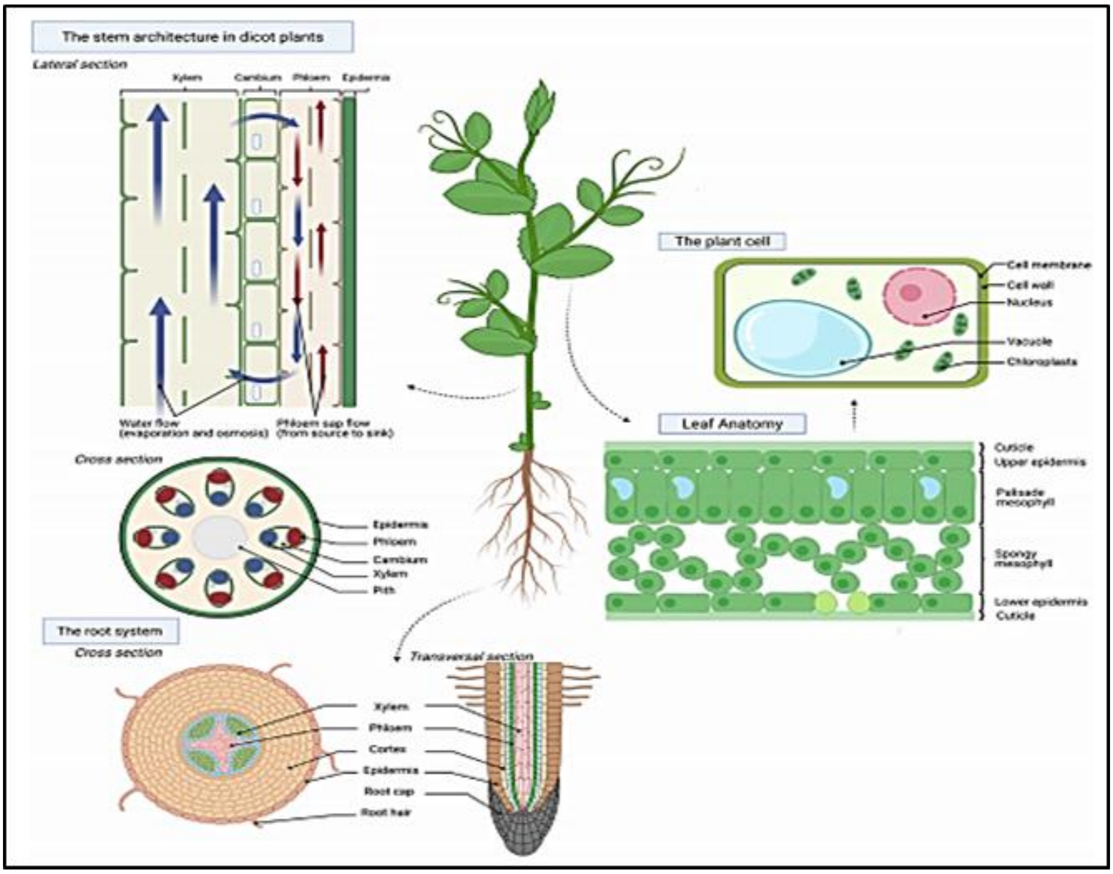


Figure 71: An overview of plant anatomy, demonstrating the stem architecture, root system, plant cell structure, and leaf anatomy (Rad, 2023)

2. ROOT ANATOMY

The root constitutes the underground portion and a vital organ of the plant. It is the downward extension of the stem. The root develops very early, at the onset of germination, and differs from the stem in several respects:

- Its internal structure,
– Its positive geotropism,
– The presence of a root cap and root hairs,
– The absence of leaves and buds.
– Roots are generally non-chlorophyllous (except in certain epiphytic orchids) and never bear leaves. They usually grow downward (positive geotropism) and avoid light (lucifugous).

We can distinguish (figures 72 and 73):

✓ **A primary root called the taproot**: it grows straight down into the soil, and its size and proportions vary depending on the species and the environment.

✓ **A fibrous root system (rootlets)**: the finest branches that develop from secondary roots. When these roots are very small and thin, they are referred to as *rootlets*.

Figure 72: Taproot and fibrous root systems (Raven et al., 2007)

The figure above illustrates the taproot system **(a)**, as seen in the dandelion, where lateral roots develop from a larger root called the taproot. Taproot systems are typical of most dicotyledons and gymnosperms. **(b)** The fibrous root system lacks a main root; it is generally more superficial. It characterizes most monocotyledons and seedless vascular plants.

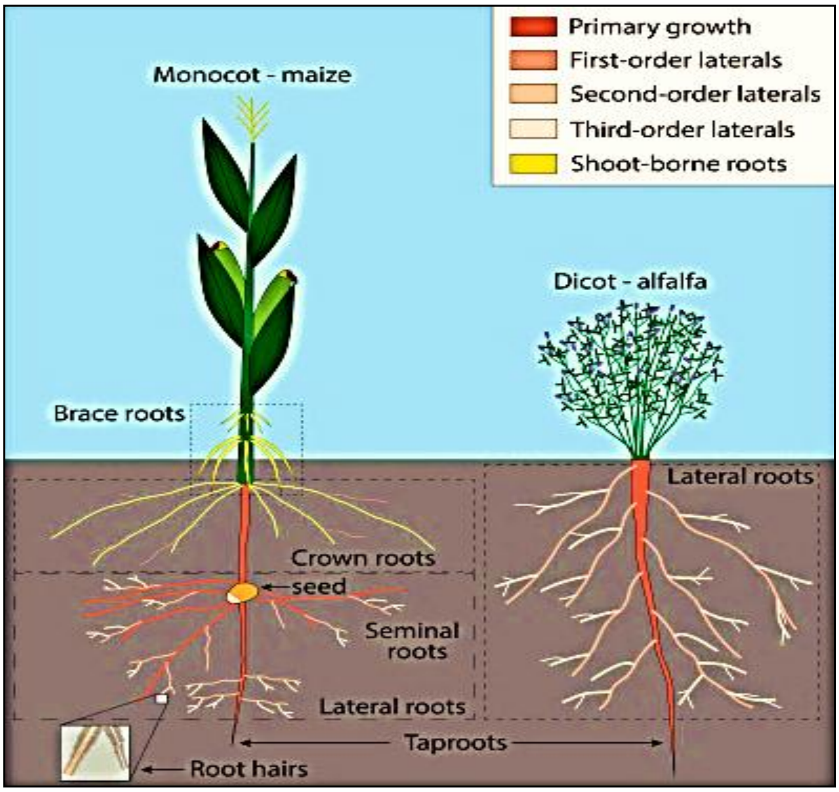


Figure 73: Monocotyledon (monocot) and dicotyledon (dicot) root systems. Root and shoot scales are exaggerated for detail. Taproots are also called radicles or primary roots (Weihs et al., 2024).

2.1 FUNCTIONS OF THE ROOT

The main functions of roots are (Figure 74):

- **Anchorage**: securing the plant in the soil on both sides, preventing it from bending.
- **Absorption and conduction** of water and mineral salts from the soil to the leaves for photosynthesis.
- **Storage of reserves**: roots transport water and mineral salts to stems and leaves, but also import organic molecules from stem and leaves for reserve accumulation (e.g., tuberization, taproot).
- In addition to absorption, conduction, and storage, roots produce **hormones** and other substances that regulate the plant's development and structure.
- **Support for complex symbiotic associations**: with microorganisms (bacteria and fungi) that, for example, assist in phosphorus solubilization, atmospheric nitrogen fixation, and the development of secondary roots.

- **Communication**: some tree species can anastomose their roots with those of trees of the same species, thereby sharing water and nutrient resources. These root anastomoses can help a stump or a severely damaged tree survive and better resist soil erosion.

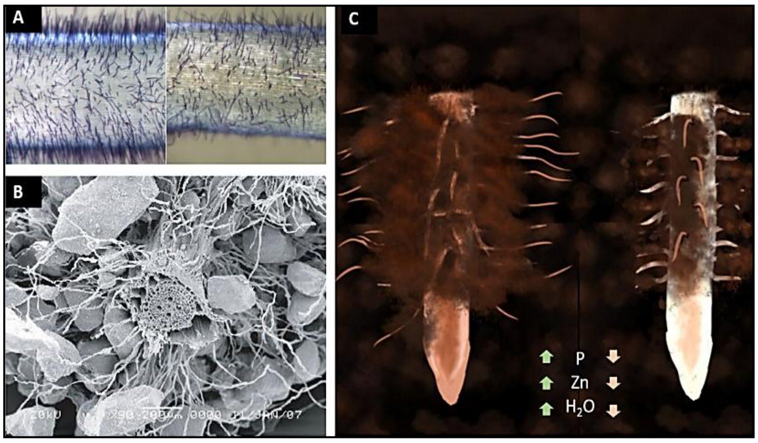


Figure 74: Importance of root hairs and rhizosheaths in improving nutrient uptake and plant performance. A) Scanning electron micrograph of root hair less mutant (Rht-1). B) Scanning electron micrograph of wild type – B73, compare the density and length of root hairs with Rht-1. C) None to bare minimum rhizosheath formation on the Rht-1 root and D) Root hairs promoting rhizosheath formation in wild type B73. Increased rhizosheath formation improves nutrient uptake e.g. P, Zn and improves stress tolerance e.g. drought (Lynch et al., 2021).

2.2 STRUCTURE AND MORPHOLOGY OF THE ROOT

In a longitudinal section, the young root (primary root) shows, starting from its tip, the following zones (Figure 75):

- **Embryonic (meristematic) zone**: constitutes the growth pole, protected by a conical root cap that safeguards the vegetative point or root apex.

  - The root cap is composed of constantly renewing suberized cells and specialized cells called statocytes, which are involved in gravity perception through their statoliths (specialized organelles in plant cells).
  - The root cap also has a lubricating function (secretion of polyosides) to facilitate better penetration of the root into the soil.

- **Elongation zone**: limited to a few millimeters, followed by the root hair zone.

- **Root hair zone (trichoblast zone)**: characterized by numerous root hairs those significantly increase the root's absorptive surface area. These hairs have a short lifespan and are replaced continuously as the root grows, maintaining the root hair zone roughly the same size. The next zone is the suberized layer.
- **Suberized zone (suberized layer)**: a layer of cells enriched with suberin

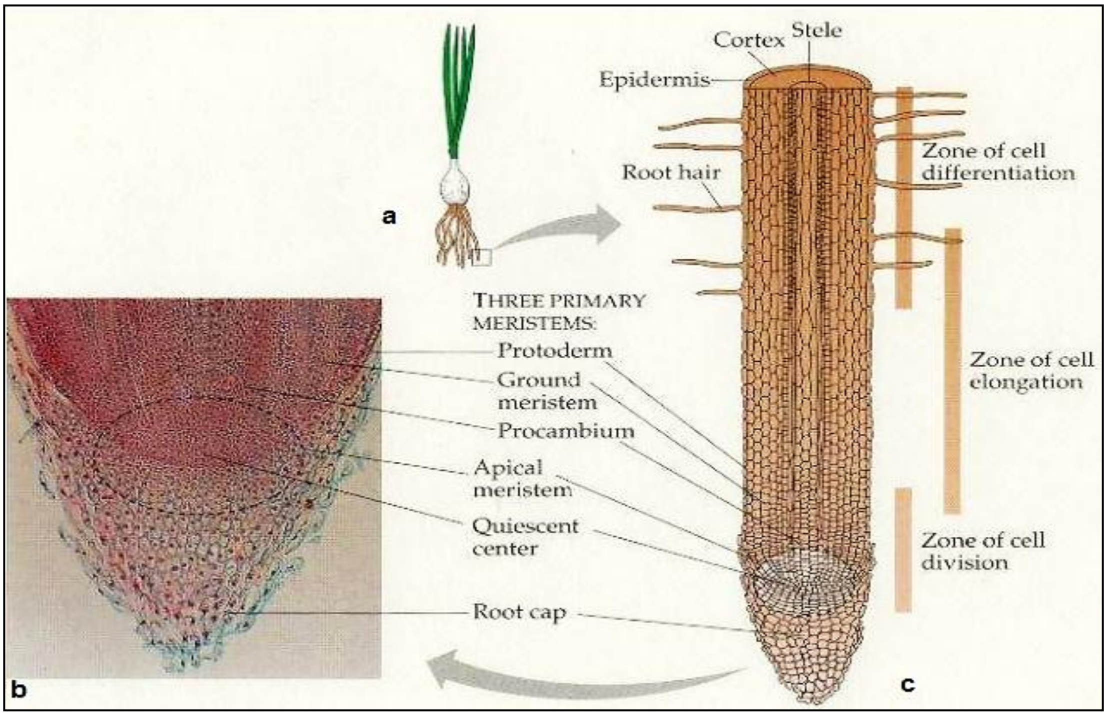


Figure 75: Coupe longitudinale dans une racine de monocotylédone (Raven et al., 2003)

The diagram above depicts the first few millimeters of a root tip. Absorbing root hairs (a) can be observed in the differentiation zone; lateral or secondary roots form further up. In this longitudinal section of a monocotyledon root tip (b), the root cap is clearly identifiable. The root apical meristem gives rise to three meristematic zones (c): the protoderm, procambium, and ground meristem. Above these are the zones of elongation and cellular differentiation. The transition from one zone to the next occurs gradually. The root cap has its own meristem, called the root cap meristem (or root cap initials). Between these two meristems lies the quiescent center, where cell division is infrequent

Secondary roots, which arise from the pericycle located around the vascular bundle, increase the root's absorptive surface area. Their morphology is similar to that of the primary root. The finest secondary roots are called rootlets and generally bear many root hairs. Fine roots represent less than 10% of the total mass of a tree but form a root hair network (root mat). The region that separates the root from the stem is called the root collar.

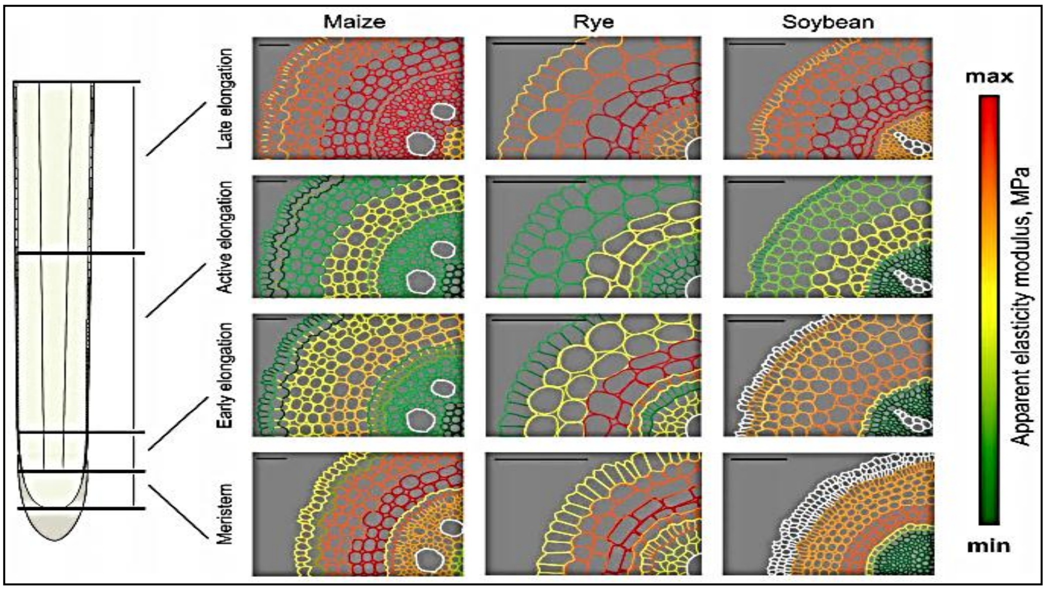


Figure 76: Apparent moduli of elasticity of different cell walls of maize, rye and soybean roots at different stages of development. Schematic drawings are made from real cross-sections of each species. The tissues not examined – xylem and root cap – are shown in white. The colour coding is based on the maximum and minimum values of the apparent Young's moduli for each species separately (Anna Petrova et al., 2023).

2.3 ANATOMICAL STRUCTURE OF THE ROOT

The root exhibits axial symmetry and a well-defined structure; a cross-section of a young root shows axial symmetry and allows us to distinguish two main zones (Figures 77, 78, 79): the cortex (composed of the rhizodermis and cortical parenchyma) and the central cylinder (stele) (composed of the endodermis, pericycle, vascular tissues, and medullary parenchyma). The cortex is slightly larger than the central cylinder.

2.3.1. The Cortex

This part is composed of:

a - Rhizodermis (root hair layer), which initially bears the root hairs (extensions of rhizodermal cells) of the root. These hairs enable the absorption of water and mineral salts. They have a diameter of 12 to 15 micrometers and a length ranging from 1 millimeter to several millimeters.

b – Cortical parenchyma, composed of cells with large intercellular spaces. The cortical parenchyma facilitates the transport of absorbed elements to the root center for their distribution throughout the plant.

2.3.2. Central Cylinder (Stele)

Comprises the following parts:

a – Endodermis: This is a layer of cells located between the cortex and the stele (central cylinder). It forms a single-cell-thick ring composed of closely packed, rectangular cells surrounding the pericycle. The external and internal tangential walls of these cells are cellulosic, while the other walls contain a band impregnated with suberin and sometimes lignin, called the Casparian strip, which plays an important role in regulating the flow of substances between the cortex and the conductive tissues of the stele.

b – Pericycle: Formed by a single layer of thin-walled, closely packed cells, from which root branches and secondary roots develop.

c – Vascular tissues: Located more centrally are the two conductive tissues, the xylem and the phloem, easily recognizable by their thick walls. They alternate regularly along a single ring and ensure the transport of raw sap (xylem or wood) to the leaves and elaborated sap (phloem or liber) throughout the plant. Xylem cells vary in size depending on their position in the central cylinder. Near the pericycle, they are young and small (protoxylem), while toward the center, they are large and mature (metaxylem). Xylem differentiation in the root is centripetal (differentiation progresses inward toward the root center).

d – Pith: Finally, at the center of the root, the pith, composed of medullary parenchyma, has no particular function except serving as a storage tissue.

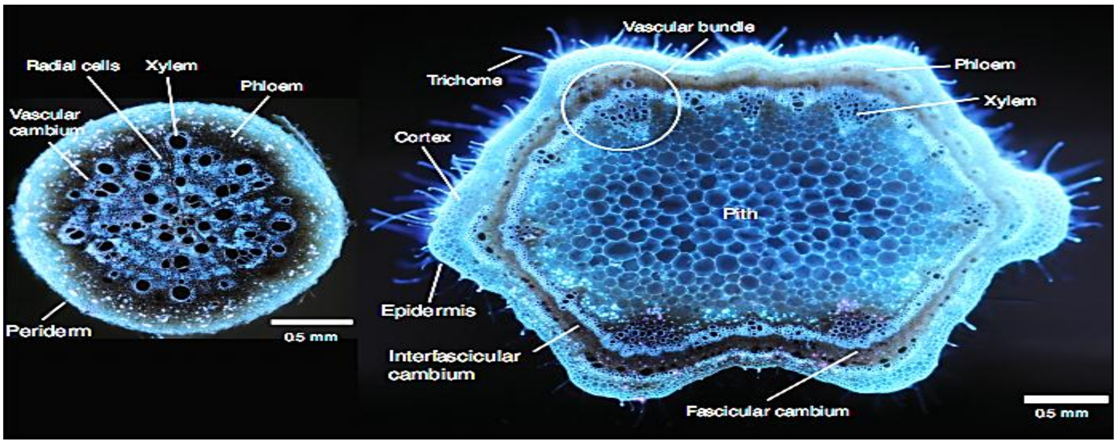
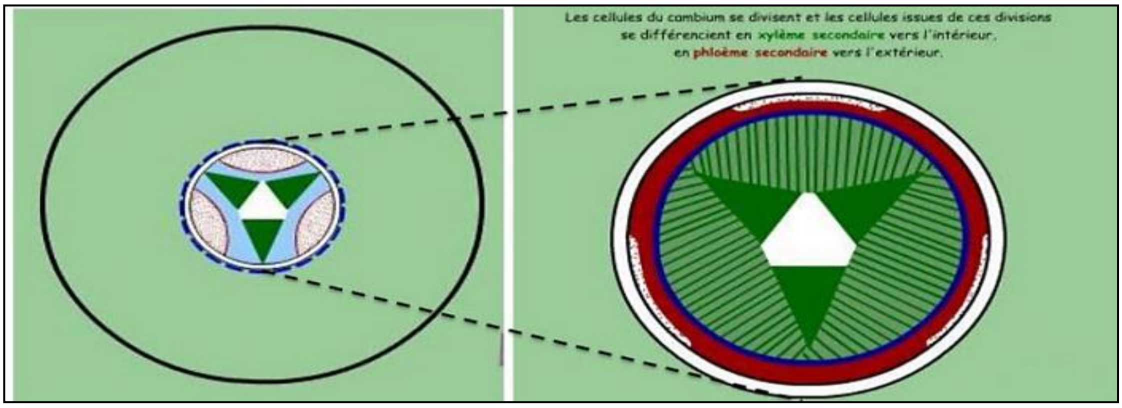


Figure 77: Comparison of root and shoot cross-sections highlighting differences in the anatomical arrangement of primary and secondary tissues of annual dicots. Shoot tissue is

characterized by having a thin cortex, vascular bundles encircling a central pith with a cambium alternating between fascicular and interfascicular regions. Contrastingly, roots have their vasculature arranged into a central stele with a vascular cambium that produces new xylem and phloem continuously throughout the entire circumference. Images of cross-sections are from root and stem tissue of common bean (Phaseolus vulgaris) (Strock and Lynch, 2020).



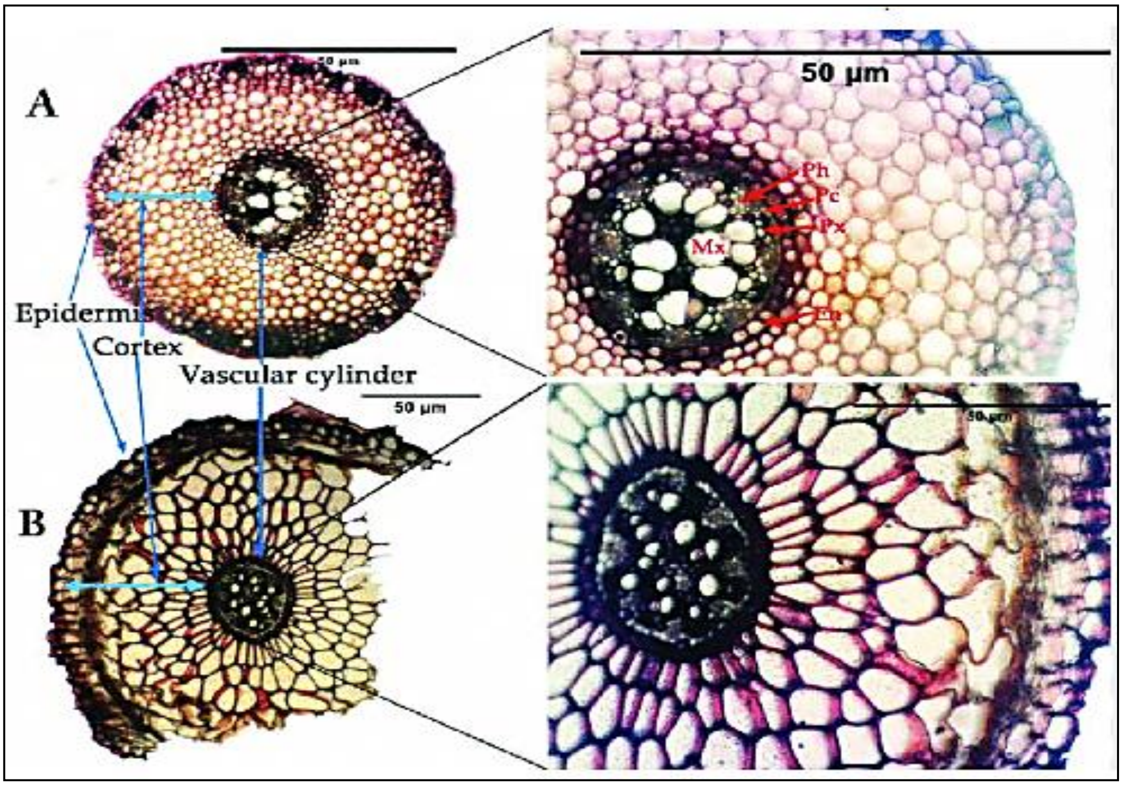


Figure 78: Cross-section of the adventitious roots (A) and contractile root (B) showing the different tissues (En -endodermis; Mx -metaxylem; Pc -pericycle; Ph -phloem; Px (Napaldet, 2017).

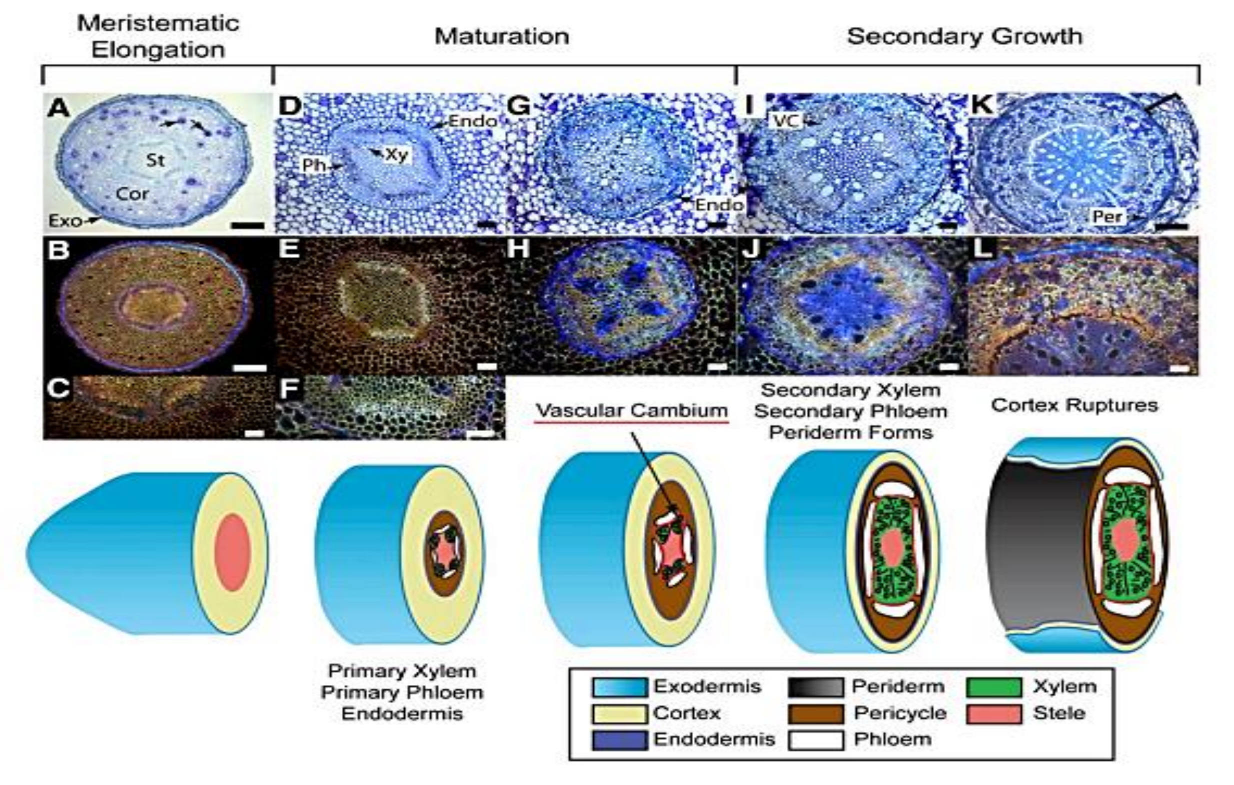


Figure 79: Developmental anatomy of grapevine fine roots visualized through the use of bright- and dark field microscopy. A to C, Undifferentiated tissue of the meristematic and elongation zones: exodermis (Exo), cortex (Cor), and stele (St). Dark blotches in A (black arrows) are raphides. D to H, Maturation zone including the appearance of primary xylem (Xy), primary phloem (Ph), and an identifiable endodermis (Endo). I to L, Secondary growth with the vascular cambium (VC) clearly visible. At later stages (K and L), the periderm (Per) forms and the exodermis, cortex, and endodermis rupture and are lost (bracketed in K) (Gambetta et al., 2013).

2.4 ANATOMICAL STRUCTURE OF A DICOTYLEDON ROOT

2.4.1 Primary Structure of Dicotyledons

- A small stele.
- Sclerified cortical parenchyma; only the radial walls of the endodermis are suberized (Casparian strip), often less visible than in monocotyledons (Figures 80, 81).
- The endodermis shows suberized and lignified thickening in the form of a band.
- There are typically 5 or 6 vascular bundles.
- The pith is composed of xylem.
- Onset of secondary growth: a vascular cambium frequently develops between the primary xylem and primary phloem, giving rise to secondary conductive tissues.

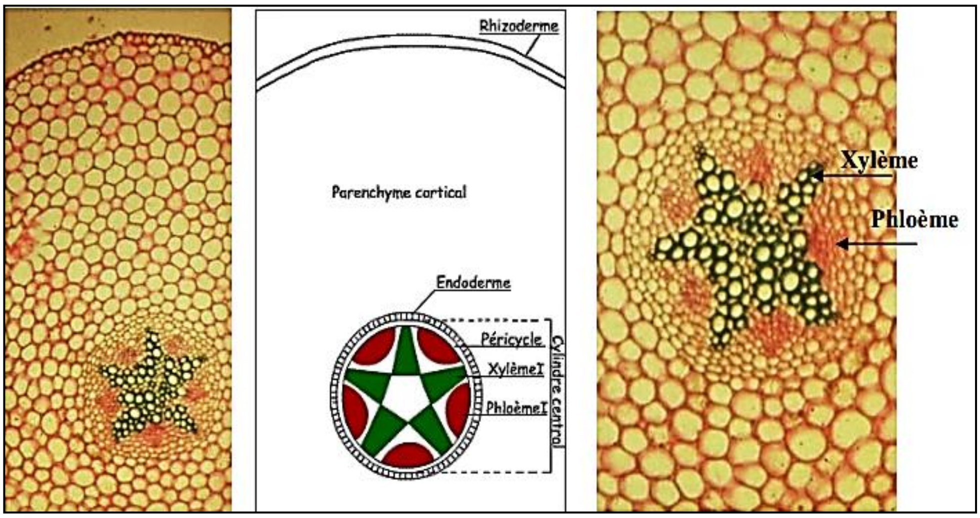


Figure 80: Primary structure of a dicotyledon root (Hellebore) (Bouzid, 2018)

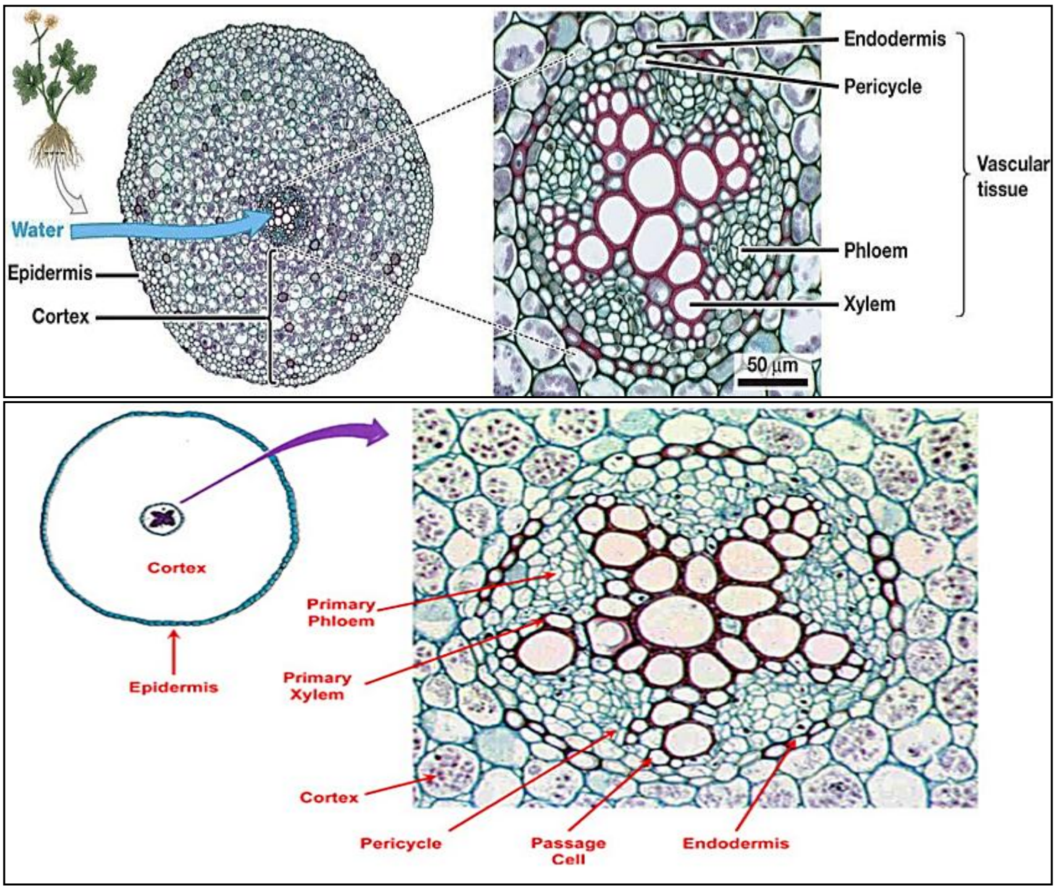


Figure 81: Across section through the region of maturation of a dicotyledon root of a Buttercup *(Ranunculus)* (Tahiri, 2015)

2.4.2 Secondary Structure of Dicotyledonous Roots

The secondary structure of a root concerns only dicotyledonous plants and is completely absent in monocotyledons.

In the roots of dicotyledonous plants (Figure 82), cells located on the inner side of the phloem bundles begin to divide and form discontinuous cambial arcs. Later, at the poles of the xylem, some cells dedifferentiate and form new cambial arcs. These arcs connect with the previously formed segments to establish a continuous cambial ring (vascular cambium). The vascular cambium (liber-wood layer) generates secondary conductive tissues: secondary xylem toward the inside (centripetal development) and secondary phloem toward the outside (centrifugal development).

The cortical cambium, located toward the periphery of the root (also known as the phellogen or cork cambium), produces an external layer of suber (cork) and an inner layer of phelloderm, both of which serve to protect the root.

The appearance of the phellogen is much later in herbaceous plants and is often entirely absent.

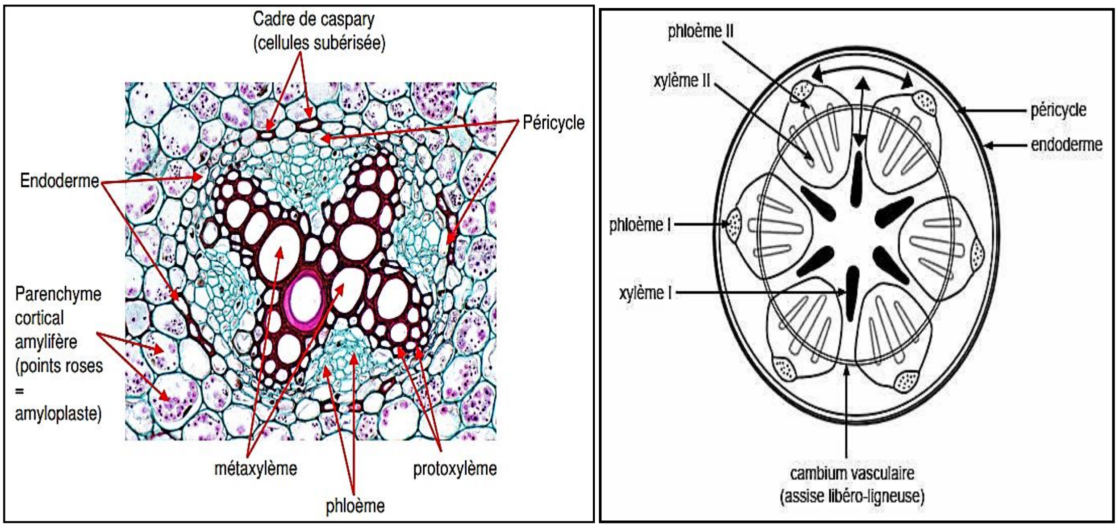


Figure 82: Secondary structures in a cross-section of a root (central cylinder) (Tahiri, 2015)

2.5 ANATOMICAL STRUCTURE OF A MONOCOTYLEDON ROOT

2.5.1 Primary Structure of Monocotyledonous Roots

- The stele of monocotyledon roots is much more developed than that of dicotyledon roots (Figure 83).
- The cortical parenchyma contains large intercellular spaces (aerenchyma).
- The endodermis exhibits U-shaped subero-lignified thickening (cell walls are entirely suberized except for the outer wall facing the xylem).
- The number of vascular bundles is higher, ranging from 8 to 20, surrounding a central parenchyma.
- The pith is composed of medullary parenchyma.
- No secondary growth occurs.

2.5.2 Secondary Structure of Monocotyledonous Roots

In monocotyledonous plants, secondary growth does not occur.

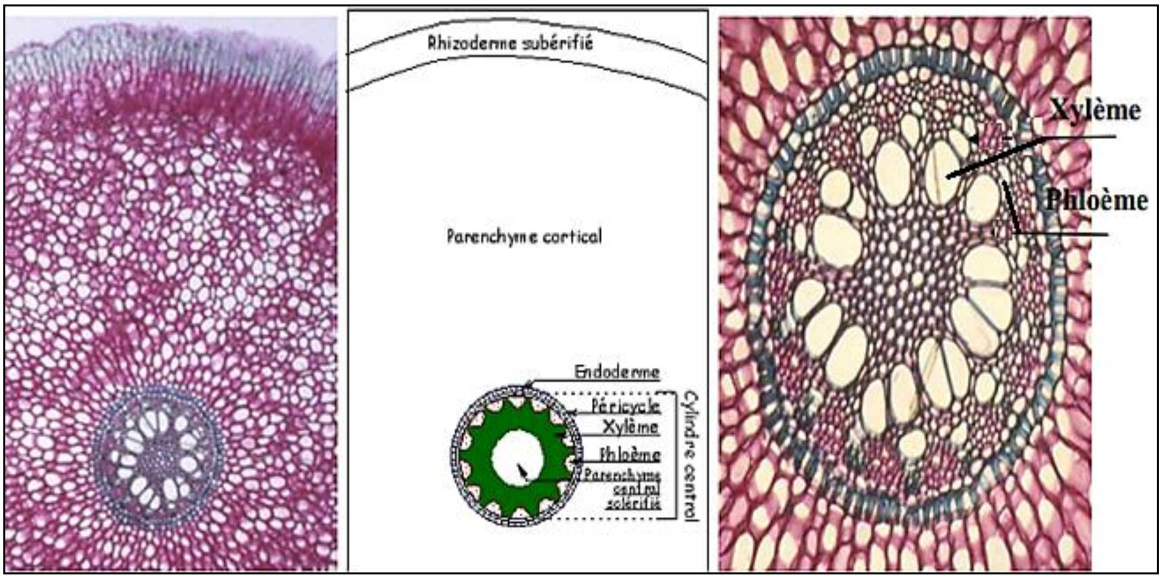


Figure 83: Primary structure of a monocotyledonous root (Iris) (Boukhalfoun, 2023)

2.6. ANATOMICAL DIFFERENCES BETWEEN MONOCOTYLEDONS AND DICOTYLEDONS

In a transverse section of a root, the anatomical differences between monocotyledons and dicotyledons can be summarized as follows (Table 5 and Figures 84, 85):

- The stele is more developed in monocotyledons than in dicotyledons.
- The pith is abundant and filled with medullary parenchyma in monocotyledons, in contrast to dicotyledons.
- The central cylinder, bounded by a single cell layer called the pericycle, contains the vascular tissues (xylem and phloem), which are arranged in an alternating pattern.
- In dicotyledons, there are typically two to five vascular bundles. The structure in monocotyledons is similar but contains a higher number of bundles, often more than 6, and typically 12 to 20.
- The endodermis in monocotyledons is characterized by a horseshoe-shaped thickening (U-shaped endodermis). The radial and inner walls are lignified and suberized, whereas the outer wall facing the cortical parenchyma remains cellulosic. In dicotyledons, the endodermis has a Casparian strip structure (Casparian frame).

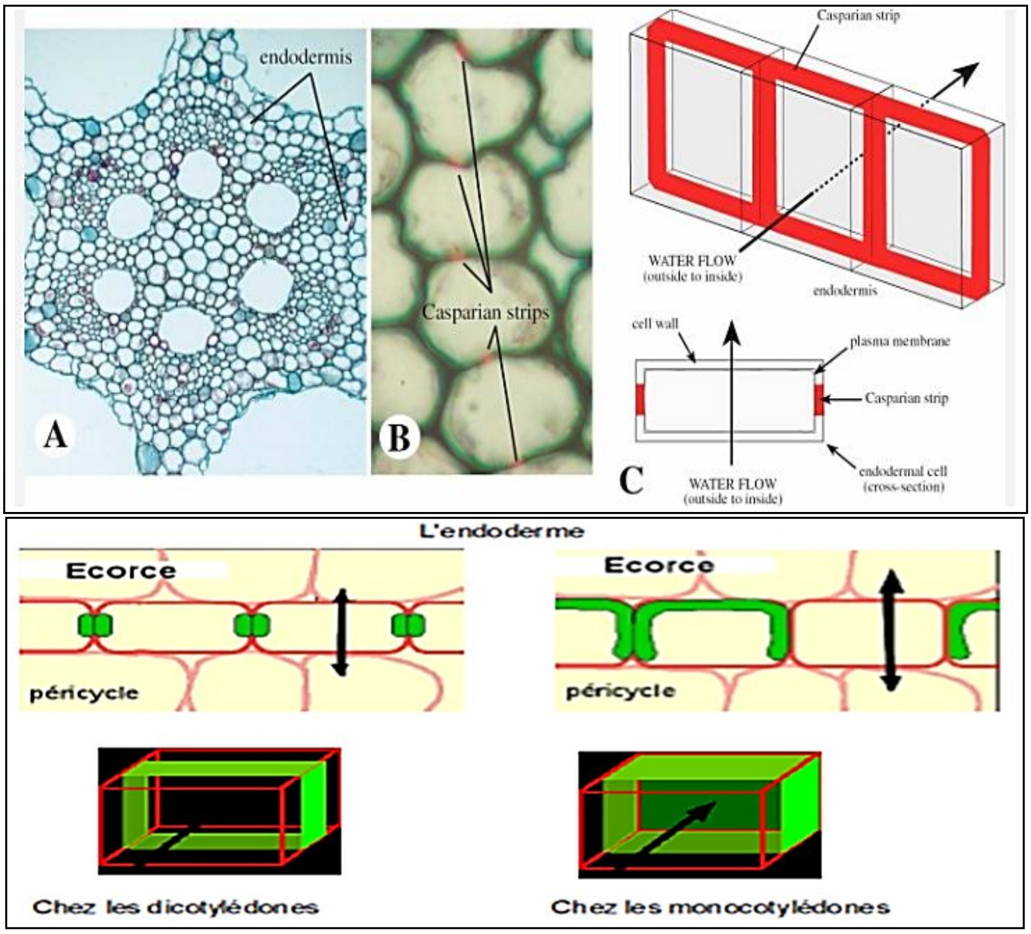


Figure 84: Endodermis of a monocotyledon and dicotyledon root (Lulai, 2007)

Table 7: Anatomical differences between monocotyledonous and dicotyledonous roots (Godinot et al., 2010)

	Monocotyledon root	Dicotyledon root
Stele	Well developed	Reduced
Cortical parenchyma	Cellulosic with large intercellular spaces	Sclerenchymatous (sclérifié)
Pericycle	Reduced	More developed
Suberized-lignified endodermis	U-shaped (horseshoe-shaped)	Casparian strip (band-shaped)
Xylem and phloem bundles	Numerous (8 to 20)	Few bundles (2 to 6)
Medullary parenchyma	Abundant	Absent or replaced by xylem
Secondary structures	Absent	Presence of cambium and phelloderm

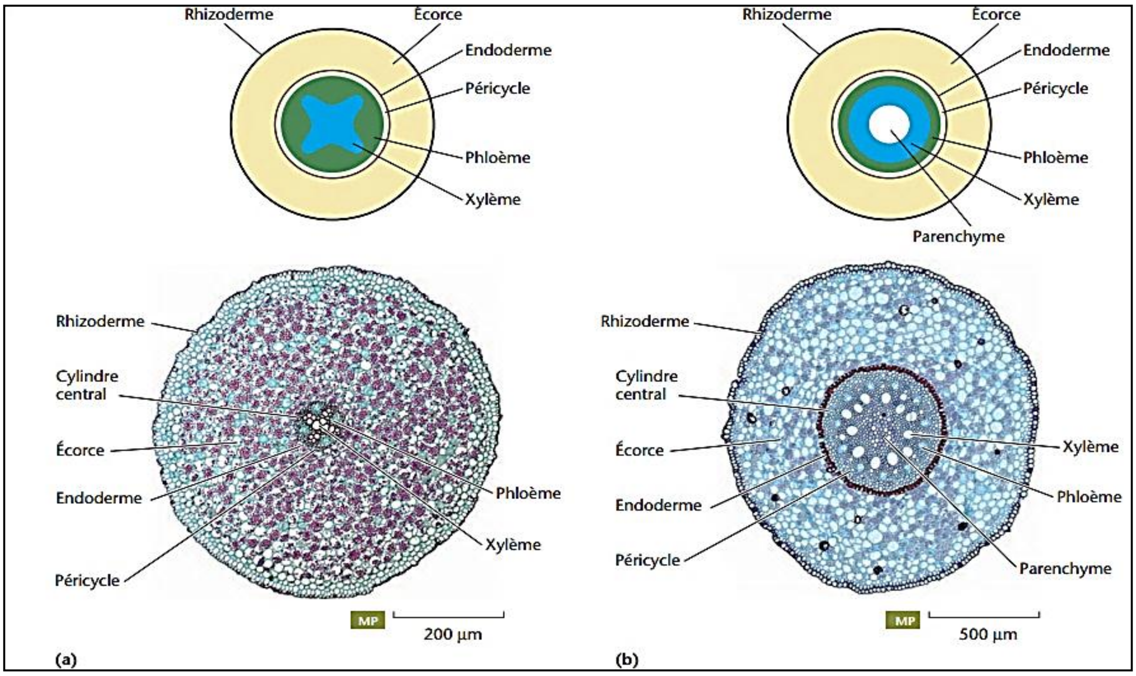


Figure 85: Primary root structure. (a) Most roots possess a protostele composed of a central cylinder of vascular tissues. In all primary roots, the vascular tissues are surrounded by a layer called the pericycle, which is itself encased externally by the endodermis. (b) Roots of monocotyledons have a stele composed of rings of xylem and phloem surrounding a medullary parenchyma (Raven et al., 2007).

2.7 DIFFERENT TYPES OF ROOTS

2.7.1 Taproots

The taproot system is characterized by a main root that is much larger than the secondary roots (Figure 86). Taproots generally penetrate deeply and vertically into the soil, firmly anchoring the plant. This root system is typical of dicotyledons. The taproot enables the plant to access water deep underground. Trees and plants from dry regions often have this system (e.g., alfalfa).

Figure 86: Taproot system (Raven et al., 2003)

2.7.2 Fibrous roots

This root system consists of very fine roots among which it is impossible to distinguish the primary root from the secondary roots (Figure 87). Plants with this root system are monocotyledons. The roots typically grow just below the soil surface (e.g., grasses).

Figure 87: Fibrous root systems (Raven et al., 2003)

2.7.3 Adventitious Roots

They can form elsewhere than at the base of the stem, for example on the internodes of creeping stems. Sometimes they appear on underground stems (Iris, couch grass), or on climbing stems (ivy). These roots originate from either aerial or underground stems, e.g., the stolons of the strawberry plant (used for vegetative propagation or plant cuttings). In maize, aerial adventitious roots called prop roots (figure 88) help reinforce the anchorage of the plant in the soil.

Figure 88: Adventitious anchoring roots of maize (Poaceae) (Raven et al., 2003)

2.7.4 Tuberous Roots (Storage Roots)

These are swollen roots due to the accumulation of storage substances (Figure 89). Examples: carrot, beetroot, radish, turnip. Tuberous roots generally live for two years, but during the harsh season, their aerial vegetative system disappears. The reserves stored in the tubers will be used the following year to nourish the plant.

Figure 89: Storage roots: the roots of the carrot are transformed into hypertrophied storage organs that accumulate water and nutrient substances (Raven et al., 2003).

2.7.5. Climbing roots

These are adventitious roots that develop along the stem (e.g., ivy) (Figure 90). These roots are used to attach the plant to a support (such as a wall). Ivy produces adventitious roots that form, at their tips, a kind of suction cup to adhere to the surface.

Figure 90: Aerial clinging roots which develop on the stems of ivy, ensure the plant's attachment to vertical surfaces (Raven et al., 2003)

2.7.6 Respiratory roots (pneumatophores or aeriferous roots)

These are secondary roots with negative geotropism, growing vertically in flooded environments to obtain oxygen (they emerge from anoxic soils where the concentration of dissolved oxygen in water is very low) (Figure 91). In Algeria, for example, in the El-Kala region: Lake Tonga (bald cypress). In Mangrove trees (aquatic farms), where the roots are immersed in brackish (salty) water - an environment that is not favorable for life - the trees develop respiratory roots called pneumatophores, which ensure better oxygen supply.

Figure 91: Pneumatophores (or aeriferous roots). Specialized roots, such as those found in mangrove plants (left) or in Taxodium (right), whose function is respiratory. Pneumatophores supply oxygen to plants growing in swamps where the water is poorly oxygenated (Raven et al., 2003).

2.7.7 Buttress roots

These are aerial (adventitious) roots that arise from branches of certain tree species in tropical regions (figure 92). Their growth toward the soil and anchorage within it provide a support function. Buttress roots are flared roots developing at the base of trunks, contributing to the tree's stability. Some tropical trees develop large buttresses that help stabilize their anchorage in the light, often loose soils typical of tropical environments.

Figure 92: Buttress roots (Raven et al., 2003)

2.7.8 Aquatic roots (hydrophytes)

These roots lack root hairs and root caps (figure 93), for example, the duckweed (Lemna). Contractile roots, observed in plants like lilies. Enhance the plant's penetration into the soil by contracting at certain stages of development. Some modified roots have evolved to improve asexual reproduction (vegetative propagation) by directly producing buds or shoots annually that emerge from the soil to generate new growth in perennial plants.

Figure 93: Racines aquatiques libres de saule (Raven et al., 2003)

3. STEM ANATOMY

The stem of a plant is an organ whose main functions are to support the foliar system, to transport water and mineral salts from the roots to the leaves, and to transfer the nutrients produced by the leaves to other parts of the plant (Figure 95).

Etymologically, the term "stem" derives from "caulis"; a plant without a stem is called "acaulescent," and a plant with a hollow stem is termed "caulicolous." The stem generally branches into shoots and twigs (secondary stems), forming the aerial shoot system (cauline apparatus).

• The stem differs from the root by the presence of:

- ✓ Nodes where axillary buds are inserted
- ✓ Leaves
- ✓ Its anatomical structure
- ✓ The transition between root and stem occurs at the “collar” (or root collar)
- ✓ Stem growth occurs opposite to gravitational pull (negative geotropism) and towards light (positive phototropism).

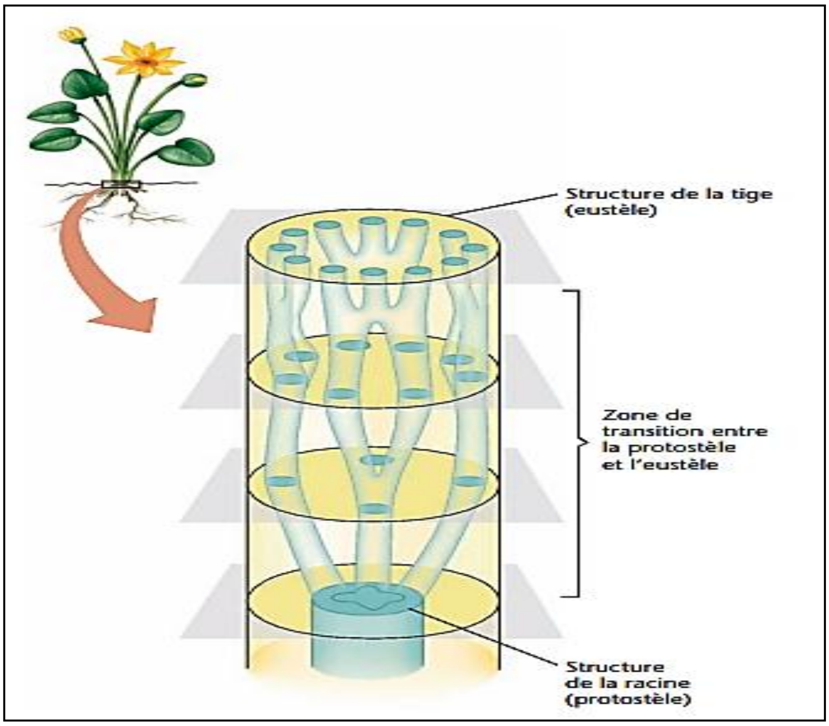


Figure 94: Transition zone between the stem and the root. In many plants, the vascular tissues of the root stele are arranged differently from those of the stem stele. This simplified example shows how part of the vascular tissues of the root protostele transforms into the stem eustele, which contains numerous discrete vascular bundles.

- **Plant habit:**

It is influenced by the way the main stem and secondary stems (branches) behave relative to each other (Figure 95):

- ✓ When the main stem is much stronger than the secondary stems, the common form of most trees is observed, with the main stem called the trunk.
- ✓ When the main stem does not grow more than its branches, the plant takes the bushy form characteristic of shrubs or small trees.
- ✓ Some stems do not branch at all, as is the case with palms, whose columnar trunk or **stipe** is topped by a large cluster of leaves.

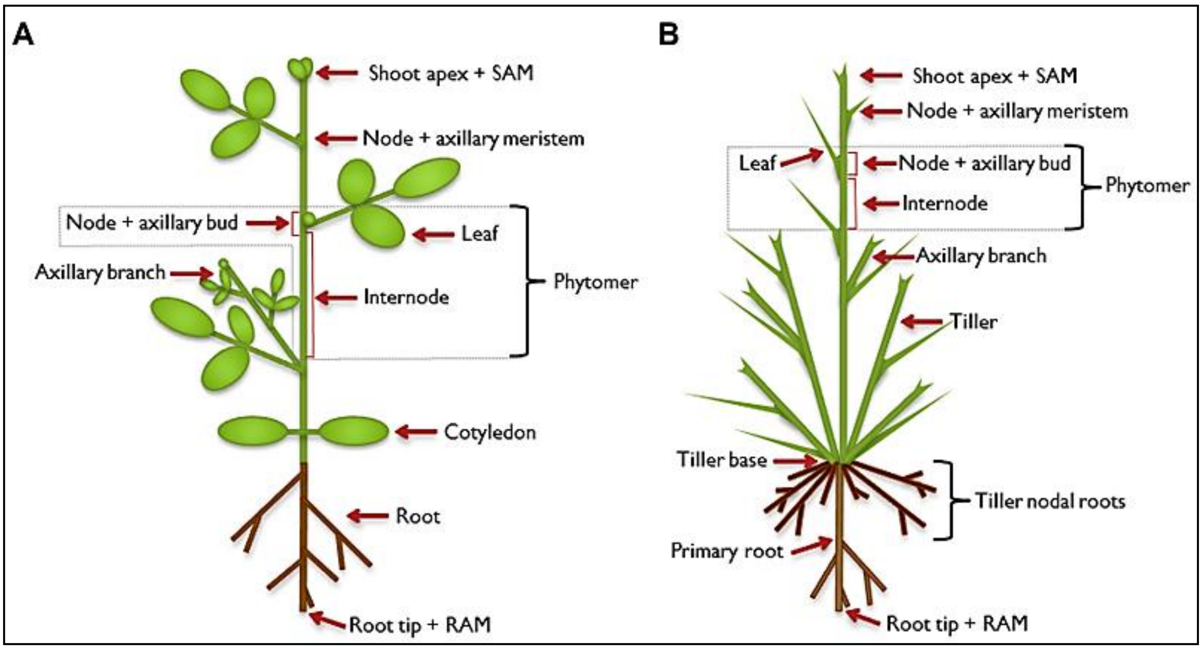


Figure 95: Illustration of plant architecture. Typical architecture of a dicot plant (A) and a monocot plant (B). The shoot apical meristem (SAM) establishes the shoot as the primary growth axis of the plant by continuously initiating phytomers, the basic modules of the plant shoot. A phytomer consists of an internode and a node with its attached leaf. In the leaf axils, axillary (secondary) meristems are formed in dicot and some monocot plants, which develop into an axillary bud and have the potential to continue growth to form an axillary branch.

This branch can be regarded as a secondary growth axis and is built in the same way as the primary shoot (figure 95). It can branch further to form higher-order branches. The primary root is established by its own meristem [root apical meristem (RAM)] and can also branch to form secondary or higher-orde lateral roots. In addition to axillary branches, monocot plants can produce tiller which emanate from the base of the plant, which has extremely condensed internodes. The tillers form adventitious roots, called tiller nodal roots (Teichmann and Muhr, 2015).

3.1. ANATOMICAL STRUCTURE OF THE STEM

What characterizes the stem anatomically is the arrangement of xylem and phloem; unlike in roots where they alternate, in the stem they are superimposed. A transverse section of a young stem shows the presence of several zones (Figures 96, 97, 98):

- **Epidermis:** Composed of a single layer of tightly joined (juxtaposed) cells, with thin walls, lacking chloroplasts. The outer surface is covered by a thin cuticle and bears stomata. Collenchyma cells may be found just beneath the epidermis, preceding the cortical parenchyma.
- **Cortex (Cortical parenchyma):** Relatively reduced in thickness, composed of large polyhedral cells with significant intercellular spaces. Peripheral cells contain chloroplasts, but their number decreases progressively toward the inner layers.
- **The central cylinder** is located beneath the cortex and contains, within a medullary parenchyma, the vascular bundles (liber-ligneous bundles) arranged in a single ring. These bundles appear as conductive tissues grouped in stacked masses of xylem and phloem, with the xylem oriented toward the center of the stem and overlain externally by the phloem.
  - Each vascular bundle is topped by a small mass of sclerenchyma.
  - The xylem exhibits centrifugal differentiation: the protoxylem is located near the center (appearing during stem growth), while the metaxylem is near the periphery (appearing after stem growth is completed).
  - The diameters of xylem cells are not uniform; they decrease progressively toward the center, with protoxylem having small-diameter cells near the center and metaxylem having large-diameter cells near the periphery.
  - It is also possible to distinguish protophloem and metaphloem. Phloem differentiation in the stem is centripetal.
- **The pith** of the stem is filled by medullary parenchyma composed of very large cells.

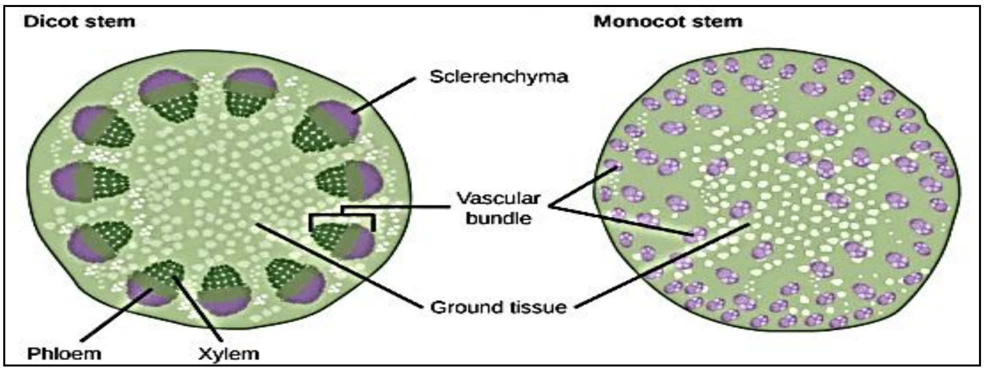


Figure 96: Structure of dicot and monocot stem (Wise, 2017)

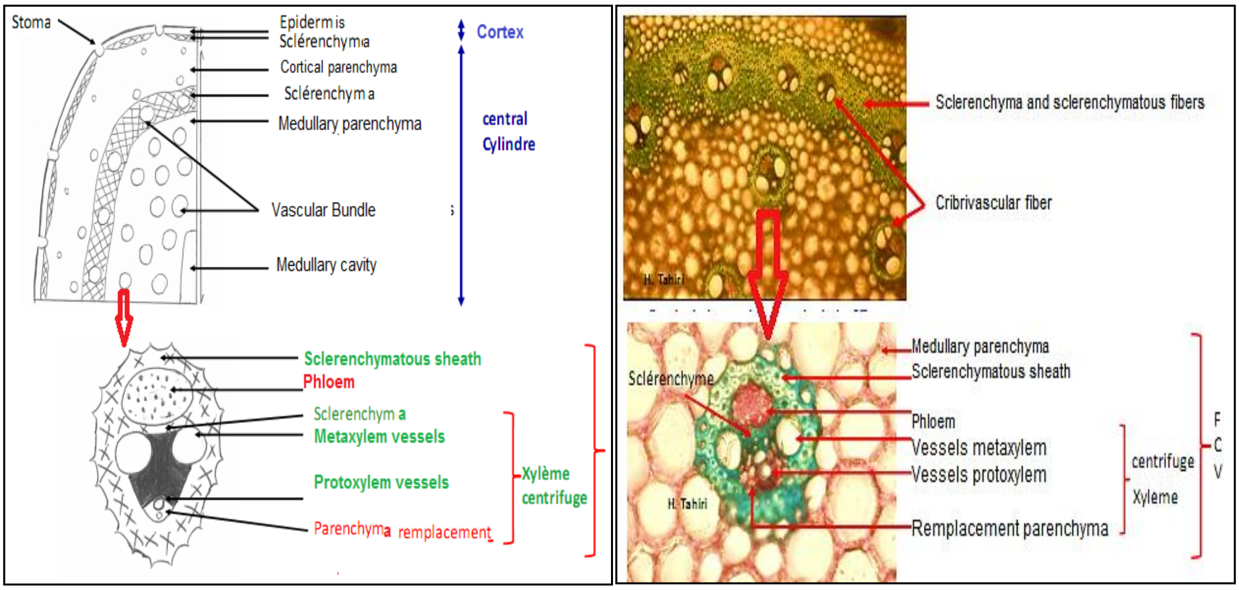


Figure 97: Diagram of a section of a transverse stem cross-section (Tahiri, 2015)

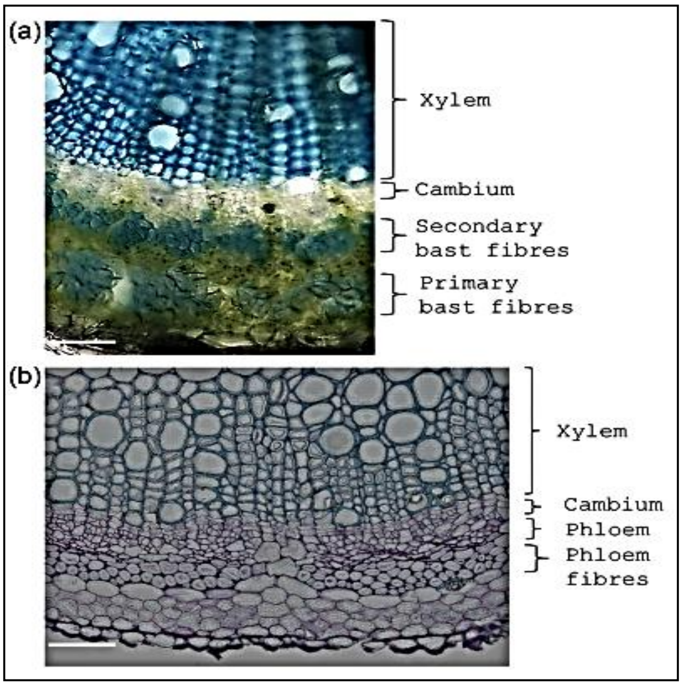


Figure 98: (a) Stem cross section of the hemp hypocotyl (21 days after sowing) showing the presence of primary and secondary bast fibres, cambium and xylem. (b) Stem cross section of the alfalfa stem showing the presence of phloem bundles, phloem tissue, cambium layer and xylem (Guerriero et al., 2014).

3.2. ANATOMICAL STRUCTURE OF A DICOTYLEDONOUS STEM

3.2.1. Primary Structure

- ✓ Firstly, an epidermis is observed, followed by a few superficial layers of collenchyma, a very reduced cortical parenchyma, and a ring of sclerenchyma.

- ✓ Above the xylem lies the phloem, and between them are cambial cells that will give rise to secondary structures.
- ✓ The central cylinder contains numerous vascular bundles arranged in a single circle in dicotyledons (Figure 99).
- ✓ The medullary parenchyma is more developed than the cortical parenchyma; sometimes a lacuna is present at the center of the stem.
- ✓ These observations correspond to a young dicotyledonous stem, but secondary growth soon develops, complicating these structures.

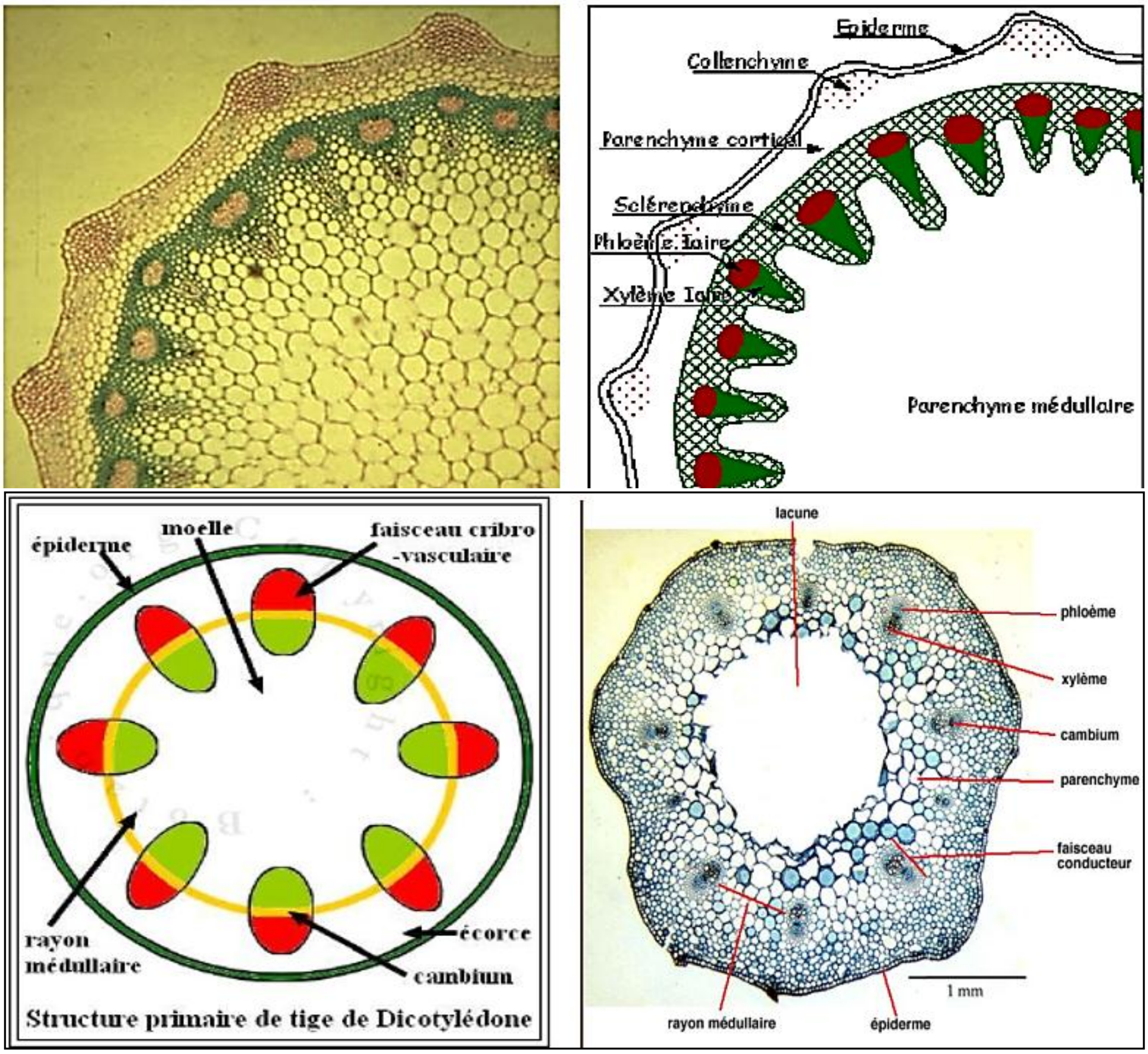


Figure 99: Primary Structure of a Dicotyledonous Stem (Remy et al, 2004)

3.2.2. Secondary Structure

Between the primary phloem and the primary xylem, a cambium forms and functions by producing secondary xylem towards the inside and secondary phloem towards the outside. In the cortex, a phellogen (cork cambium) appears, which generates suber (cork) outwardly and phelloderm inwardly. Thus, moving from the outside towards the inside of the stem (Figure 100), one can observe:

- Epidermis, collenchyma, cortical parenchyma, primary phloem, secondary phloem, cambium, secondary xylem, then primary xylem, and finally the pith.

In the stem, the cambium appears very early at the level of the vascular bundles (between the xylem and phloem). Later, following the dedifferentiation of parenchyma cells, interfascicular cambium arcs appear, which can connect with the intrafascicular cambium cells (located inside the bundle between xylem and phloem) to form a continuous meristematic cambial ring.

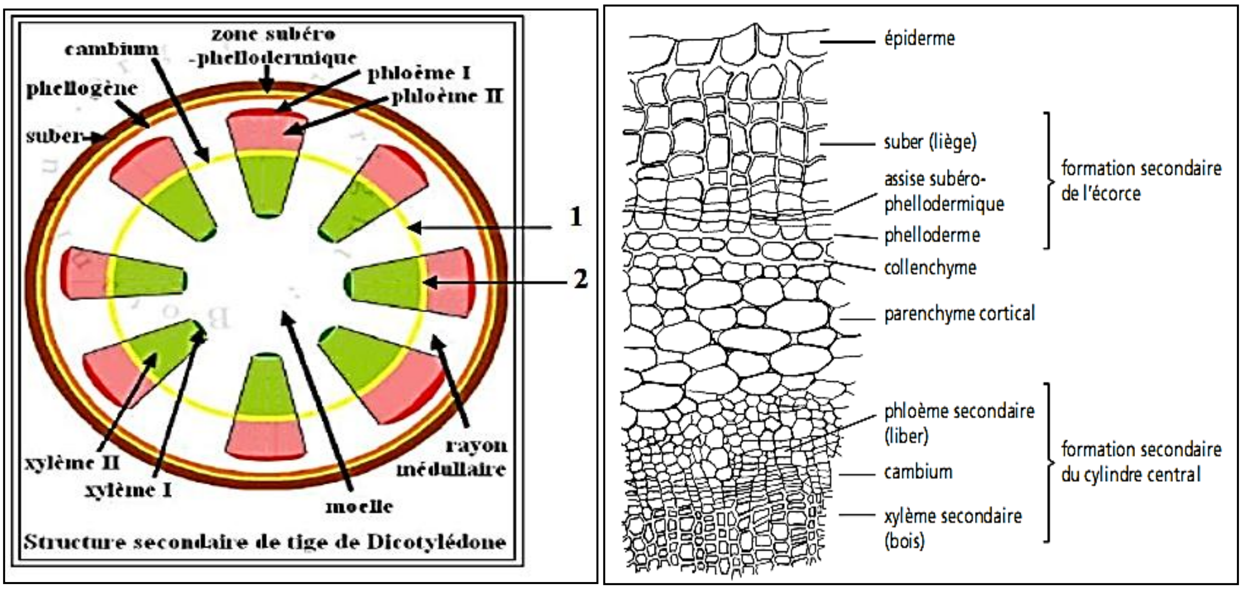


Figure 100: Diagram of a transverse section of an older stem (1) interfascicular cambium, (2) intrafascicular cambium) (Remy et al, 2004 ; Laberche, 2010)

3.3. ANATOMICAL STRUCTURE OF A MONOCOT STEM

3.3.1. Primary Structure

In monocotyledons, there is no secondary growth. From the outside to the inside, the following structures can be observed (Figures 101, 102):

- ✓ An epidermis, a very reduced cortical parenchyma, **and a** highly developed and often lignified pith.
- ✓ Several concentric rings of vascular bundles (collateral bundles).
- ✓ A sclerenchymatous ring surrounding the outermost circle of bundles.
- ✓ The diameter of the vascular bundles decreases from the center toward the periphery of the stem, with the older bundles being pushed toward the center.
- ✓ Stem thickening in monocots occurs by increasing the number of vascular bundles.
- ✓ The central part of the stem may be hollow.

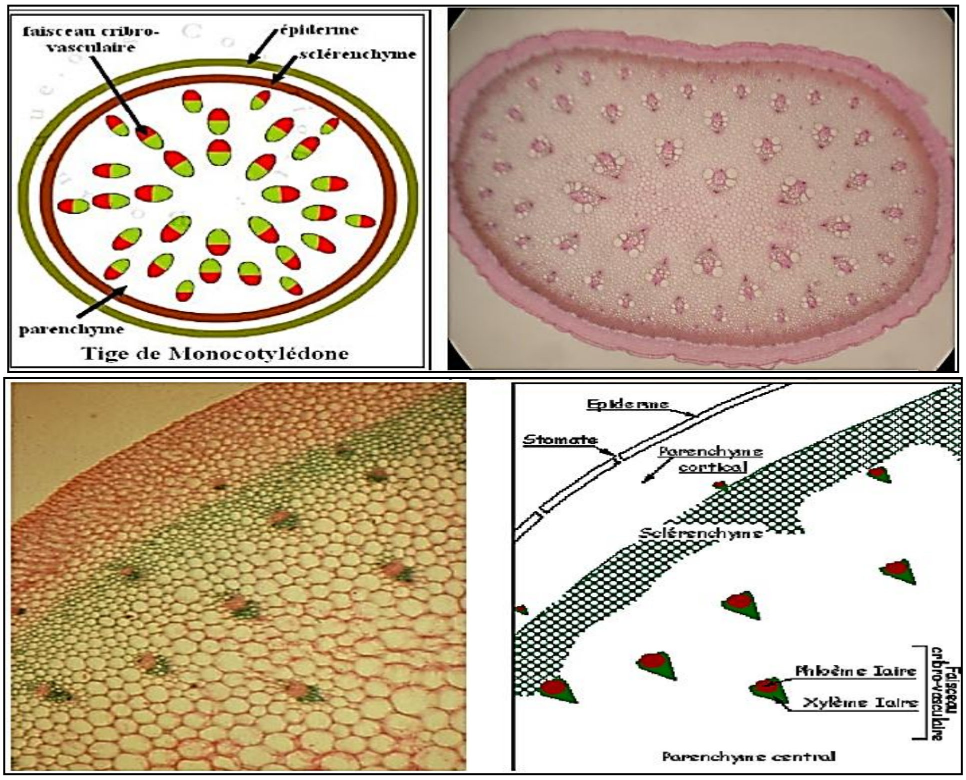


Figure 101: Primary structure of a monocot stem (Remy et al, 2004)

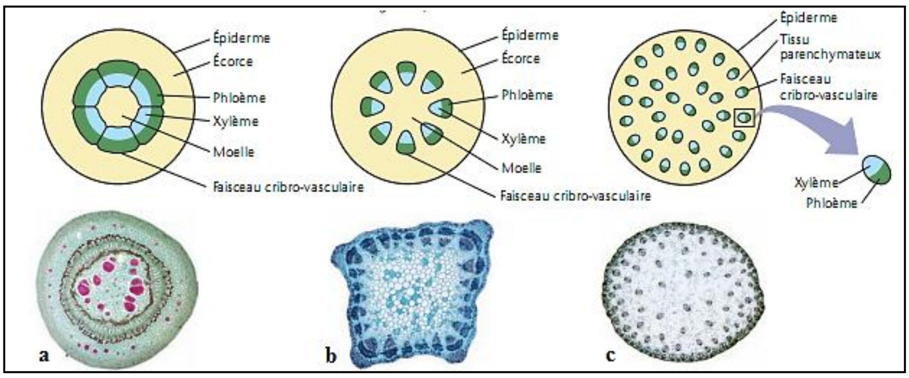


Figure 102: Primary structure of stems. In most vascular bundles, the xylem is located on the inner side while the phloem is on the outer side. These vascular bundles are often surrounded by

a sheath of sclerenchyma. These transverse sections show the basic organization of stems in plants. a) Eustele: a stele with vascular bundles arranged in a ring around the pith (some dicotyledons and gymnosperms). b) Eustele: a stele with vascular bundles separated from each other (most dicotyledons and some gymnosperms). c) Atactostele: a stele with vascular bundles scattered throughout the parenchymatous tissue (most monocotyledons) (Raven et al., 2007).

3.3.2. Secondary Structure

There is a complete absence of secondary structure in monocotyledonous plants.

Tables 8 and 9, along with the following figures (103, 104, 105), provide information on the anatomical differences between the roots and stems of monocotyledons and dicotyledons.

Table 8: Differences between a Monocotyledonous and a Dicotyledonous Stem (Godinot et al., 2010)

Monocotyledon	Dicotyledon
Multiple concentric circles of vascular bundles	Central cylinder (stele) contains numerous vascular bundles arranged in a single ring
Cortex absent or reduced; well-developed pith	Pith (medullary parenchyma) more abundant than cortical parenchyma
Lack of secondary structures	Presence of secondary structures

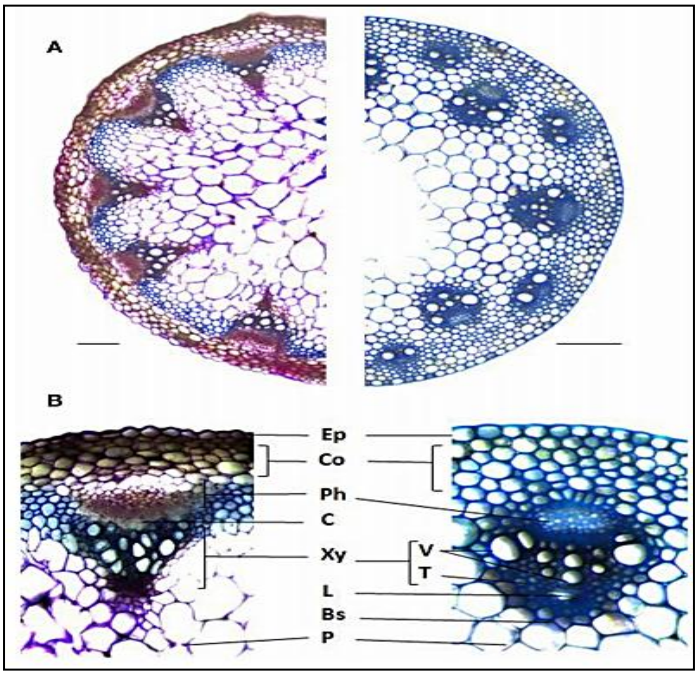


Figure 103: Stem cross sections illustrating the different cell types and arrangements between dicots and monocots. (A) *Arabidopsis thaliana* (left) and *Brachypodium distachyon* (right)

stained with Toluidine blue. (B) Vascular bundle anatomy of A. thaliana (left) and B. distachyon (right). Ep, Epidermis; Co, Cortex; Ph, Phloem; C, Cambium; Xy, Xylem; V, Vessels; T, Tracheads; L, Lacuna; Bs, Bundle Sheath; P, Pith (Handakumbura and Hazen, 2012)

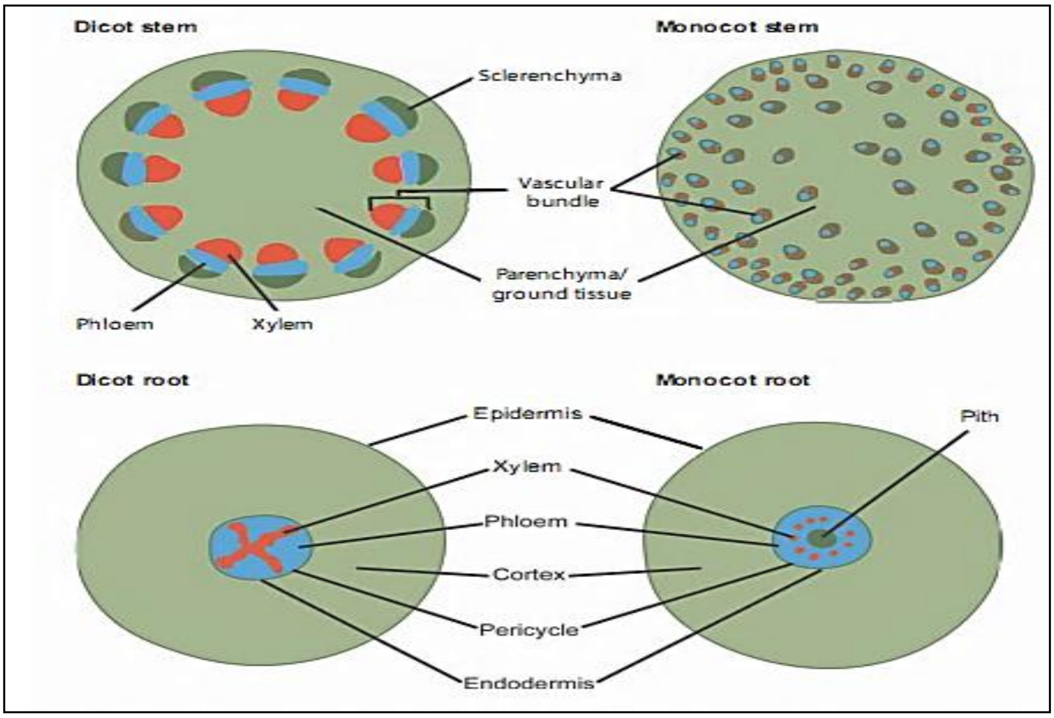


Figure 104: Anatomical structure of stem and primary root tissues in dicots/eudicots and Monocots **(**Florin, 2022)

Table 9: Comparative Anatomy of Monocot and Dicot Stems and Roots (Godinot et al., 2010)

	ROOT	**STEM**
CORTEX	Large (thick)	Reduced cortex
STELE	Presence of stele (central cylinder)	Absence or minimal presence of a stele
ENDODERMIS AND PERICYCLE	Presence of endodermis and pericycle	Absence of endodermis and pericycle
PITH (Medulla)	Reduced	Well-developed (prominent) pith
VASCULAR BUNDLES	Alternating xylem and phloem	Xylem and phloem are superimposed (phloem external to xylem)
XYLEM	Xylem exhibits centripetal differentiation	Xylem exhibits centrifugal differentiation
Supporting tissues	Absence of supporting tissues	Presence of supporting tissues

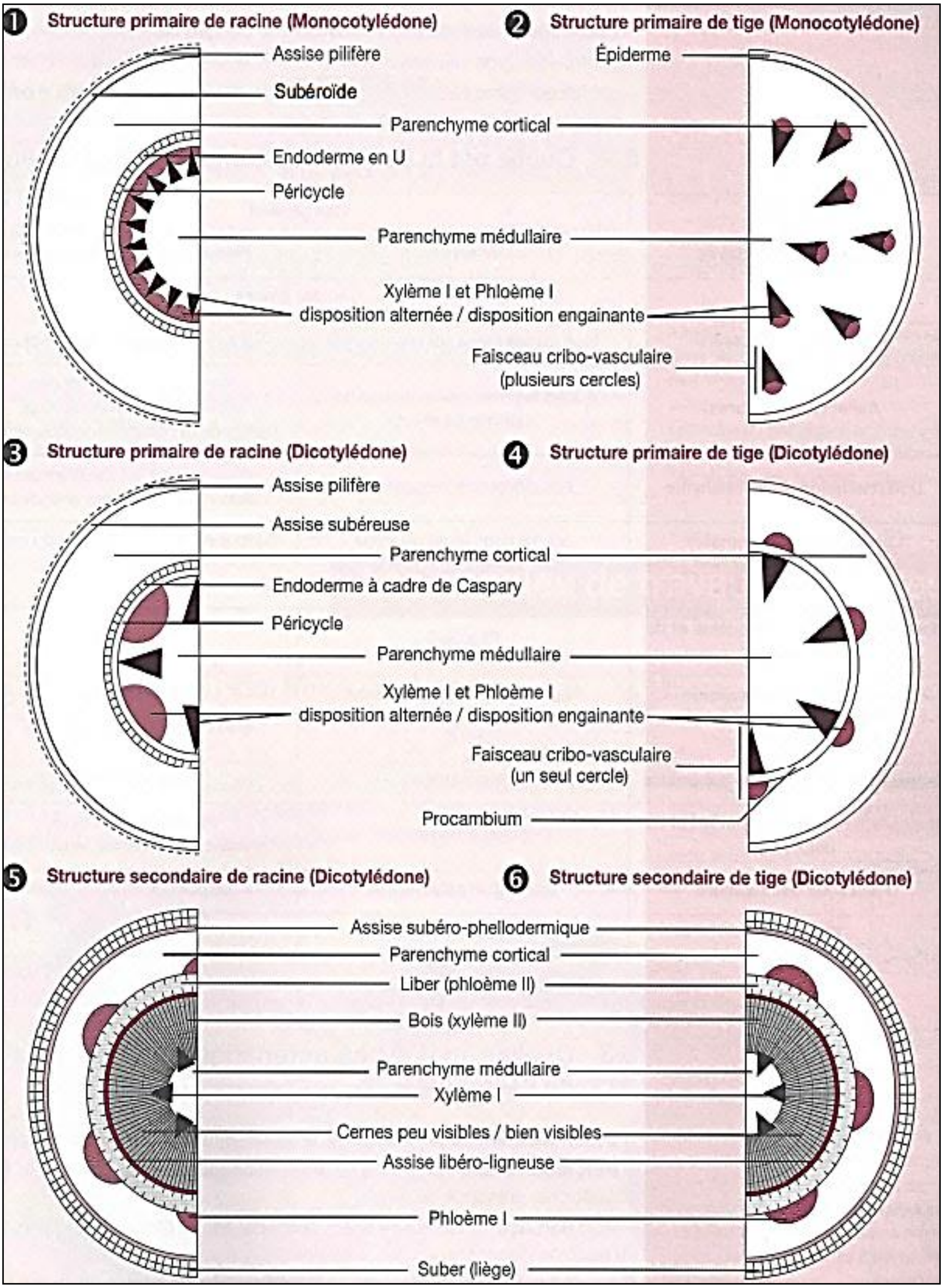


Figure 105: Conventional schematic representation of the main vegetative organs (transverse sections) (Godinot et al., 2010)

3.4. DIFFERENT TYPES OF STEMS

3.4.1. Aerial Stems

Aerial stems consist of an upright axis bearing a terminal bud at its apex. These stems, whether erect or ascending, usually have short internodes at the base, which become progressively longer toward the apex. They may be simple or branched.

a. Erect stems

The erect stem is sufficiently strong to grow vertically, as seen in trees and shrubs (Figure 106). These stems may be referred to by specific names: *trunk* in trees (they are branched and thicken from year to year), *stipe* in palms, and *culm* in grasses.

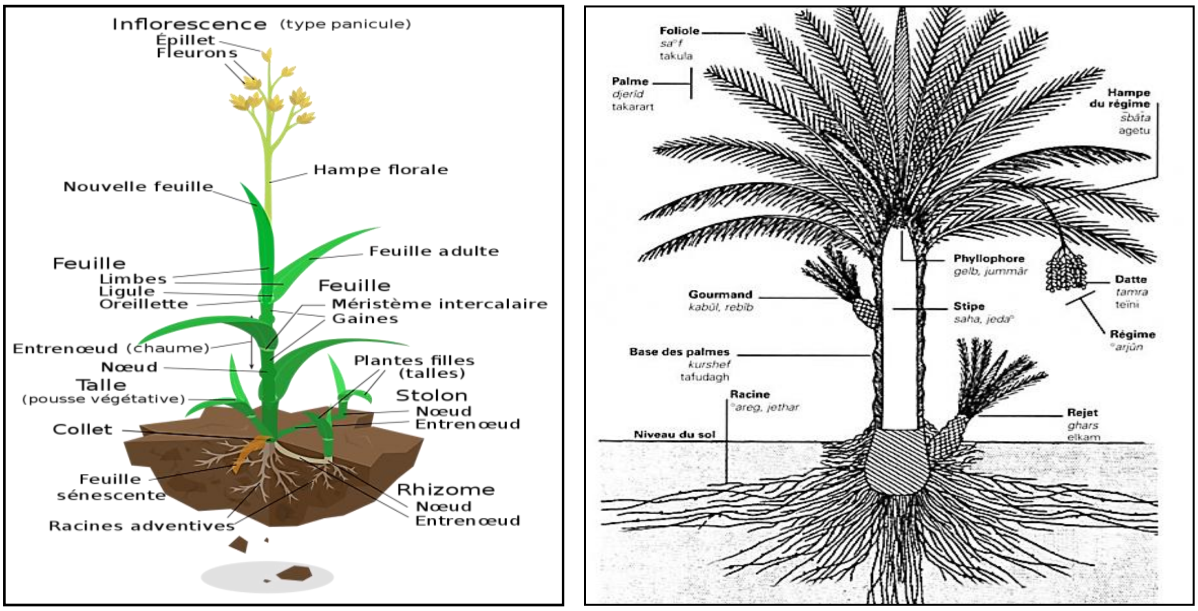


Figure 106: Grass stem: culm (left) and palm trunk: stipe (right)

b. Creeping stems

These stems spread along the ground and rise little or not at all (Figure 107). Their tips penetrate the soil to give rise to a new plant, which later separates from the mother plant through stolon breakage. These are also referred to as prostrate plants. Plants such as the strawberry have creeping stems (or Stolons) that root near the original plant to form new ones. This is a case of natural vegetative propagation

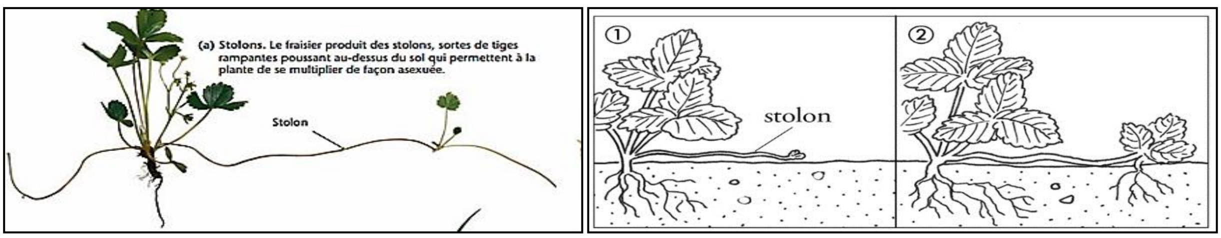


Figure 107: Strawberry stolon plant (Raven, al., 2007)

c. Climbing stems

These stems attach to a support by means of holdfasts, which are adventitious roots (figure 108), for example, ivy, or by tendrils, which are modified leaves, for example, grapevine and tendril-bearing shoots. There are also twining plants, whose stems coil around the support, such as bindweed and lianas.

Tendril of grapevine, lignifie *Twining stem of a liana* *Aristolochia*

Figure 108: Climbing stems (tendrilled stem and twining stem) (Raven et al., 2007)

d. Cladodes (modified shoots)

These are specialized shoots resembling leaves and performing the same functions (photosynthesis, respiration, and storage). Cladodes are short, flattened, and consist of a single internode (figure 109). Cladodes and phylloclades belong to the shoot system and exhibit characteristics that differentiate them from leaf organs: they are generally inserted in the axil of a leaf (often highly reduced) and can bear buds. In cacti of the genera *Opuntia* and *Brasiliopuntia*, the paddle-shaped segments constitute cladodes, while the leaves themselves have degenerated into spines.

Figure 109: Cladodes of Opuntia and butcher's broom (Ruscus aculeatus) (Boukhalfoun, 2023)

e. Thorns or Spiny Branches

Spiny branches are cauline thorns derived from the transformation of a bud or a stipule. They are axillary shoots whose apical meristem has aborted prematurely (Figure 110). The associated leaves and lateral buds are always reduced. Due to their high degree of lignification and hardness, they represent the most common type of thorns (referred to as dards). These shoots have limited growth. Examples: thorns of brambles (Rubus), roses (Rosa), and stipular spines in black locust (Robinia).

Prickle on a rose stem *Stipular spines on black locust (Robinia)*

Figure 110: *Thorns (Dards)*

f. Succulent stems

These are fleshy, water-filled stems found in plants adapted to arid environments (Figure 111); e.g., the *Cactaceae* family, *Adansonia digitata* (Baobab). The stems of these plants contain an aquiferous parenchyma, an epidermis lacking stomata and covered with a very thick cuticle. Leaves are either absent, very small (scales), or reduced to spines, all of which help prevent water loss. The stems are often covered with a waxy bloom (pruinose coating) that reflects the sun’s rays.

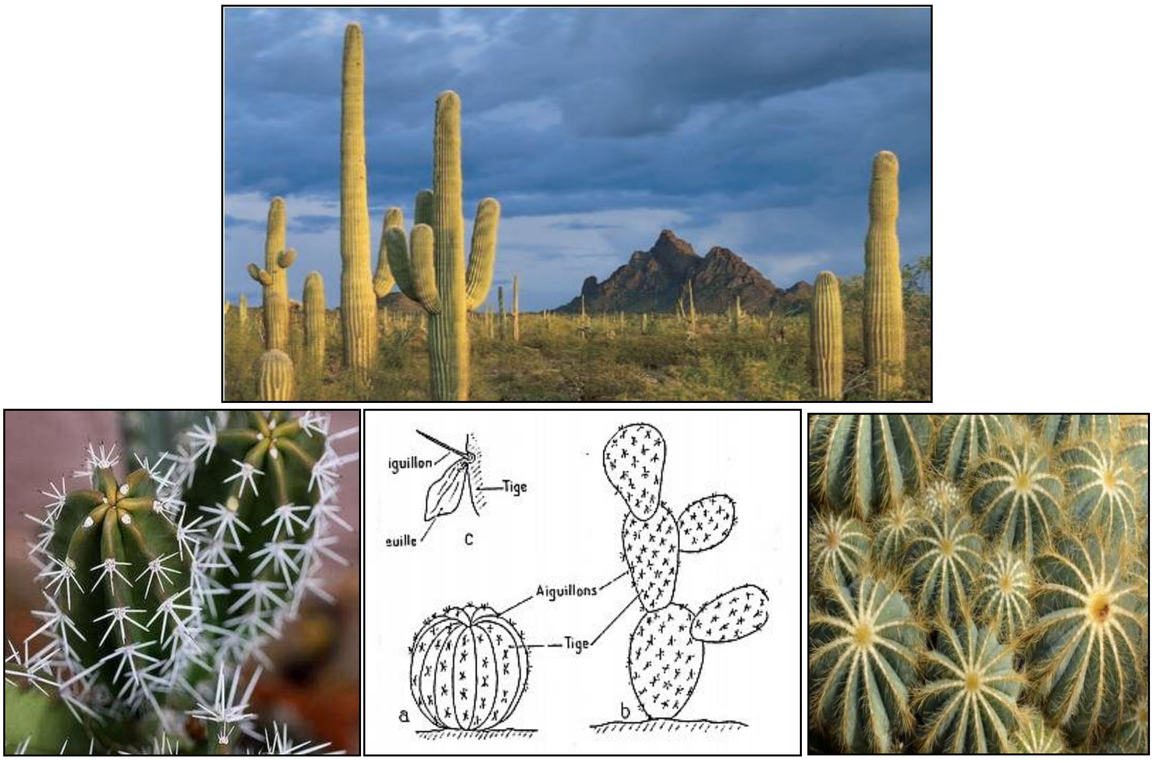


Figure 111: Succulent stems (Bouzid, 2018)

3.4.2. Underground stems or cormus

They are characterized by the presence of nodes and function as storage organs (Figure 112). The following types are distinguished:

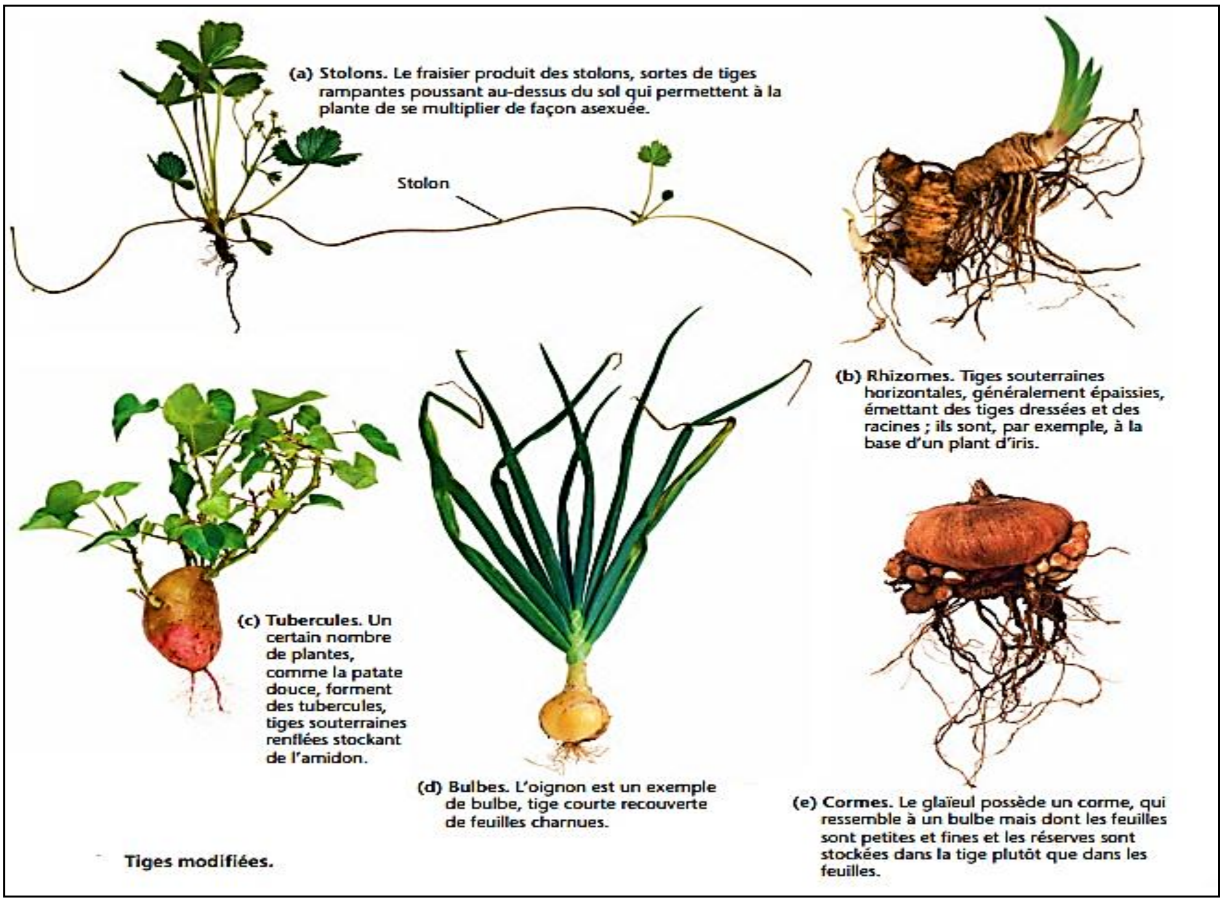


Figure 112: Different types of stems (Raven et al., 2007)

a. Rhizome

Rhizomes are horizontal underground stems equipped with tiny scale-like leaves. They are characterized by the presence of buds that give rise to aerial shoots. In addition, rhizomes bear scales and adventitious roots (Figure 112b). They are commonly found in monocotyledons (such as Lily of the Valley), and less frequently in dicotyledons (such as Mint). Irises have rhizomes that produce new shoots annually.

Other modified stems store water or reserves, mainly in the form of starch within parenchyma cells. Underground stems also play a role in the vegetative reproduction of plants. Example: rhizomes of *Stipa tenacissima* (alfa grass), Iris.

b. Tuber

The tubers of sweet potato are underground stems (of cauline origin) in which parenchyma cells, rich in starch, form tuberous swellings at their extremities (Figure 112c). Tubers are enlarged portions of organs that accumulate storage substances. They bear buds at the level of scale leaves. The "eyes" of the potato are actually axillary buds arranged in a helical pattern on the surface of the tuber.

c. Bulb

As in the onion, starch accumulates in thick and fleshy leaves attached to the stem (Figure 112d). The bulb (the base of the flowering stem) corresponds to an underground stem that results from the tuberization of leaves (scales) or leaf sheaths. It functions as a storage and reproductive organ in plants with a period of dormancy.

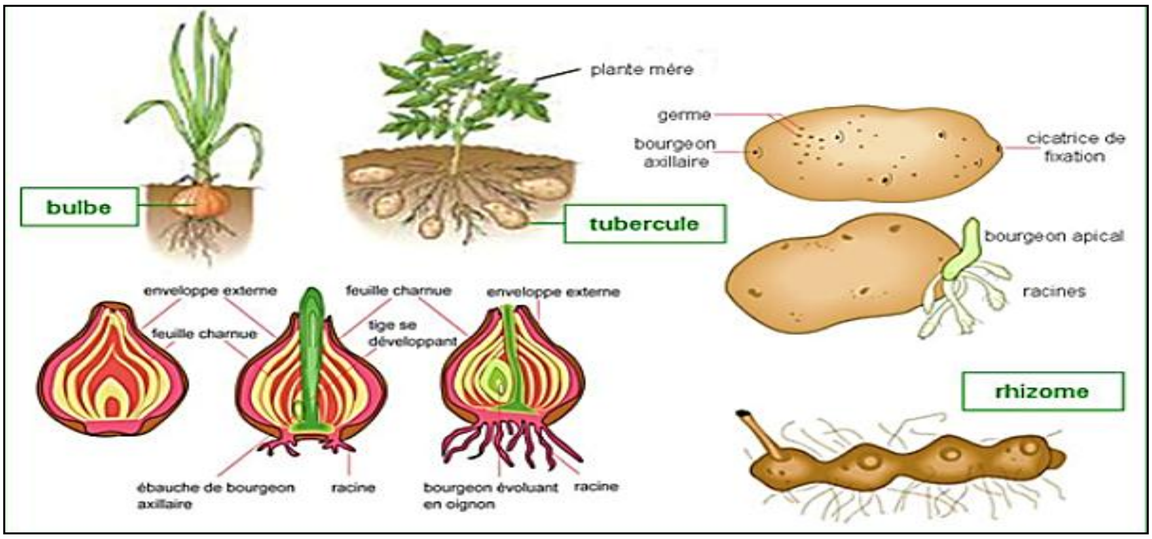


Figure 113: Bulb, Tuber and rhizome

d. Corms

Corms, like those of the gladiolus, are underground stems that resemble bulbs (Figure 112e). However, unlike bulbs, reserves are stored in the stem tissues rather than in the leaves. Nutrients accumulate to the point of making the stem solid. These thickened stems, which store water, are common in desert plants, particularly cacti, whose spines are actually modified leaves attached to the fleshy stem.

3.4.3. Aquatic stems

The stems of species living submerged in water (hydrophytes) have a specialized organization that allows them to absorb water, carbon dioxide, oxygen, and nutrients directly. They lack a cuticle, stomata, and sclerenchyma. Conductive tissues are poorly developed, and exchanges occur directly between the plant and the water. Example: duckweed (*Lemna*). These aquatic plants exhibit a remarkable development of intercellular spaces, which trap air, enhancing buoyancy and gas diffusion within the plant.

3.4.4. Caulescent plants (acaulescent plants)

These are plants without stems or with extremely reduced stems (very short or almost absent). Leaves appear directly from the ground. The root is topped by a rosette of leaves and flowers. Examples include some species of violets, rosette plants such as lettuce (*Lactuca*), and carline thistle (*Carlina)*.

4. LEAF ANATOMY

The vegetative organs of a plant are the root and the stem, which bear buds and leaves. Leaves are generally green in color because they contain a pigment, chlorophyll, stored in chloroplasts and responsible for photosynthesis (Figure 114). Through this characteristic process of plants, carbon dioxide from the air and water from the soil are converted into oxygen and sugars using solar energy. Stomata allow gas exchange, enabling the intake of CO_2. Photosynthesis enables the synthesis of organic matter, which is then distributed to other organs via the phloem.
At the leaf level, thanks to photosynthesis, the raw sap becomes elaborated sap by loading sugars that will be distributed throughout the other organs. Parasitic plants extract sugars from other plants and lack chlorophyll, hence they are not green (e.g., *Orobanche, Neottia*). Sometimes they are only partially parasitic and retain their chlorophyll (e.g., *Mistletoe*).

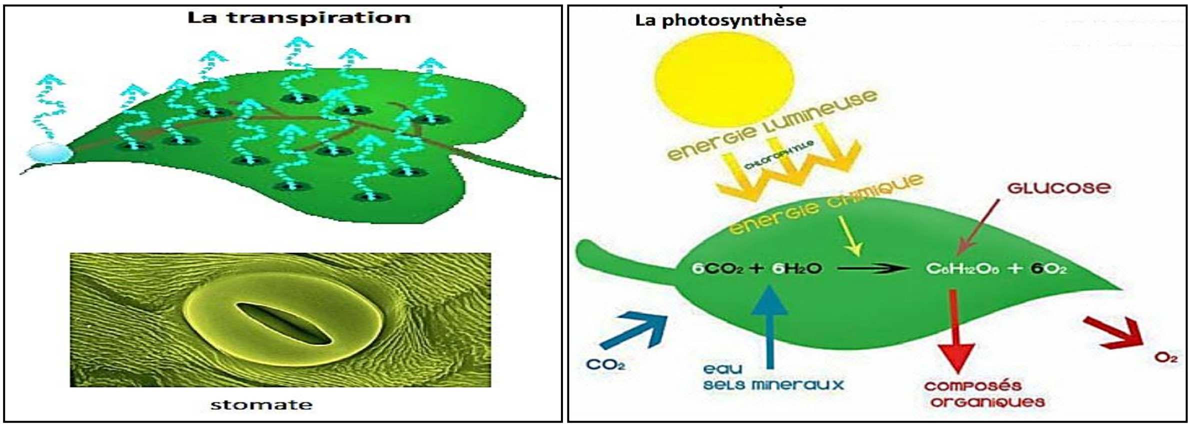


Figure 114: Plant respiration and photosynthesis

4.1. LEAF MORPHOLOGY

A simple leaf consists of a flat part, the blade (the main body of the leaf), and a thinner part between the blade and the stem called the petiole (the supporting stalk or leaf stalk) (Figure 115). The petiole can sometimes widen at its base, becoming a sheath that more or less surrounds the stem. This sheath is called the leaf base, the point where the leaf attaches to the stem. At the base of the petiole, there is sometimes a structure resembling a small leaf called the stipule (e.g., hawthorn).

In some species, leaves may be incomplete and lack a blade, sheath, and petiole; these are called sessile leaves (e.g., maize).

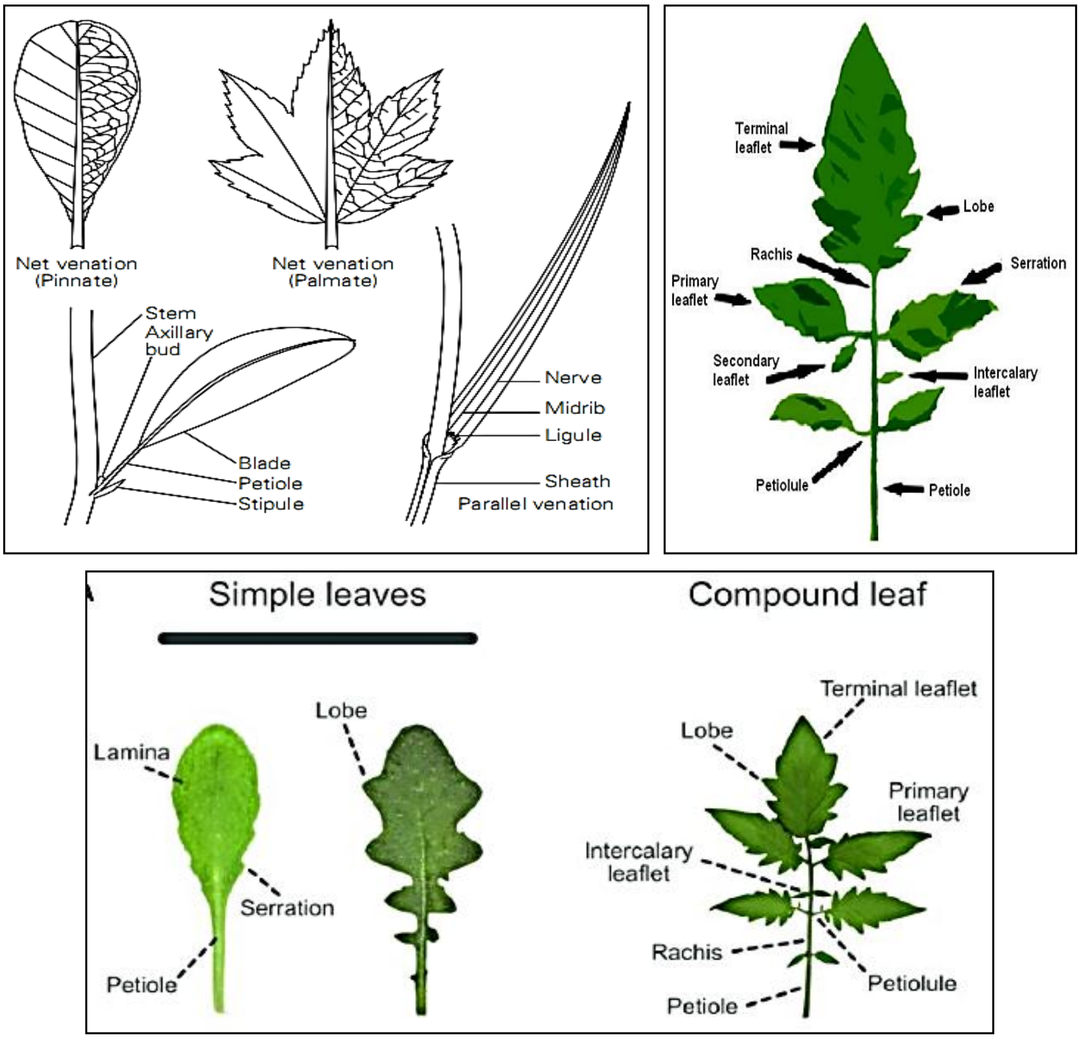


Figure 115: Leaf structure; diagram of simple and compound leaves (Terral et Heinz, 2011; Altartouri et al., 2015; King, 2025)

4.2. ANATOMICAL STRUCTURE OF THE LEAF

The leaf is a lateral appendage of the stem, where it is attached at a node. It develops through the activity of the shoot apical meristem located at the apex of a bud and most often consists of a petiole and a blade. Its flattened shape allows it to capture maximum light, enabling photosynthesis in the parenchyma cells. According to the figure below (Figure 116), the leaf is composed of:

- ***Upper epidermis:*** Constitutes the entire upper (adaxial) surface of the blade. It is made up of tightly packed cells covered by a cuticle that protects the leaf.
- ***Palisade parenchyma:*** Located beneath the upper epidermis, composed of cells filled with chloroplasts.
- ***Spongy parenchyma***: Made up of a layer of less regular, loosely arranged cells with large intercellular spaces (lacunae). These cells contain fewer chloroplasts, especially towards the center of the leaf.
- ***Vascular bundles (vascular tissues):*** These conducting tissues are stacked and similar to those found in the stem. They are essentially continuous from the stem and petiole and correspond to the veins of the blade. Secondary formations will appear rapidly.
- ***Lower epidermis***: Also composed of tightly packed cells covered by a waxy layer. It is perforated by stomatal cells that allow air to enter or exit the leaf. The stomatal pore (ostiole) is the opening at the center of the stoma.

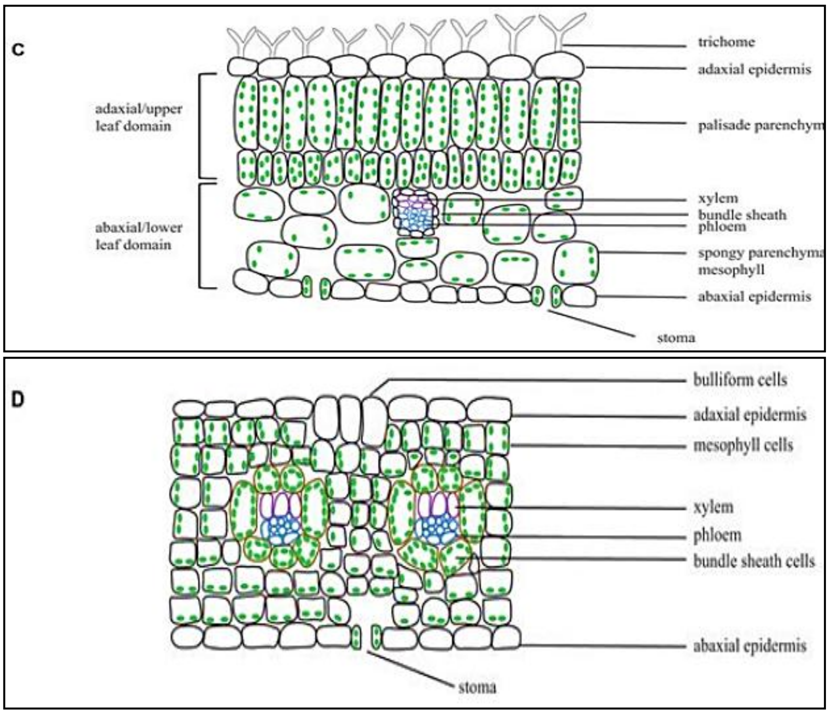


Figure 116: Leaf polarities**:** (C) Schematic diagram of cross section through a typical dicot leaf. A leaf is enclosed by the upper (adaxial) epidermis and lower (abaxial) epidermis. The upper

epidermis has trichomes. The upper mesophyll cells are tightly organized and enriched in chloroplast, whereas the lower mesophyll cells are loosely organized with fewer chloroplasts. Vascular bundles exhibit polarity with adaxially localized xylem and abaxially localized phloem. Stoma are abundant on the lower epidermis and trichome may or may not be present on the lower epidermis. (D) Schematic diagram of cross section through a monocot C4 plant leaf. Bulliform cells are present on the adaxial surface, and bundle sheath cells enclosing the vascular bundle are large and have chloroplasts (**Manuela and Xu, 2020).**

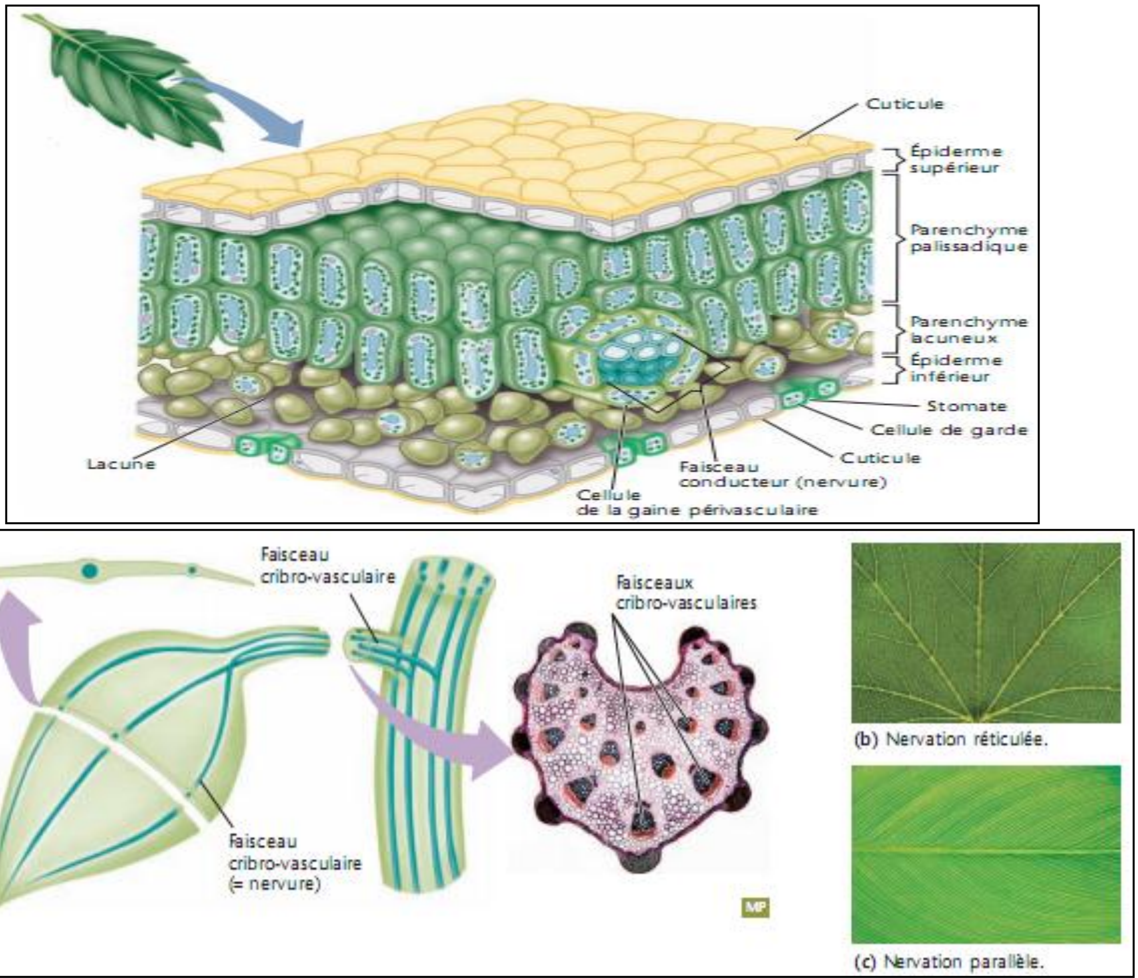


Figure 117: Cross-section of a leaf at the level of the vascular bundles and different types of venation: In the blade, the vascular strands become the veins, which can branch or fuse. As shown in the cross-sectional diagram, the carrot petiole contains numerous vascular bundles (Raven et al., 2007).

4.2.1. Anatomical Structure of a Dicotyledonous Leaf

In the cross-section below, we observe from the outside toward the inside (Figures 118, 119):

- **Two epidermises**: the lower epidermis on the dorsal side, equipped with a thin cuticle and rich in stomata, and the upper epidermis on the ventral side, bordered by a thick cuticle with fewer stomata.

- **A heterogeneous "Mesophyll" parenchyma**: this is the leaf parenchyma, mostly a bifacial asymmetrical chlorophyllous parenchyma.

It includes a palisade parenchyma located on the ventral side, formed by one or several layers of cells that are rich in chloroplasts, situated just below the upper epidermis.

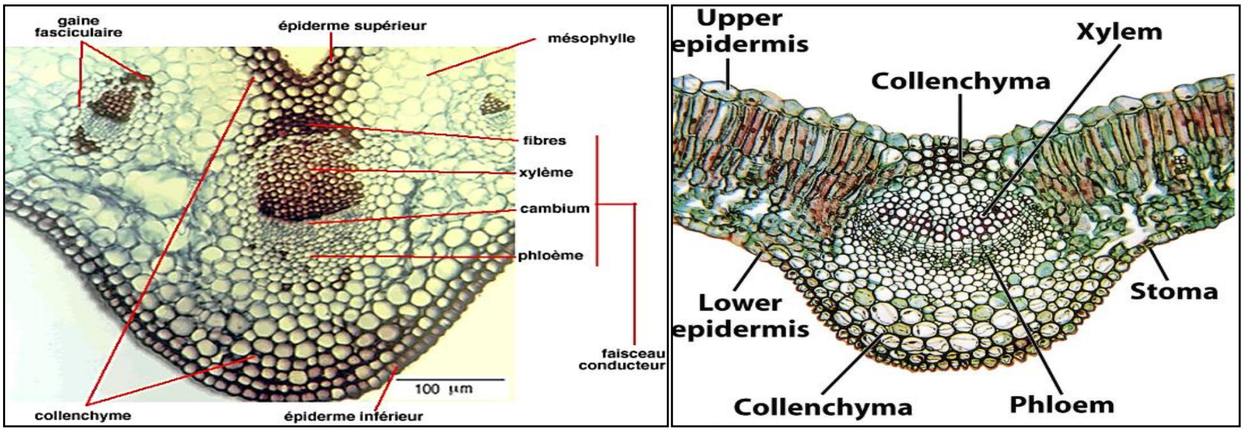


Figure 118: Cross-section of a dicotyledonous leaf (Remy et al, 2004)

- **Spongy parenchyma:** located on the abaxial side, situated between the lower epidermis and the palisade parenchyma, less rich in chloroplasts, it regulates gas exchange between the leaf and the atmosphere.

- **A vascular system** composed of phloem I and II and xylem I and II on either side, along with the cambium. The main vein contains supportive tissues: collenchyma near the epidermis and sclerenchyma close to the vessels.

- **Dicotyledonous leaves** are characterized by pinnate venation (a large central vein with secondary veins branching off obliquely).

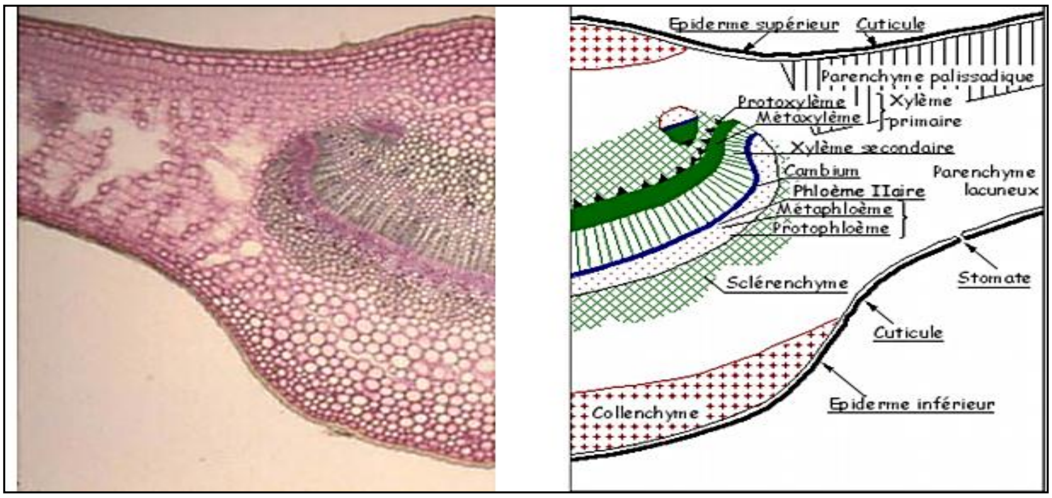


Figure 119: Cross-section of the main vein of a holly (Ilex) leaf blade (Bouzid, 2018)

4.2.2. Structure of a Monocotyledon Leaf

In the cross-section above, the following features are observed from the outside to the inside (Figures 120, 121):

- **An epidermis on the surface** of the organ (young leaves have a more or less thick cuticle, not visible in this section),
- **Stomata** are evenly distributed on both the adaxial (upper) and abaxial (lower) epidermis,
- A homogeneous **mesophyll parenchyma**,
- **A vascular system** corresponding to the veins, composed of primary ventral xylem and primary dorsal phloem,
- **A sclerenchyma** sheath covering and protecting the vascular tissues,
- **A parenchyma** with cellulose walls surrounding the vascular bundle,
- **The veins** consist of median and marginal veins, which are parallel and connected by fine transverse veins.

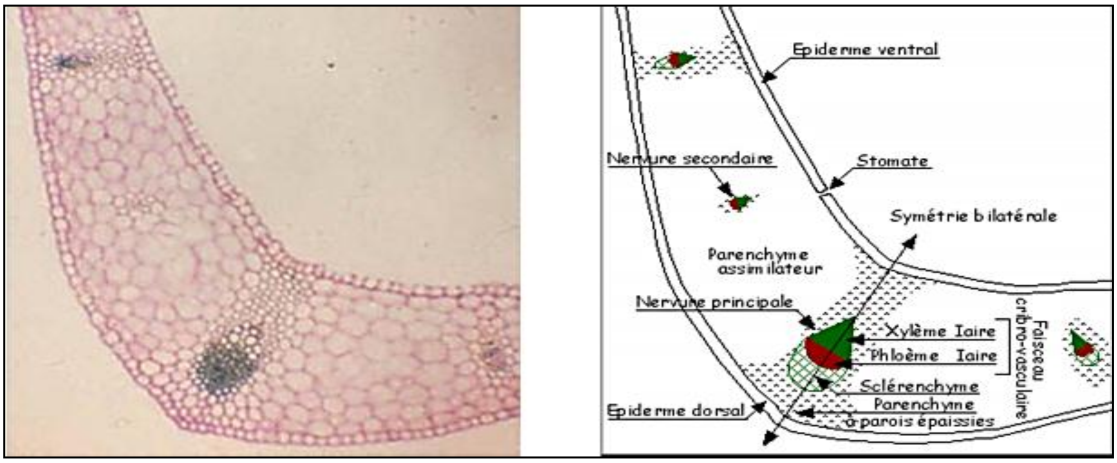


Figure 120: Cross-section of the leaf blade of Lily of the Valley (*Convallaria)* (Bouzid, 2018)

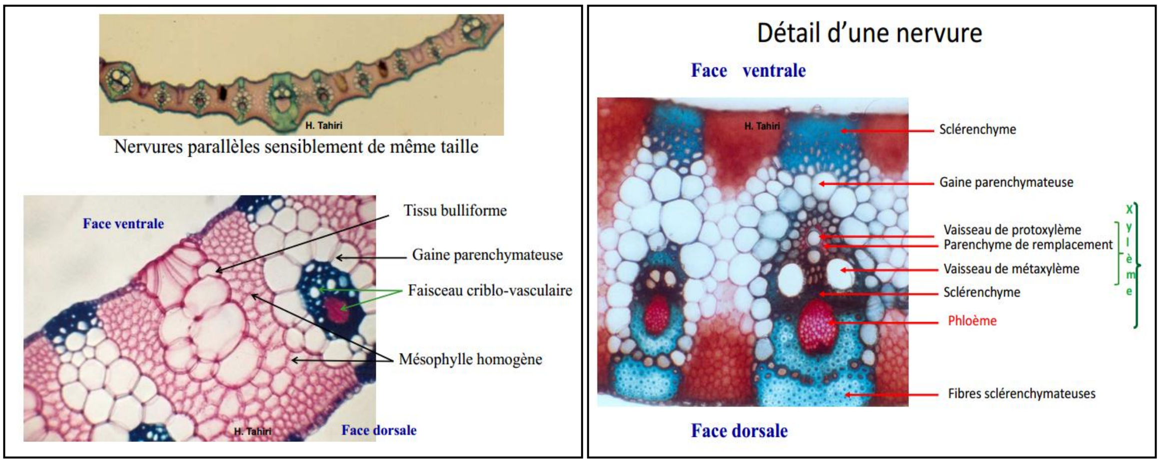
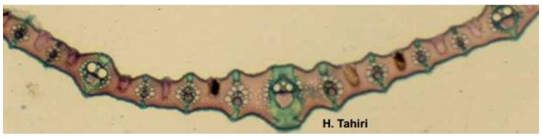
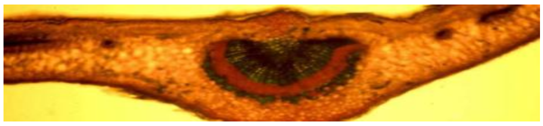


Figure 121: The structure of a monocotyledonous plant leaf (Tahiri, 2015)

The following table (Table 10) provides information on the main criteria differentiating a monocotyledonous leaf from a dicotyledonous leaf.

Table 10: Differences between a monocotyledonous leaf and a dicotyledonous leaf (Godinot et al., 2010 ; Tahiri, 2015)

	Monocotyledon	**Dicotyledon**
PARENCHYMA	 - Homogeneous mesophyll. - Stomata are evenly distributed on both the adaxial (upper) and abaxial (lower) epidermis.	 - Heterogeneous mesophyll (palisade and spongy parenchyma). - Lower (abaxial) epidermis rich in stomata.
VASCULAR BUNDLES	Parallel venation composed of a single vascular bundle, often connected to the upper epidermis by strands of sclerenchymatous fibers.	Reticulate venation consisting of one or several vascular bundles with internal xylem and external phloem, surrounded by supporting tissues.
SECONDARY STRUCTURES	No secondary growth	Secondary growth generally poorly developed at the level of the main vein (secondary xylem and phloem).

4.3 DIFFERENT TYPES OF LEAVES

- When the leaf has a single, continuous blade at the end of an unbranched petiole, it is called a **simple leaf.**
- Sometimes, the petiole branches out, and each branch bears a blade (leaflet); in that case, the leaf is referred to as a **compound leaf**. These compound leaves can have leaflets arranged in pairs on either side of a central axis, resembling the structure of a feather; they are called **pinnately compound leaves**.

Leaf shapes are highly variable. Depending on whether the blade is undivided or divided, we distinguish between simple leaves and compound leaves. Then, we consider the shape of each blade, the characteristics of the margins, and the type of venation.

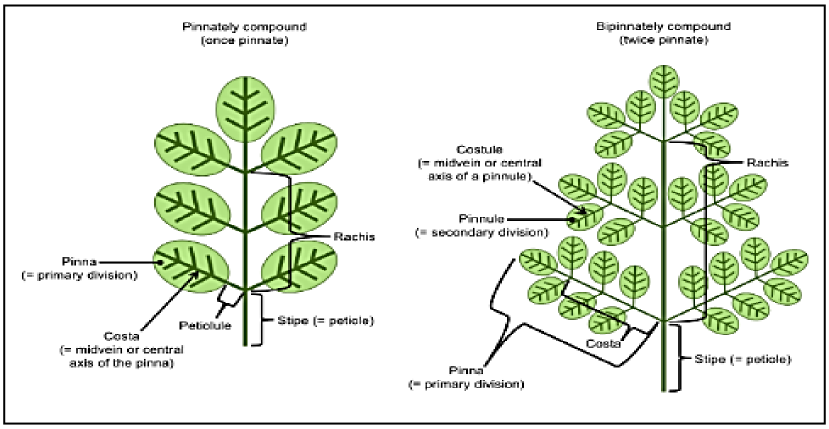
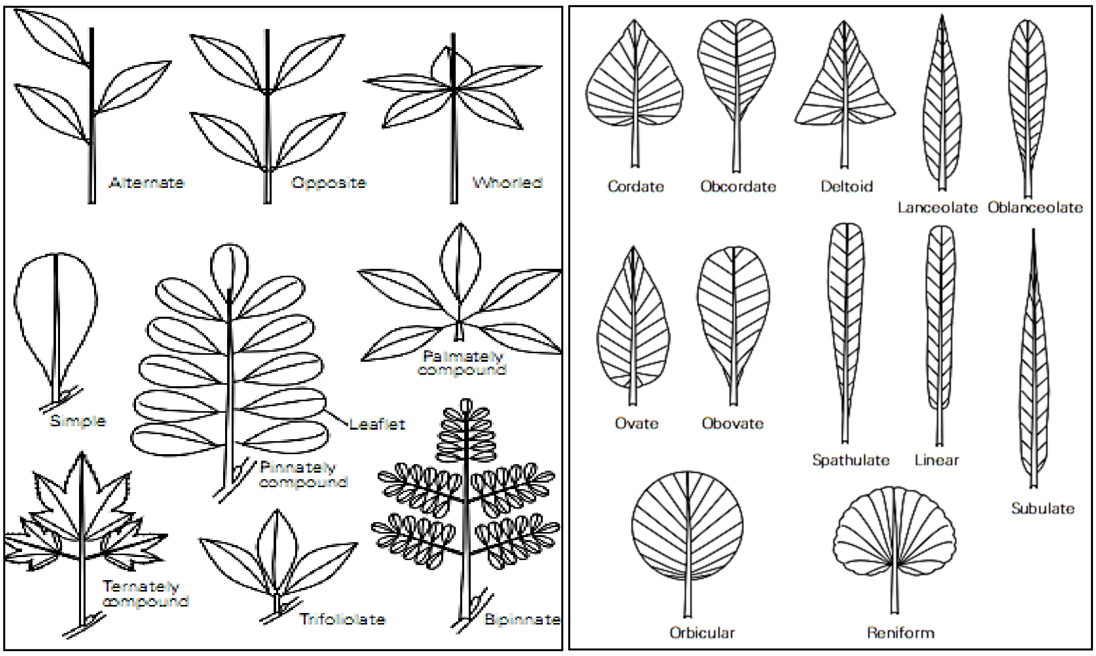
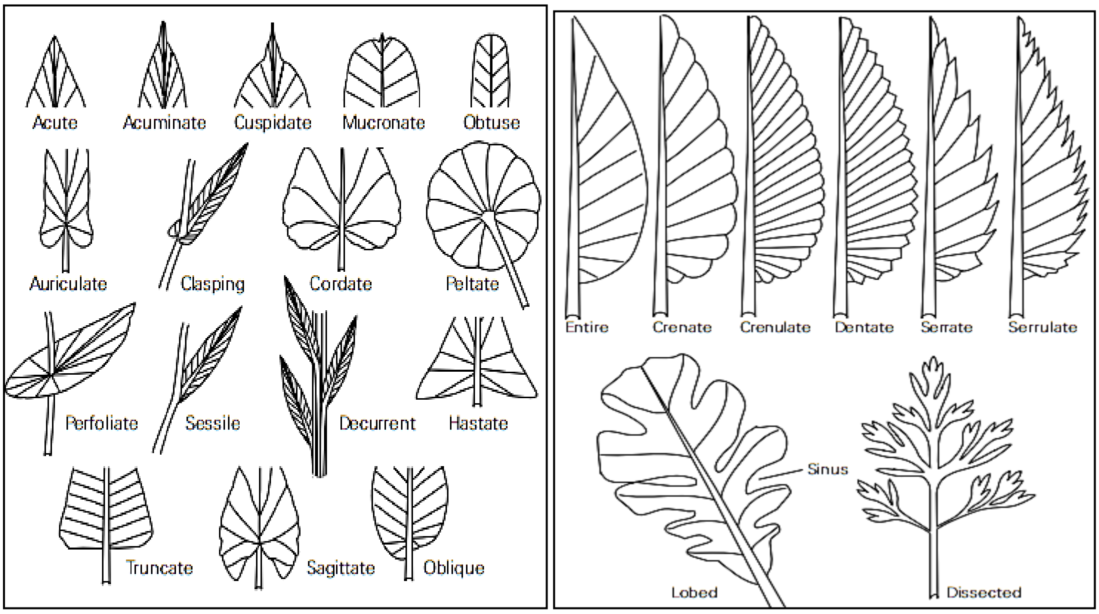


Figure 122: Diagram of compound leaves (Nakayama et al., 2022)



Leaf arrangement: compound leaves *leaf shapes*

Figure 123: Different types of leaves according to the arrangement and shape of the blade (King, 2025)



Leaf apices: leaf bases *Leaf margins*

Figure 124: Different types of leaves (Thanikkal et al., 2023 ; King, 2025)

- **According to the shape of the blade:** entire, toothed, lobed, deeply dissected, compound; this applies to both pinnate and palmate venation leaves.

- **According to the margins of the blade:** the edges can be entire (e.g., lilac), toothed (e.g., rose), or lobed (e.g., oak).

- **According to the parity and arrangement of the leaflets, we distinguish:**
  - ***Paripinnate compound leaves***: pinnate leaves with an even number of leaflets.
  - ***Imparipinnate compound leaves***: pinnate leaves with an odd number of leaflets.
  - ***Pedate leaves***: leaves with parallel segments, where the two basal leaflets are oriented downward.

- **Leaves can have alternate arrangement:** one leaf per node (e.g., cherry), or opposite arrangement: two leaves opposite each other (e.g., lilac, privet), or whorled: several leaves per node (e.g., catalpa).

- **According to the venation pattern:**
  - ***Simple or pinnate venation:*** secondary veins branching on both sides of a main central vein (e.g., rose).
  - ***Palmate venation:*** an odd number of veins all originating from a single point near the petiole (like spread fingers of a hand) (e.g., maple).

- ***Parallel venation:*** veins run parallel along the entire length, common in monocotyledons (e.g., Chlorophytum).

➢ **According to the leaf lifespan:**

- ***Deciduous leaves***: present in most plants, they emerge in spring and fall off in autumn.
- ***Evergreen leaves***: their lifespan extends over several years.

4.3.1. Leaves of dicotyledons

There may be a sheath (quite often); sometimes this sheath can be topped by stipules. Two distinguishing criteria are noted:

- ***Type of venation***: pinnate or palmate (all veins originate from the same point near the petiole); a third type of venation, much rarer, is pedate venation (a secondary vein branches off the main or previous vein, then a new vein branches off the previous one again, and so on).

- ***Shape of the blade:*** entire, toothed, lobed, deeply dissected, or compound.

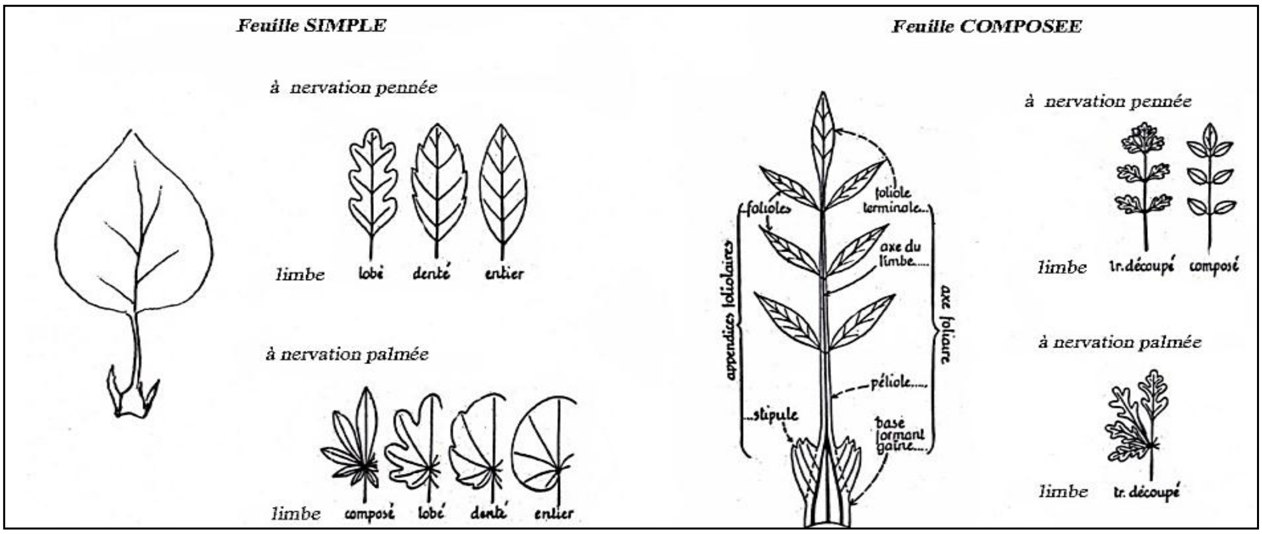


Figure 125: Morphology of a dicotyledon leaf (Meyer et al., 2008)

4.3.2. Leaves of monocotyledons

The veins are parallel. The leaves are most often elongated, linear, or ribbon-shaped. The sheath may have a very particular morphology.

- For example***, in cereals***, it wraps around the stem and takes its shape; it is split. At the junction between the stem and the blade, there is a ligule (important for species identification in the *Poaceae* family).

- ***In onions***, the sheath surrounds the bulb and there is a longer, higher ligule.
- ***In irises***, the sheath is split with the blade positioned above it.

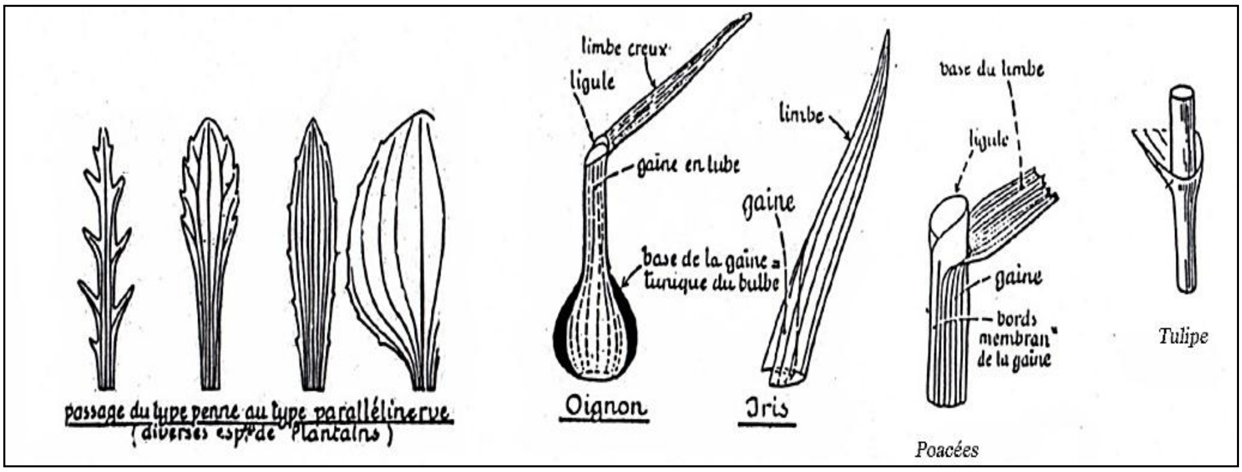


Figure 126: Morphology of a monocotyledon Leaf (Meyer et al., 2008)

4.4. PHYLLOTAXY

Leaves are not distributed randomly on stems; they are arranged in a pattern determined by the plant's genetic makeup. The distribution of leaves is called phyllotaxy. The point where a leaf attaches to the stem is called a node. There are three types of phyllotaxy:

- ***Alternate***: one leaf appears at each node.
- ***Opposite:*** two leaves are attached at the same node, arranged at 180°.
- ***Whorled (Verticillate):*** three or more leaves are attached at a single node.

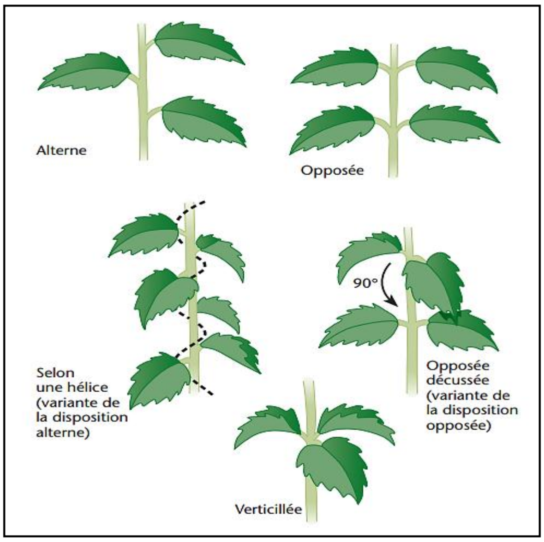


Figure 127: phyllotaxie ou insertion des feuilles sur la tige (Raven et al., 2007)

The following table and figures (Table 9 and Figures 128, 129) provide information on the main anatomical comparison criteria between root, stem, and leaf in monocotyledons and dicotyledons.

Table 11: Anatomical Comparison between the root, stem, and leaf (Godinot et al., 2010)

CHARACTERISTICS	ROOT	STEM	FEUILLE
Symmetry	Axial	Axial	Bilatérale
Cortex / Central cylinder ratio	- Well-developed cortex - Reduced central cylinder - C > CC	- Reduced cortex -Well-developed central cylinder - C < CC	/
Protective Tissues	- Root hair layer - Cork or suberized layer	Epidermis	Épidermis
Supporting Tissue	Rare	Frequent	Frequent
Boundary between cortex vs central cylinder	Clear due to the always-present endodermis	More or less marked	/
Specific Tissues	Pericycle	/	Mesophyle
Conducting Tissues	- Alternating primary xylem I and phloem I - Centripetal xylem I -Secondary xylem with centrifugal differentiation	- Superposed xylem I and phloem I - Centrifugal differentiation of xylem I	- Superposed xylem I and phloem I - Xylem I oriented towards the upper surface

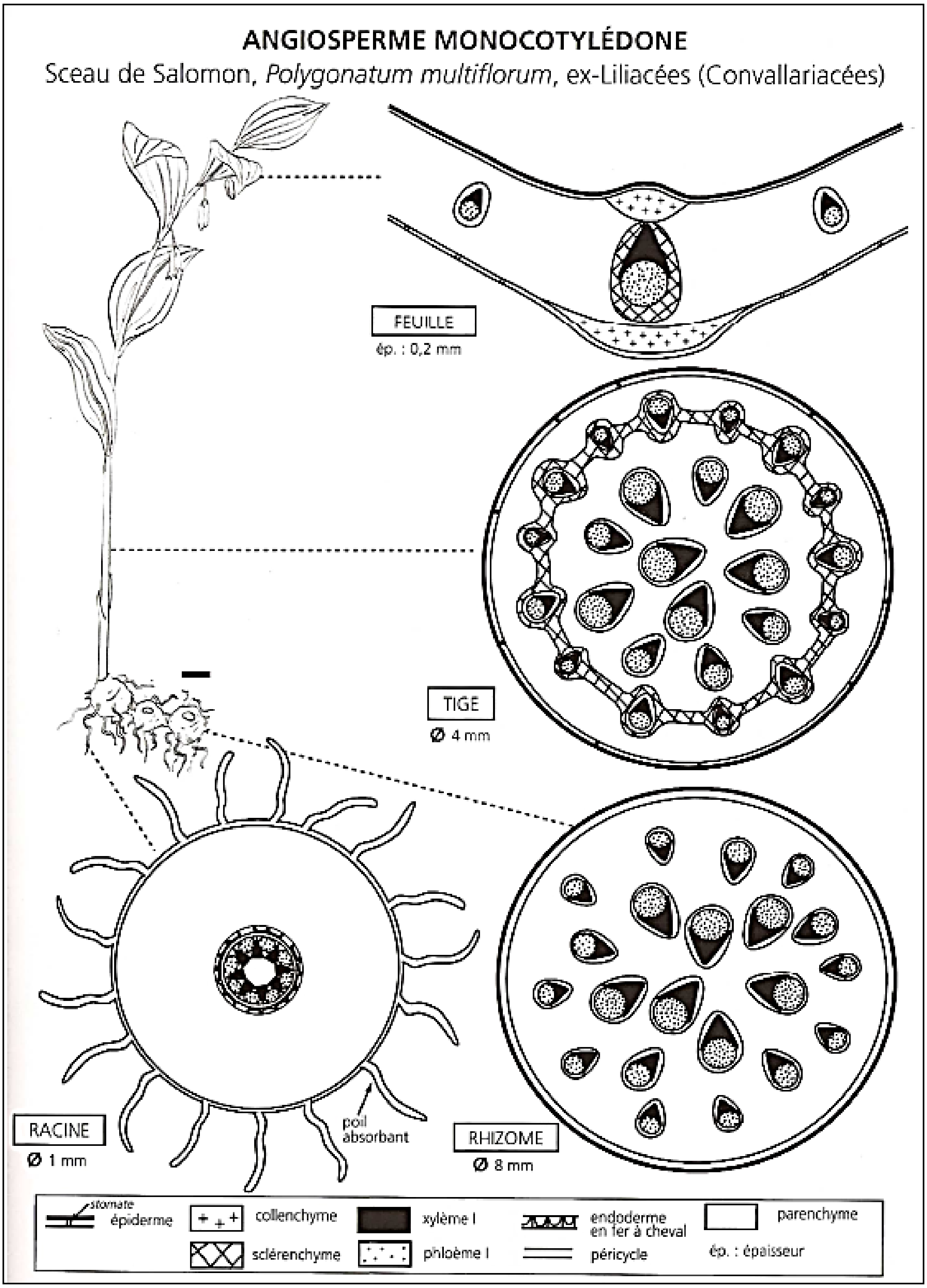


Figure 128: Conventional Symbolic Representations of the Main Vegetative Organs monocotyledon (Transverse Sections) (Meyer et al., 2008)

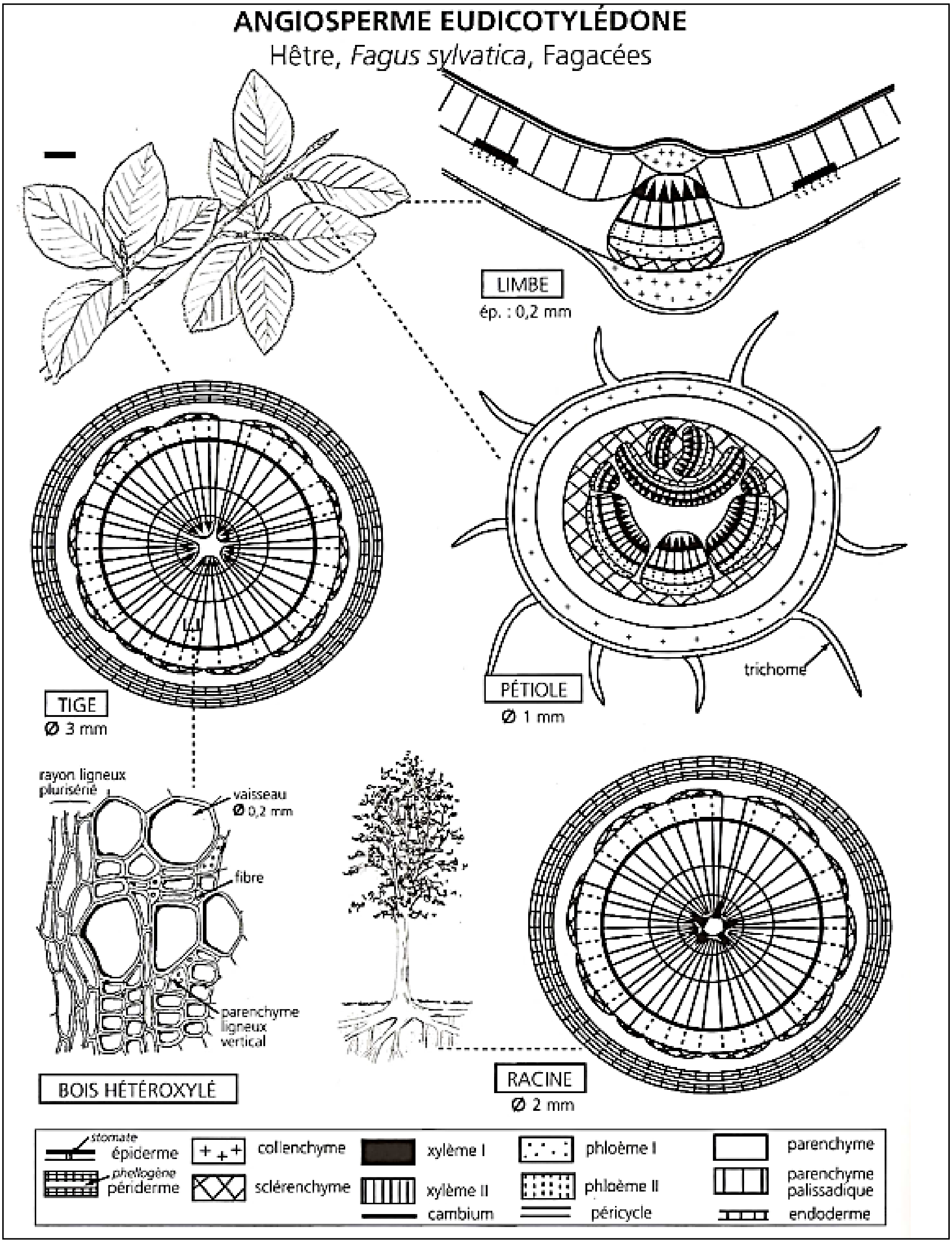


Figure 129: Conventional Symbolic Representations of the Main Vegetative Organs dicotyledon (Transverse Sections) (Meyer et al., 2008)

GLOSSARY

A

- **Abscission** – The process by which a leaf, flower, or fruit dies and detaches from the plant, often as a normal part of development or in response to stress.
- **Absorption** – The process by which plants take up water from the soil. Minerals are absorbed as ions dissolved in water through the root system.
- **Acaulescent** – Describes a plant with a very short stem, with internodes so reduced that the leaves appear to arise directly from the ground. *Example: dandelion (Taraxacum officinale).*
- **Achene** – A dry, indehiscent fruit containing a single seed not fused to the pericarp (e.g., acorn, hazelnut).
- **Acorn** – The fruit of the oak tree (*Quercus*), a type of nut.
- **Actinomorphic** – A flower with radial symmetry, star-shaped.
- **Actinomycetes** – Symbiotic association with nitrogen-fixing bacteria, particularly in non-leguminous plants (e.g., alder – *Alnus* genus).
- **Adventitious** – Describes a structure developing in an unusual or atypical position, e.g., buds forming outside leaf axils, roots growing from stems or leaves.
- **Aleurone** – Protein granules deposited in the cells of the endosperm or cotyledons.
- **Alternation of Generations:** The plant life cycle alternating between gametophyte and sporophyte stages.
- **Androecium** –The collective male reproductive organs of a flower (i.e., stamens).
- **Anemophilous** – Describes wind-mediated seed or pollen dispersal.
- **Angiosperms** Flowering plants that produce seeds enclosed in fruit.
- **Anther** – The upper part of the stamen in flowering plants, consisting of two pollen sacs (thecae) where pollen grains develop and are released at maturity.
- **Apicifixed (or apically attached)** – Describes an anther that is attached to the filament at its apex.
- **Autotroph** – Organism that produces its own food (e.g., plants, cyanobacteria).
- **Axillary** – Refers to a bud located in the axil, the angle formed between a leaf and the stem.

B

- **Basifixed** – Describes an anther attached to the filament at its base.

- **Beech nut** – An achene (usually occurring in pairs) enclosed in a cupule formed by bracts, covered with stiff hairs.
- **Berry** – A fleshy fruit, generally dehiscent or indehiscent, containing multiple seeds. (In strict botanical usage, berries are typically indehiscent, but some classifications may vary depending on context).
- **Binary Fission** – Asexual reproduction method in prokaryotes; one cell splits into two.
- **Binomial Nomenclature** – The two-part scientific naming of species using Genus + species. Introduced by *Carl Linnaeus.*
- **Bract** – A modified or specialized leaf, often small, located at the base of a flower stalk (peduncle).
- **Branching** – The process by which secondary roots or stems emerge from existing roots or stems.
- **Bryophytes** – Non-vascular plants like mosses, liverworts.
- **Bulbil** – A small bulb-like structure formed from a modified bud, often used for asexual reproduction.

C

- **Cambium** – A layer of actively dividing cells between xylem and phloem (secondary growth).
- **Capitulum** (or **Head**) – A highly condensed inflorescence consisting of sessile flowers (without stalks) grouped on a common receptacle, and often surrounded by involucral bracts. (Characteristic of *Asteraceae*).
- **Capsule** – A dry, dehiscent fruit formed from multiple carpels, opening in various ways (e.g., slits, pores) to release seeds.
- **Carpel** – A leaf-derived, ovule-bearing unit of the gynoecium (female reproductive part of a flower); may be free or fused.
- **Caryopsis** – A dry, indehiscent fruit in which the seed coat is fused to the fruit wall (pericarp); typical of grasses (Poaceae).
- **Catkin** – A flexible spike-like inflorescence bearing small, usually unisexual flowers, often wind-pollinated (e.g., in hazel, birch).
- **Cauline** – Refers to anything related to the stem of a plant (e.g., cauline leaves are those that grow on the stem, as opposed to basal leaves).
- **Cell Membrane** – Phospholipid bilayer that surrounds all cells, controlling what enters/exits.
- **Cell Plate** – The precursor to a new cell wall that forms during cytokinesis in plant cells.

- **Cell Wall** – A rigid layer outside the plasma membrane in plant cells made of cellulose.
- **Cell** – The basic structural and functional unit of all living organisms.
- **Chalaza** – The point where vascular tissue from the placenta enters the ovule, opposite the micropyle.
- **Chestnut** – The edible nut (fruit) of the chestnut tree (*Castanea* spp.).
- **Chloroplast** – Organelle where photosynthesis takes place, containing chlorophyll.
- **Chromatin** – DNA-protein complex within the nucleus that condenses into chromosomes during cell division.
- **Chromosome** – A threadlike structure of nucleic acids and protein that carries genetic information.
- **Cilia** – Short hair-like projections used for movement or sensing (in eukaryotes).
- **Clade** – A group of organisms descended from a common ancestor.
- **Class** – A rank below division. Example: *Magnoliopsida* (dicotyledons).
- **Coleoptile** – A protective sheath enclosing the emerging shoot (plumule) in grass seedlings.
- **Coleorhiza** – A protective sheath covering the radicle in grass embryos.
- **Collenchyma** Cell – Elongated cell with uneven cell wall thickness providing flexible support.
- **Competition** – A biological interaction in which an organism may be inhibited or outcompeted due to insufficient availability of one or more essential resources (e.g., nutrients, light, water).
- **Cotyledon** – A seed leaf; a fleshy or leaf-like structure within the seed, part of the embryo, and may store nutrients.
- **Cryptogams**–Non-seed plants (mosses, algae, ferns); reproduce via spores.
- **Culm** – A hollow stem typical of grasses (Poaceae), usually solid at the nodes. *Example: bamboo.*
- **Cup-shaped receptacle** – A bowl-like floral structure formed by a concave receptacle.
- **Cuticle** – Waxy outer layer of plant leaves and stems that reduces water loss.
- **Cyathium** – A condensed inflorescence specific to *Euphorbia* species, consisting of highly reduced flowers enclosed in a cup-like structure.
- **Cytoplasm** – Gel-like substance within the cell membrane where organelles are suspended.

D

- **Defoliation** – The loss of leaves from a plant, either naturally (seasonal or due to stress) or artificially induced.
- **Dehiscence** – The natural opening of a closed organ (such as an anther or fruit) at maturity, to release its contents (e.g., pollen or seeds).
- **Diadelphous** – Describes the stamens arranged in two groups: one group with fused filaments, and a second solitary stamen. *(Characteristic of many Fabaceae)*
- **Dichotomous** – A mode of branching or division where an organ (e.g., a stem or leaf) splits into two equal parts, typically due to meristem bifurcation. *Example: Lycopodium clavatum.*
- **Diclinous Plants** – Plants with unisexual flowers (male and female flowers are separate).
- **Dicotyledons (Dicots)** – Plants with two seed leaves. Example: roses, sunflowers. Angiosperms with two seed leaves, net-like veins, and floral parts in multiples of 4 or 5.
- **Dioecious** – Male and female flowers are on separate plants.
- **Diplostemonous** – Describes a flower with two whorls of stamens, where the outer whorl alternates with petals and the inner whorl is opposite the petals.
- ***Dispersal*** – The process by which seeds are spread away from the parent plant.
- **Division** – Equivalent to Phylum in zoology; a major group within a kingdom. Example: *Magnoliophyta* (flowering plants).
- ***Dormancy*** – A physiological state in which seeds do not germinate even under favorable conditions.
- **Drupe** – A fleshy, indehiscent fruit with a single hard stone (endocarp) enclosing the seed (e.g., cherry, apricot, walnut, olive); develops from a superior, free ovary.
- **Drupelet** – A small individual drupe, typically found in aggregate fruits such as raspberries or blackberries (*Rubus* spp.).

E

- **Embryo** – The initial developmental stage of spermatophytes including the hypocotyl, radicle, and one or more cotyledons.
- **Embryo sac** – The female gametophyte in flowering plants (angiosperms), functionally equivalent to the female gametophyte or nutritive tissue (e.g., endosperm precursor) in gymnosperms.
- **Endocarp** – The innermost layer of the pericarp, often forming a hard shell around the seed.

- **Endoplasmic Reticulum (ER)** – Network of membranes; rough ER has ribosomes and synthesizes proteins, smooth ER synthesizes lipids.
- **Endosperm** – Storage tissue formed around the embryo in the seed, produced by division of the endosperm mother cell; nearly synonymous with albumen (though some reserve albumen for gymnosperm seeds).
- **Endosymbiosis** – Theory that mitochondria and chloroplasts originated from free-living prokaryotes.
- **Epicarp** – The outermost layer of the pericarp, also called the fruit skin.
- **Epicotyl** – The portion of the embryonic axis above the cotyledon attachment point and below the first true leaves.
- **Eukaryote** – A cell with a true nucleus and membrane-bound organelles (e.g., plants, animals, fungi, protists).

F

- **Family** – A group of related genera. Example: *Rosaceae* (rose family).
- **Fertilization** – The fusion of male and female gametes to form a zygote.
- **Fertilization** – Fusion of male and female gametes to form a zygote.
- **Fibrous root system** – A root system composed of many roots of similar size and thickness, typical of grasses (*Poaceae*) and most monocotyledons.
- **Filament** – The elongated stalk of the stamen connecting the anther to the flower.
- **Flagellum** – A tail-like structure used for movement, especially in prokaryotes.
- **Fleshy** – Describes tissue that is thick and juicy.
- **Floral receptacle** – The enlarged or modified part of the flower axis (stem tip) on which the floral organs are attached (sepals, petals, stamens, carpels). Also called torus in some contexts.
- **Follicle** – A dry fruit developed from a single carpel and dehiscing along one suture only.
- **Fruit** – A mature ovary containing seeds, resulting from fertilization and seed development.
- **Fruit set** – Beginning of fruit formation after fertilization.
- **Funiculus** – A thin cord-like structure that connects the ovule to the placenta in seed plants.

G

- **Gametophyte**– The haploid (n) stage in a plant’s life cycle that produces gametes.
- **Gamosepalous** – Describes a flower with fused sepals.
- **Genus** – A group of closely related species. Example: Rosa (roses).

- **Glume** – Each of the two greenish, keel-shaped bracts located at the base of a grass spikelet (*Poaceae*).
- **Golgi Apparatus** – Modifies, sorts, and packages proteins and lipids for transport.
- **Grooved** – Having longitudinal ridges or striations.
- **Guard Cells** – Specialized cells that open and close the stomata.
- **Gymnosperms** – Non-flowering plants that produce naked seeds (not enclosed in fruit). Seed-producing plants whose seeds are not enclosed in fruits (e.g., conifers).
- **Gynoecium** – The female reproductive structures of a flower, collectively (carpels).
- **Gynophore** – The floral stalk or extension of the receptacle that elevates the gynoecium, notably prominent in some *Rosaceae* species.

H

- **Herbarium** – A collection of preserved plant specimens used for study.
- **Hermaphrodite** – Describes a flower or organism that possesses both male and female reproductive organs.
- **Hesperidium** – A type of berry with a thick, leathery rind divided into segments; characteristic of *Citrus* fruits (e.g., *lemon*).
- **Heterotroph** – Organism that consumes other organisms for energy.
- **Hilum** – Scar on the seed marking the point where the *funiculus* was attached.
- **Husk (**or **bur)** – The spiny outer covering of a chestnut, formed from modified bracts.
- **Hypocotyl** – The portion of the embryo or young seedling located between the cotyledons and the radicle (embryonic root).

I

- **Inferior (ovary)** – Describes an ovary embedded below the floral parts, sunken into the floral receptacle.
- **Inflorescence** – The arrangement or cluster of flowers on a plant; the flowering part of the shoot.
- **Intercalary meristem** – A meristematic tissue located between mature tissues, responsible for growth between nodes in certain plants (e.g., grasses).
- **Isostemonous** – Describes a flower with a single whorl of stamens, alternating with the petals.

K

- **Karyotype** – The number and appearance of chromosomes in the nucleus of a cell.
- **Keel** – The lower, boat-shaped petal in flowers of the *Fabaceae* family (e.g., in *Papilionaceous* flowers).

- **Kingdom *Plantae*** – The plant kingdom; includes multicellular, autotrophic organisms with cell walls.
- **Kingdom** – The highest taxonomic rank; for plants, this is *Plantae*.

L

- **Latex** – A milky-looking emulsion secreted by certain plants, often stored in *Laticifers* ; may serve as defense against herbivores.
- **Layering** – A vegetative propagation technique involving the induction of adventitious roots on a still-attached stem, which is later separated from the parent plant.
- **Leaflet** – Each of the segments of a compound leaf. For example, a clover has 3 leaflets.
- ***Legume (*or *pod)*** – A dry, dehiscent fruit developing from a single carpel that splits along two seams (e.g., bean, pea), typical of the *Fabaceae* family.
- **Lemma and Palea** – The two bracts that directly enclose the flowers in grass spikelets.
- **Lignin** – A complex polymer in plant cell walls that adds rigidity and resistance to decay.
- **Ligule** – In *Asteraceae*: a tongue-shaped extension of the corolla (as in ray florets). In *Poaceae* (grasses): a membranous appendage at the junction of the leaf sheath and blade.

M

- **Medifixed** – Describes an anther that is attached by its middle to the filament, allowing it to pivot.
- **Meiosis** – Eukaryotic cell division producing gametes with half the chromosome number.
- **Meristematic Cell** – Undifferentiated plant cell capable of continuous division and growth.
- ***Mesocarp*** – The middle layer of the pericarp, usually the fleshy part of the fruit.
- **Mesosome** – Fold in the plasma membrane of prokaryotes, possibly involved in respiration.
- **Mitochondrion** – The powerhouse of the cell, responsible for ATP production via respiration.
- **Mitosis** – Eukaryotic cell division producing genetically identical cells.
- **Monadelphous** – Describes a flower in which the stamens are united by their filaments into a single bundle, while the anthers remain free (Typical in some *Fabaceae and Malvaceae*).
- **Monocotyledons (Monocots)** – Plants with one seed leaf (cotyledon). Example: grasses, lilies. Angiosperms with one seed leaf, parallel veins, and floral parts in multiples of 3.
- **Monoecious** – Plant with both male and female flowers on the same individual.
- **Morphology** – Study of the form and structure of plants.

- **Multiseeded** (or **Multispermous**) – Describes a fruit or ovary containing multiple seeds.
- **Mycorrhizae** – A symbiotic association between a fungus and plant roots, which enhances nutrient and water absorption, especially phosphorus.

N

- **Nomenclature** – The system of assigning names to organisms.
- **Non-vascular Plants** – Plants that lack vascular tissue (e.g., Mosses).
- **Nucleoid** – Region in prokaryotic cells where DNA is located (not membrane-bound).
- **Nucleolus** – Dense region within the nucleus where ribosomal RNA (rRNA) is produced.
- **Nucleus** – The control center of the cell containing DNA and responsible for gene expression.
- **Nut** – A dry, indehiscent fruit (i.e., it does not open at maturity), typically one-seeded, with a very hard pericarp (fruit wall), as in acorns, hazelnuts, or chestnuts.

O

- **Obdiplostemonous** – Describes a flower with two whorls of stamens, where the inner (lower) whorl is opposite the petals, and the outer (upper) whorl is alternating with them (Typical of some *Caryophyllaceae* and *Geraniaceae*).
- **Obstemonous** – Describes a flower with a single whorl of stamens that are opposite the petals (not alternating with them).
- **Order** – A taxonomic rank below class. Example: Rosales.
- **Organelle** – Specialized cell structures with specific functions (e.g., mitochondria, chloroplasts).
- **Ovary** – The enlarged, basal part of the pistil, formed from one or more fused carpels, containing the ovules which will become seeds after fertilization, and the ovary wall will develop into the fruit.

P

- **Panicle** – A branched, compound racemose inflorescence, often pyramidal in shape, typical of grasses (*Poaceae*).
- **Pappus** – A specialized structure aiding wind dispersal in the achenes of some plants (e.g. *Asteraceae*), typically made of bristles, hairs, or scales, often derived from the calyx or style.
- **Parenchyma Cell** – Fundamental plant cell type involved in photosynthesis, storage, and regeneration.
- **Pepo** – A large berry with a hard rind typical of Cucurbits (e.g., Pumpkin).

- **Perianth** – The collective term for the floral envelopes, composed of the calyx (sepals) and corolla (petals), which surround the reproductive organs.
- **Pericarp** – The fruit wall derived from the ovary wall, typically consisting of the epicarp, mesocarp, and endocarp.
- **Peroxisome** – Organelle containing enzymes for breaking down fatty acids and hydrogen peroxide.
- **Petal** – A leaf-like floral organ, usually colored and showy, forming part of the corolla, often functioning to attract pollinators.
- **Phanerogams** – Seed plants (visible reproductive structures).
- **Phloem** – Vascular tissue that transports sugars from leaves to the rest of the plant.
- **Phragmoplast** – Structure that guides cell plate formation during plant cell cytokinesis.
- **Phylogeny** – The evolutionary history and relationships among species.
- **Phylum (Division)** – A major taxonomic rank below kingdom and above class. In botany, the term Division is more commonly used.
- **Placentation** – The arrangement of placentas and ovules within the ovary.
- **Plasma Membrane** – The semi-permeable membrane that surrounds the cytoplasm, controlling substance entry/exit.
- **Plasmid** – Small circular DNA found in some prokaryotes.
- **Plasmodesmata** – Channels between plant cells allowing communication and transport of molecules.
- **Plasmolysis** – Shrinking of the cell membrane from the wall due to water loss.
- **Plastids** – A group of organelles involved in photosynthesis, storage, and pigmentation (e.g., chloroplasts, chromoplasts, leucoplasts).
- **Pod** – Dry, unilocular fruit that splits open along two valves, each bearing a row of seeds (e.g., bean).
- **Pollination** – Transfer of pollen grains to the stigma of a flower.
- **Polypetalous** – Said of a flower whose petals are free (not fused together).
- **Polyploidy** – Condition of having more than two sets of chromosomes, common in plants.
- **Polysepalous** – Said of a flower whose sepals are free (not fused).
- **Polystemonous** – Describes a flower with a large number of stamens, arranged in spirals or in several whorls.
- **Poricidal** – Refers to a capsular fruit that releases seeds through small pores, rather than by splitting open along seams.

- **Primary growth** – Growth in length of roots or stems, initiated by apical meristems (primary meristems).
- **Prokaryote** – A cell without a nucleus or membrane-bound organelles (e.g., *Bacteria*, *Archaea*).
- **Pteridophyta** – Seedless vascular plants like ferns.

R

- **Radicle** – Embryonic root within the seed.
- **Receptacle** – The enlarged tip of the flower stalk (peduncle) bearing the floral organs.
- **Rhizobium** – A nitrogen-fixing symbiotic bacterium that forms root nodules primarily in legumes, allowing the fixation of atmospheric nitrogen into usable forms.
- **Rhizosphere** – The soil region directly influenced by root secretions and associated microorganisms, crucial for nutrient cycling and uptake.
- **Ribosome** – Site of protein synthesis; found in both prokaryotic and eukaryotic cells; found freely in cytoplasm or on rough ER.
- **Root cap** – A mass of protective cells covering the apical meristem of the root, facilitating penetration through soil and perceiving gravity.
- **Rose hip** – A multiple fruit of the rose, formed by the enlarged fleshy receptacle containing numerous achenes.
- **Rosette** – The circular arrangement of leaves at the base of an acaulescent plant.

S

- **Samara** – Dry, indehiscent, single-seeded fruit with a thin membranous wing on the edge (e.g., maple fruit).
- **Scape** – A long, leafless floral stalk that arises from the ground or basal rosette and bears one or more flowers. (e.g., dandelion, onion)
- **Schizocarp** – Dry fruit composed of two or more carpels that separate at maturity (e.g., carrot fruit).
- **Sclerenchyma Cell** – Supportive cell with thick lignified walls, often dead at maturity.
- **Secondary growth** – A type of growth characterized by an increase in thickness of the stem or root, initiated by lateral meristems (secondary meristems, such as the vascular cambium and cork cambium). Occurs in Gymnosperms, most dicotyledons, and a few monocotyledons
- **Seed coat** (or **Testa**) – The protective outer covering of a seed, derived from the integuments of the ovule.
- **Seed dispersal** – The process by which seeds are spread away from the parent plant.

- **Seminal root** – A root that develops directly from the seed, usually referring to the initial roots formed after germination.
- **Sepal** – A leaf-like, typically green floral organ that forms the outermost whorl (calyx) in a flower, especially in dicots with colorful petals.
- **Septum** – A false or true partition that appears in the ovary of certain plants, dividing the locule(s); also found in capsules.
- **Silicle** – A short, broad form of silique, a type of dry dehiscent fruit, characteristic of *Brassicaceae*.
- **Silique** – A dry, dehiscent fruit that splits open along two seams and has a persistent central partition (replum) bearing the seeds (distinct from legumes).
- **Species** – The basic unit of classification, representing a group of individuals that can interbreed. Example: *Rosa canina*.
- **Spermatophytes** – Seed-producing plants (includes gymnosperms and angiosperms).
- **Spikelet** – The basic inflorescence unit of grasses (*Poaceae*), consisting of one or more florets (reduced flowers) and enclosed by two bracts (glumes).
- **Sporophyte** – The diploid (2n) stage that produces spores by meiosis.
- **Stamen** – The male reproductive organ of flowering plants typically composed of a filament and an anther (where pollen is produced).
- **Staminal tube** – A cylindrical structure formed by the fusion of stamens (usually their filaments), often encasing the pistil. Found in some families like *Malvaceae* and *Fabaceae.*
- **Standard petal** – The uppermost and often largest petal in the *Papilionaceous* (butterfly-like) corolla of *Fabaceae* (legume family), standing upright and acting as a visual attractant for pollinators.
- **Stomata** – Small openings in leaves that control gas exchange and transpiration.
- **Sucker** – A shoot arising from an adventitious bud formed on a root, often at some distance from the parent plant.
- **Superior (ovary)** – Describes an ovary that is positioned above the other floral parts, i.e., not embedded in the floral receptacle.
- **Synantherous** – Describes flowers where stamens are united, typically by their anthers, as seen in *Asteraceae.*
- **Synergid** – One of the two specialized cells located next to the egg cell within the embryo sac, playing a key role in guiding the pollen tube
- **Systematics** – The study of the diversity and relationships among organisms.

T

- **Taproot system** – A root system where the primary root remains dominant, with lateral roots branching from it. Typical of most dicotyledons and gymnosperms.
- **Taxonomy** The science of naming, describing, and classifying organisms.
- **Tendril** – A slender, coiling structure that responds to touch and is used by climbing plants for attachment and support.
- **Tepal** – A perianth segment that is not clearly differentiated into sepals and petals; typically seen in monocots and flowers where sepals and petals are similar in shape and color.
- **Thalamus** (or **Receptacle**) – The swollen floral axis or receptacle, often domed, on which the floral organs are inserted; particularly in primitive angiosperms like the *Magnoliaceae* (in older texts, "thalamus" is used synonymously with receptacle).
- **Tonoplast** – The membrane that surrounds the vacuole.
- **Totipotency** – The ability of a single plant cell to regenerate into a whole plant
- **Tracheophytes** – Vascular plants with xylem and phloem (includes ferns, gymnosperms, angiosperms).
- **Turgor Pressure** – Pressure exerted by the vacuole against the cell wall, keeps plant firm.

U

- **Umbel** – A type of inflorescence where flower stalks (pedicels) radiate from a common point and are usually of equal length, forming a flat or rounded cluster (e.g., Apiaceae family).

V

- **Vacuole** – A large central organelle filled with cell sap that maintains turgor pressure.
- **Vascular Tissue** – Tissue in plants (xylem and phloem) that conducts water and nutrients.

W

- **Whorl** – A circular arrangement of similar organs (e.g., leaves, sepals, petals, stamens) attached at the same level around an axis (stem or branch) (Common in floral structures: whorls of sepals, petals, stamens, and *carpels).*

X

- **Xylem Vascular** – tissue that transports water and minerals from roots to shoots.

Z

- **Zygomorphic** – Describes a flower with bilateral symmetry, meaning it can be divided into two mirror-image halves along only one plane (axial symmetry). Examples: flowers of *Fabaceae* (e.g., *Pea*), *Orchidaceae.*

BIBLIOGRAPHIC REFERENCES

1. ALTARTOURI H., ABU MAIZER D., IDAIS A., TAMIMI H., ARAFEH R. 2015. Computerized Extraction Of Morphological And Geometrical Features For Plants With Compound Leaves. Journal of Theoretical and Applied Information Technology 2015. Vol.81. No.3
2. BABALI B. 2018. Botanique systématique des spermaphytes. Polycopié de Travaux Pratiques 3me année Licence en Ecologie et Environnement. Université Abou Bekr Belkaid-Tlemcen. 45p.
3. BELHACINI F. 2017 Polycopié cours Botanique. 2eme année licence Biologie &Nutrition. Université Hassiba Benbouali de Chlef. 97p.
4. BENAZIZA A. 2022. Eléments fondamentaux en Biologie végétale. 1ère année SNV Université de Biskra.48p.
5. BIEL K. Y., Fomina I. R., Nazarova G. N., Soukhovolsky V. G., Khlebopros R. G., Nishio J. N. 2010. Untangling metabolic and spatial interactions of stress tolerance in plants. 1. Patterns of carbon metabolism within leaves. Protoplasma (2010) 245:49–73. DOI 10.1007/s00709-010-0135-7.
6. BOUKHALFOUN L. 2023. Polycopié de cours de biologie végétale. 1ere année licence sciences de la nature et de la vie. Université de Médéa. 85p.
7. BOUTIN, V., J.-F. FOGELGESANG, J.-F. BEAUX & F. RIBOLA. 2010. *Atlas de Biologie végétale BCPST 1re et 2e années.* Dunod, Paris.
8. BOUZID S. 2018. Cours de biologie végétale.1ere Année biologie LMD. Université Des Frères Mentouri Constantine. 82p.
9. Cardoso C. M. V., Proen S. L., Sajo M. G. 2009.Foliar anatomy of the subfamily Myrtoideae (*Myrtaceae*). Australian Journal of Botany, 2009, 57, 148–161
10. CARDOSO C. M. V., Proen S. L., Sajo M. G. 2009.Foliar anatomy of the subfamily Myrtoideae (*Myrtaceae*). Australian Journal of Botany, 2009, 57, 148–161
11. CHANG W, GUO Y, ZHANG H, LIU XAND GUO L (2020) Same Actorin Different Stages: Genes in ShootApical Meristem Maintenanceand Floral Meristem Determinacyin Arabidopsis. Front. Ecol. Evol. 8:89.
12. CHEN, M.-Y.; ZHUO, G.-Y.; CHEN, K.-C.; WU, P.-C.; HSIEH, T.-Y.; LIU, T.-M.; CHU, S.-W. BMC Plant Biol. 2014, 14, 175. doi:10.1186/1471-2229-14-175

13. CHOUDHURY A. 2024. Phylogenetic Systematics in Parasitology. Chapter 2. Concepts in Animal Parasitology. Zea Books, Lincoln, Nebraska, United States. Open access CC BY-NC-SA. doi: 10.32873/unl.dc.ciap002 2024. In S. L. Gardner and S. A. Gardner, eds.
14. COUDERT Y, BES M, LE TV, PRE M, GUIDERDONI E, GANTET P (2011). Transcript profi ling of crown rootless1 mutant stem base reveals new elements associated with crown root development in rice. BMC Genomics 12:387.
15. DETTMER J., ELO A., HELARIUTTA Y. 2009. Hormone interactions during vascular development. Plant Mol Biol (2009) 69:347–360. DOI 10.1007/s11103-008-9374-9
16. DI PIETRO E., BURLA R., LA TORRE M., GONZALEZ-GARCIA M. P., DELLO IOIOR., SAGGIOI. 2024. Telomeres: an organized string linking plants and mammals. Biology Direct (2024) 19:119.
17. DIJKWEL P.P., LAI A.G. 2019. Hypothesis: Plant stem cells hold the key to extreme longevityTranslational Medicine of Aging 3 (2019) 14-16.
18. FLORIN A. S. 2022 Identifying the presence of vegetative parenchyma. Creative Commons, PO Box 1866, Mountain View, CA 94042, USA
19. GAILLOCHET C., LOHMANN J.U. 2015. The never-ending story: from pluripotency to plant developmental plasticity, Development 142 (2015) 2237-2249.
20. GAMBETTA G. A., FEI J., ROST T. L., KNIPFER T., MATTHEWS M. A., SHACKEL K. A., WALKERM. A., MCELRONE A. J. 2013. Water Uptake along the Length of Grapevine Fine Roots: Developmental Anatomy, Tissue-Specific Aquaporin Expression, and Pathways of Water Transport[1[W][OPEN].] Plant Physiology, 2013, Vol. 163, pp. 1254–1265.
21. GHARABI D. 2021. Cours de biologie végétale. 1ère Année Sciences de la Nature et de la Vie. Université Ibn Khaldoun, Tiaret.106p.
22. GHELLAI M. 2022. Polycopié de cours de la matière : BOTANIQUE. 2eme Année Domaine Sciences de la nature et de la vie. Université de Relizane. 65p.
23. GODINOT C., MOREAU H., PAULHIAC-PISON M., TEJEDOR F. (2010). Biologie-Géologie 1re année BCPST-véto. Tec & Doc, Lavoisier, Paris
24. GONZALEZ M. E. AND BARRETT D. M. 2010. Thermal, High Pressure, and Electric Field Processing Effects on Plant Cell Membrane Integrity and Relevance to Fruit and Vegetable Quality. Concise Reviews in Food Science. Journal of Food Science. R121Vol. 75, Nr. 7, 2010.
25. GUERRIERO G., SERGEANT K., HAUSMAN J. F. 2014. Wood biosynthesis and typologies: a molecular rhapsody. PubMed Tree Physiology 00, 1–17. DOI: 10.1093/treephys/tpu031

26. GUIGNARD J. L. 2015. Abréger de Botanique: les familles de plantes. 16ED
27. GUIGNARD, J.-L. & F. DUPONT .2004. *Botanique. Systématique moléculaire.* Masson, Issy-les-Moulineaux (92), 13e édition (1e édition 1974).
28. HAMMICHE V. (1988) : Systématique et Morphologie botaniques. OPU, Alger.
29. HANDAKUMBURA P. P., HAZEN S. P.2012. Grass cell wall transcriptional regulation. www.frontiersin.org April 2012 | Volume 3 | Article 74 MINI REVIEW ARTICLE. 2012. doi: 10.3389/fpls.2012.00074
30. HANI M. 2023. Cours de Botanique 2ème Année Biologie LMD. Université Ferhat Abbas Université Setif 1. 222p.
31. HARRIS PJ, STONE BA. 2009. Chapter 4. Chemistry andmolecular organization of plant cell walls, p 61–93. In Himmel ME (ed), Biomass recalcitrance: deconstructing the plant cell wall for bioenergy. Blackwell Publishing Ltd, Oxford, United Kingdom. doi.org/10.1002/9781444305418.ch4.
32. HARRY J. FLINT, SCOTT K. P., DUNCAN S. H., FORANO P. L. E. 2012. Microbial degradation of complex carbohydrates in the gut. Gut Microbes (Review). 3:4, 289-306; July/August 2012; 2012 Landes Bioscience
33. HWANG BG, RYU J, LEE SJ (2016). Vulnerability of Protoxylem and Metaxylem Vessels to Embolisms and Radial Refilling in a Vascular Bundle of Maize Leaves. Front. Plant Sci. 7:941. doi: 10.3389/fpls.2016.00941
34. JOUANNET, V., BRACKMANN, K., GREB, T. 2015. (Pro) cambium formation and proliferation: two sides of the same coin? Current opinion in plant biology, 23, 54-60.
35. KHEYRODIN H., JAMI R., REHMAN FU. 2022. Cellular structure and molecular functions of plants, animals, bacteria, and viruses. Cellular, Molecular and Biomedical Reports 2(1):33- 41. doi:10.55705/cmbr.2022.330941.1021.
36. KING F W. (2025). Dictionary of basic botany terminology. Version 1.250102 (January 02, 2025)
37. KUMAR N, SINGH S, MANVI, GUPTA R. 2012. Trichosanthes dioica Roxb.: An overview. Phcog Rev 2012;6:61-7
38. LABERCHE, J.-C. 2010. *Biologie végétale.* Dunod, Paris, (1e édition 1999 ; 2e édition 2004).
39. LANE, N., 2009. Life Ascending: The Ten Great Inventions of Evolution. Norton, New York, p. 344
40. LEE Y., WOO LEE S., KIM S. H. 2012. Hormonal regulation of stem cell maintenance in roots. Journal of Experimental Botany, Vol. 64, No. 5, pp. 1153–1165, 2013. doi:10.1093/jxb/ers331

41. LULAI, E. C. (2007). Skin-Set, Wound Healing, and Related Defects. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. MacKerron, M. A. Taylor, & H. A. Ross (Eds.), *Potato Biology and Biotechnology: Advances and Perspectives* (pp. 471–500). Elsevier. doi.org/10.1016/B978-044451018-1/50056-7
42. LYNCH J. P., STROCK C. F., SCHNEIDER H. M., SIDHU J. S., AJMERA I., KLEIN S. P., GALINDO-CASTAÑEDA T. , HANLON M. T. 2021. Root anatomy and soil resource capture. Marschner Review. Plant Soil (2021) 466:21–63. doi.org/10.1007/s11104-021-05010-y
43. MANUELA D., XU M. 2020. Patterning a Leaf by Establishing Polarities. Front. Plant Sci. 11:568730. doi: 10.3389/fpls.2020.568730
44. MATTE RISOPATRON J. P., SUN Y., JONES B. J. 2010. The vascular cambium: molecular control of cellular structure. Protoplasma vascular cambium review. DOI 10.1007/s00709-010-0211-z
45. MELIANI S, 2021. Taxonomie et systématique des végétaux inferieurs. Polycopié du cours de 3éme année licence en biotechnologie et génomique végétal. Université Mouhamed Boudiaf d'Oran.118p.
46. MESNOUA M. 2016. Stress abiotiques sur *Atriplex halimus* L : Effet des métaux lourds et caractérisation des biomarqueurs et bioindicateurs. Thèse de doctorat en sciences Université Abdelhamid Ben Badis-Mostaganem. p 137.
47. MEYER, S., C. REEB & R. BOSDEVEIX. 2008. Botanique. Biologie et physiologie végétales. Maloine, Paris, 2e édition (1e édition 2004).
48. MICHELET, L.; ZAFFAGNINI, M.; MORISSE, S.; SPARLA, F.; PEREZ-PEREZ, M. E.; FRANCIA, F.; DANON, A.; MARCHAND, C. H.; FERMANI, S.; TROST, P.; LEMAIRE, S. D. 2013. Redox regulation of the Calvin-Benson cycle: something old, something new. Front. Plant Sci. 2013, 4, 470. doi:10.3389/fpls.2013.00470
49. MOHAMAD-MATROL A.A., CHANG S. W., ABU1A. 2018. Plant data visualisation using network graphs. PeerJ 6:e5579; DOI 10.7717/peerj.5579.
50. MURRAY JAH, JONES A, GODIN C, TRAAS J. 2012. Systems analysis of shoot apical meristem growth and development: integrating hormonal and mechanical signaling. The Plant Cell 24: 3907–3919.
51. NAKAYAMA H., LEICHTY A. R, SINHA N. R. 2022. Molecular mechanisms underlying leaf development,morphological diversification, and beyond. THE PLANT CELL 2022: 34: 2534–2548. doi.org/10.1093/plcell/koac118.
52. NAPALDET J. T. 2017. Morpho-Anatomical Characterization of Benguet Lily(*Lilium philippinense Baker*). The Thailand Natural History Museum Journal 11(2): 47-56, 2017.

53. NOLL G. A., FURCH A.C.U., ROSE J., VISSER F., PRÙFER D. 2022. Guardians of the phloem-forisomes and beyond. New Phytologist (2022) 236: 1245–1260. doi: 10.1111/nph.18476
54. PALM E. R., VOLKENBURGH E. V. 2014. Physiological adaptations of plants to serpentine soil. Plant Ecology and Evolution in Harsh Environments. Chapter 6. (2014) Eds. Rajakaruna N, Boyd RS, Harris TB. Nova Science Publishers Inc.
55. PÉRET, B.; DE RYBEL, B.; CASIMIRO, I.; BENKOVÁ, E.; SWARUP, R.; LAPLAZE, L.; BEECKMAN, T.;BENNETT, M.J. 2009. Arabidopsis lateral root development: An emerging story. Trends Plant Sci. 2009,14, 399–408
56. PETRICKA, J.J.; WINTER, C.M.; BENFEY, P.N. 2012. Control of Arabidopsis root development. Annu. Rev.Plant Biol. 2012, 63, 563–590.2.
57. PETROVA A., AGEEVA M., KOZLOVA L. 2023. Root growth of monocotyledons and dicotyledons is limited by different tissues. The Plant Journal, Society for Experimental Biology and John Wiley & Sons Ltd., (2023), doi: 10.1111/tpj.16440
58. RAD F. Z. 2023. Microneedle Technologies for Food and Crop Health: Recent Advances and Future Perspectives. Advanced Engineering Materials. 2023, 25, 2201194.
59. RADOEVA T,WEIJERS D. 2014. A roadmap to embryo identity in plants. Trends in Plant Science 19: 709–716.
60. RAJAKARUNA N, BOYD RS, HARRIS TB. 2014. Plant Ecology and Evolution in Harsh Environments Chapter 6 (2014) Eds. Nova Science Publishers Inc.
61. RAVEN P. H., EVERT R. F., EICHHORN S. E. 2003. Biologie végétale. Chapitre 4 Racines, tiges et feuilles : le corps primaire de la plante. 3ème Edition De Boeck Superieur.
62. RAVEN, P. H., R. F. EVERT, S. E. EICHHORN (2007). Biologie végétale. De Boeck, Bruxelles. Traduction de la 7e édition américaine par J. Bouharmont, révision C. Evrard.
63. REMY S.,BODSON M., TROUSSART J.-P., WELCOMME L., CALMANT P., VANCLEVE J. DEPIEREUX E. (2004). Atlas d'histologie et d'anatomie des plantes vasculaires par Namur, Belgique. Presses universitaires de Namur.
64. REYNAUD J. 2010 Cours de Botanique. Deuxième et troisième partie.234p.
65. REYNAUD J. 2011. Comprendre la botanique Histoire, évolution, systématique, 231 p.
66. RODRIGUES A. C, EMILIAM., ESTELITA M. 2004. Anatomie des racines de Cyperus giganteus Vahl (Cyperaceae) en développement. Magazine Brésil. Bot., V.27, n.4, p.629-638. 2004.
67. RYTIOJA J., HILDEN K., YUZON J., HATAKKA A., DE VRIES R. P., MÄKELÄA M. R. 2014. Plant-Polysaccharide-Degrading Enzymes from Basidiomycetes.

Microbiology and molecular biology Reviews. MMBR. DOI: 10.1128/MMBR.00035-14 · Source: PubMed. Volume 78 Number 4. p. 614–649.

68. SJÖSTRÖM E. 1993.Wood chemistry: fundamentals and applications. Academic Press, San Diego, CA.
69. STROCK C. F., LYNCH J. P. (2020). Root secondary growth: an unexplored component of soil resource acquisition (viewpoint). Annals of Botany XX: 1–14, 2020. DOI: 10.1093/aob/mcaa068
70. TAHIRI H. 2015. La structure primaire. SVT- S2- TP N°3 Embryophytes. Faculté des Sciences de Rabat. Université Mouhamed V de Rabat. p27.
71. TEICHMANN T., MUHR M. 2015. Shaping plant architecture. Front. Plant Sci. 6:233. doi: 10.3389/fpls.2015.00233
72. TERRAL J. F., HEINZ C. 2011. Diversité et fonction des structures morpho-anatomiques des végétaux : l'exemple des Angiospermes FLBI204, Université Montpellier 2, Licence Biologie - L1S22010-2011.
73. THANIKKAL J. G., DUBEY A. K., THOMAS M.T. 2023. Deep - Morpho Algorithm (DMA) for medicinal leavesfeatures extraction. Multimedia Tools and Applications (2023) 82:27905–27925
74. URSACHE R., NIEMINEN K., HELARIUTTA Y. 2013. Genetic and hormonal regulation of cambial development. Physiologia Plantarum, 147(1), 36-45.
75. WANG B, SMITH SM, LI JY. 2018. Genetic regulation of shoot architecture. Annual Review of Plant Biology 69: 437–468.
76. WEIHS B.J., HEUSCHELE D.J., TANG Z., YORK L.M., ZHANG Z., XU Z. 2024. The State of the Art in Root System Architecture Image Analysis Using Artificial Intelligence: A Review. Plant Phenomics 2024;6: Article 0178. Doi.org/10.34133/plantphenomics.017
77. WI, S. G., LEE, K. H., BAE, H. J., PARK, B. D., & SINGH, A. P. (2014). Variability in the Distribution of Middle Lamella Lignin in Secondary Vascular Tissues of Kenaf Stems. IAWA Journal, 35(1), 61–68. doi.org/10.1163/22941932-00000048
78. WISE N. 2017. "The Science Behind Holganix: Monocots vs Dicots: What You Need To Know."HOLGANIX The Natural Green Solution. N.p.n.d. 30.
79. ZEGHAD N. 2018. BIOLOGIE VEGETALE. Cours de Biologie végétale 1ère année LMD. Université des Frères Mentouri-Constantine 1. 101p.
80. ZITOUNI A. 2017. Cours de botanique systématique (1ere partie). 2ème année tronc commun sciences de la nature et de la vie. Université de Guelma. p 47.