PLANT PHYSIOLOGY

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1.
Introduction

Plant Classification

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

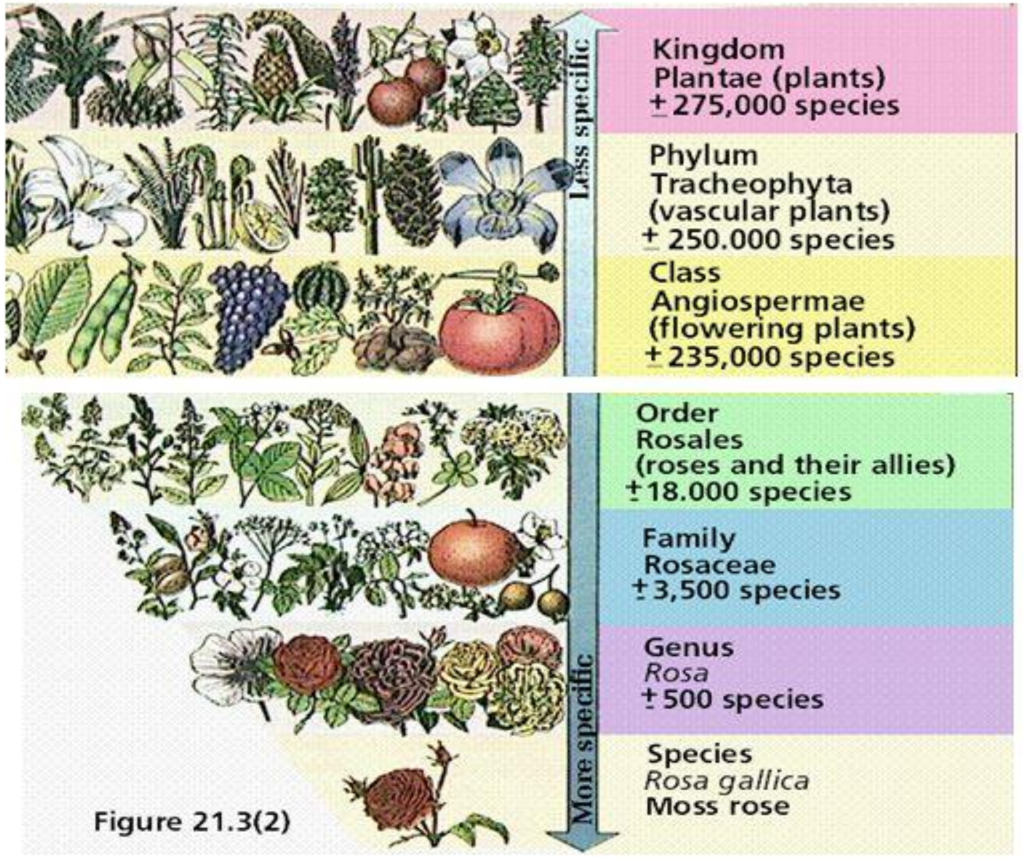
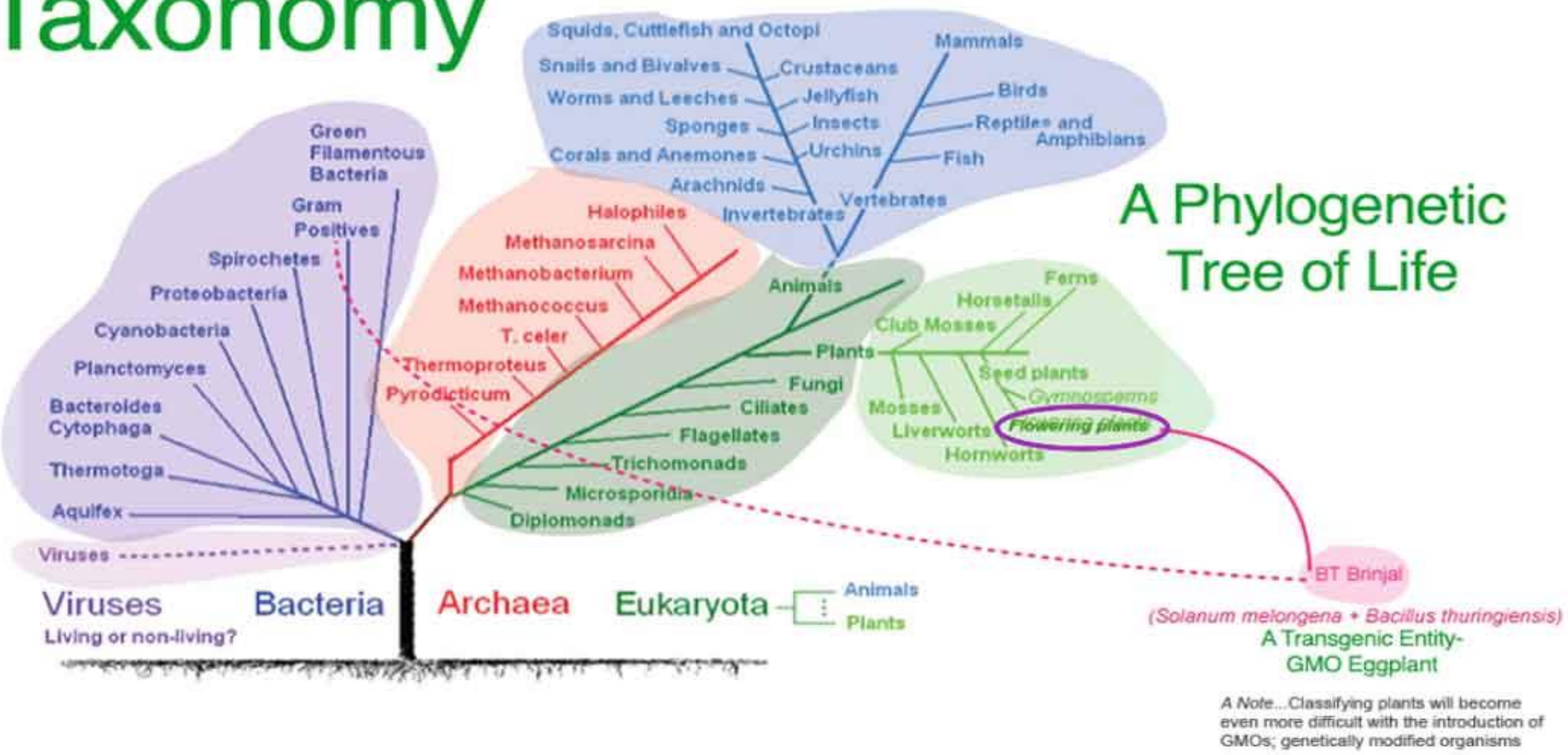


Figure 21.3(2)

GENOMIC Taxonomy

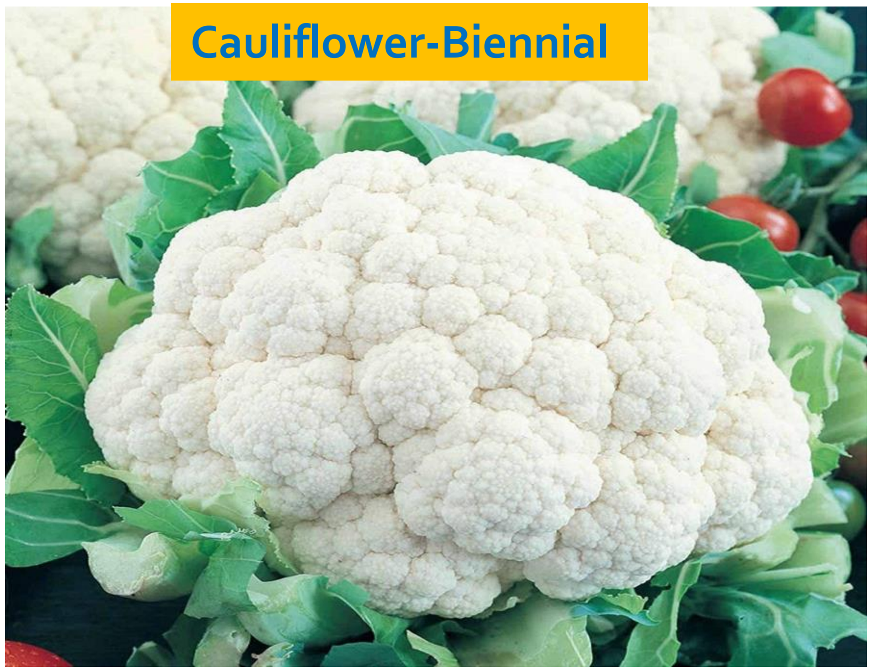


Today, "plants" make up only a branch of the Eukaryota domain. In regard to fruits and vegetables, we are only interested in the limb called "flowering plants."


Zinnia-Annual

Foxglove-Biennial

Bee Balm-Perennial

Tomatoes-Annual

Cauliflower-Biennial

Arthichoke-Perennial


Apple

Grape

Apricot

Cherry

Ilex

Judas Tree

What is Plant Physiology?

- **Plant Physiology** is a science that studies plant function or what is going on in plants that accounts for their being alive.
- **Plant Physiology** as a branch of biological science, studies life processes that are often similar or identical in many organisms.
- The scope of **Plant Physiology** as a science is very broad, ranging from biophysics and molecular genetics to environmental physiology and agronomy.

Some Basic Postulates on Plant Physiology

1. Plant function can ultimately be understood on the basis of the principles of physics and chemistry.

2. Botanists and plant physiologists study members of 4 of the 5 kingdoms of organisms; Monera-prokaryotic organisms with no nucleus, Protista-eukaryotic organisms *(single-celled organisms like protozoa, some algae)*, Fungi, and Plantea-most algae and all green plants, true plants.

3. The cell is the fundamental unit of life; all living organisms consist of cells.

4. Eukaryotic cells contain membrane-bound organelles such as *chloroplasts, mitochondria, nuclei,* and *vacuoles*, whereas prokaryotic cells contain no *membrane-bound organelles*.

5. Cells are characterized by special macromolecules, such as *starch* and *cellulose*; also as *proteins* and *nucleic acids* *(RNA and DNA)*.

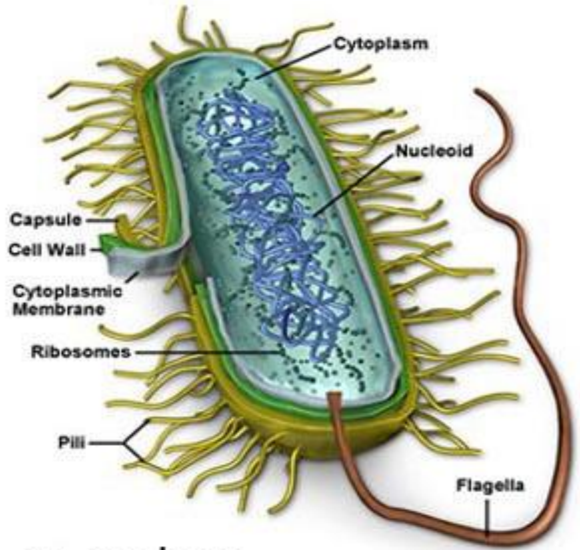
6. In multicellular organisms, cells are organized into tissues and organs.

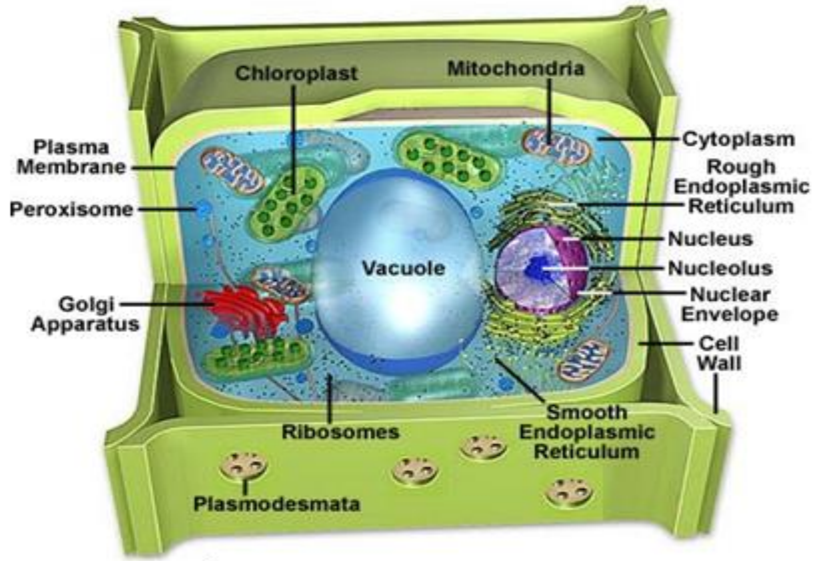
7. Living organisms are self-generating structures, called development *(cell division, enlargement, differentiation)*.

8. Organisms grow and develop within their environments and interact with these environments.

9. In living organisms, as in other machines, structure and function are intimately wedded.

Prokaryotic vs. Eukaryotic





- no nucleus
- no membrane enclosed organelles
- single chromosome
- no streaming in the cytoplasm
- cell division without mitosis
- simple flagella
- smaller ribosomes
- simple cytoskeleton
- no cellulose in cell walls
- no histone proteins

- nucleus
- membrane enclosed organelle
- chromosomes in pairs
- streaming in the cytoplasm
- cell division by mitosis
- complex flagella
- larger ribosomes
- complex cytoskeleton
- cellulose in cell walls
- DNA bound to histone proteins

Plant Life

1. Spectacular diversity of **plant size** and **form** is familiar to everyone.

2. Plants range in size from less than **1 cm tall** to greater than **100 m.**

3. **Green plants** are the ultimate color **collectors**. They harvest the energy of sunlight by converting light energy to chemical energy.

4. **Plants are non-motile**, but they have ability to grow toward essential resources, such as light, water and mineral nutrients.

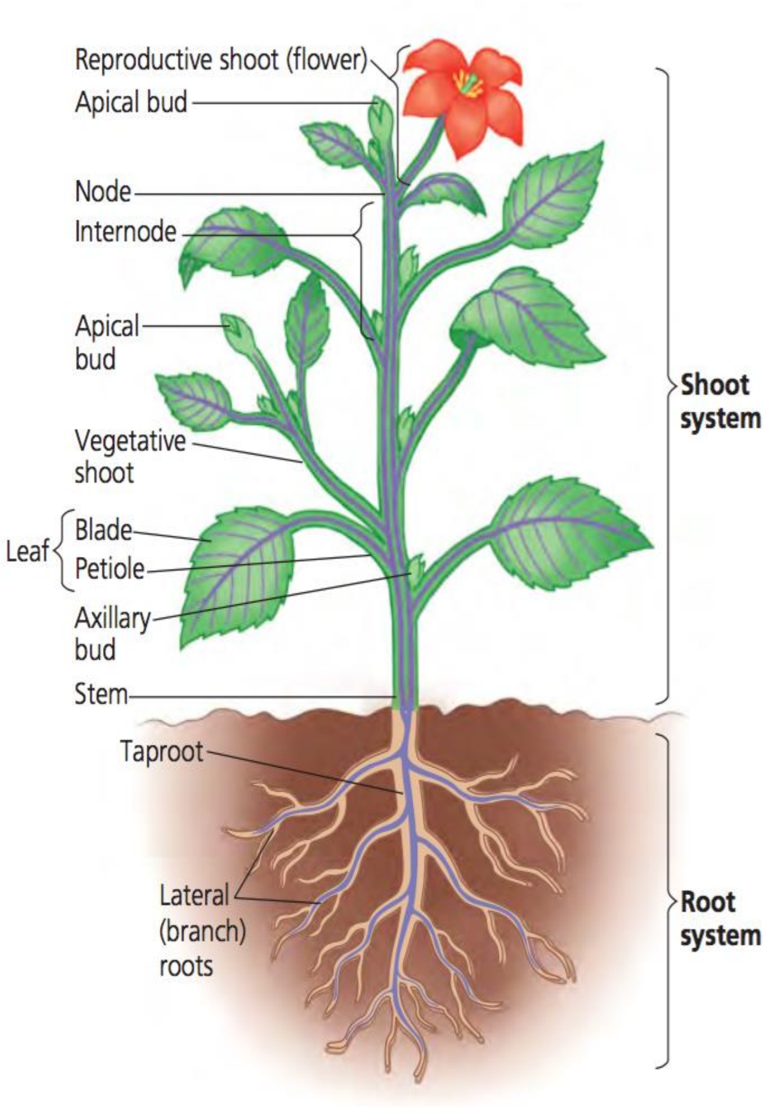
5. **Terrestial plants** are structurelly reinforced to support their mass as the grow toward sunlight against the pull of gravity.

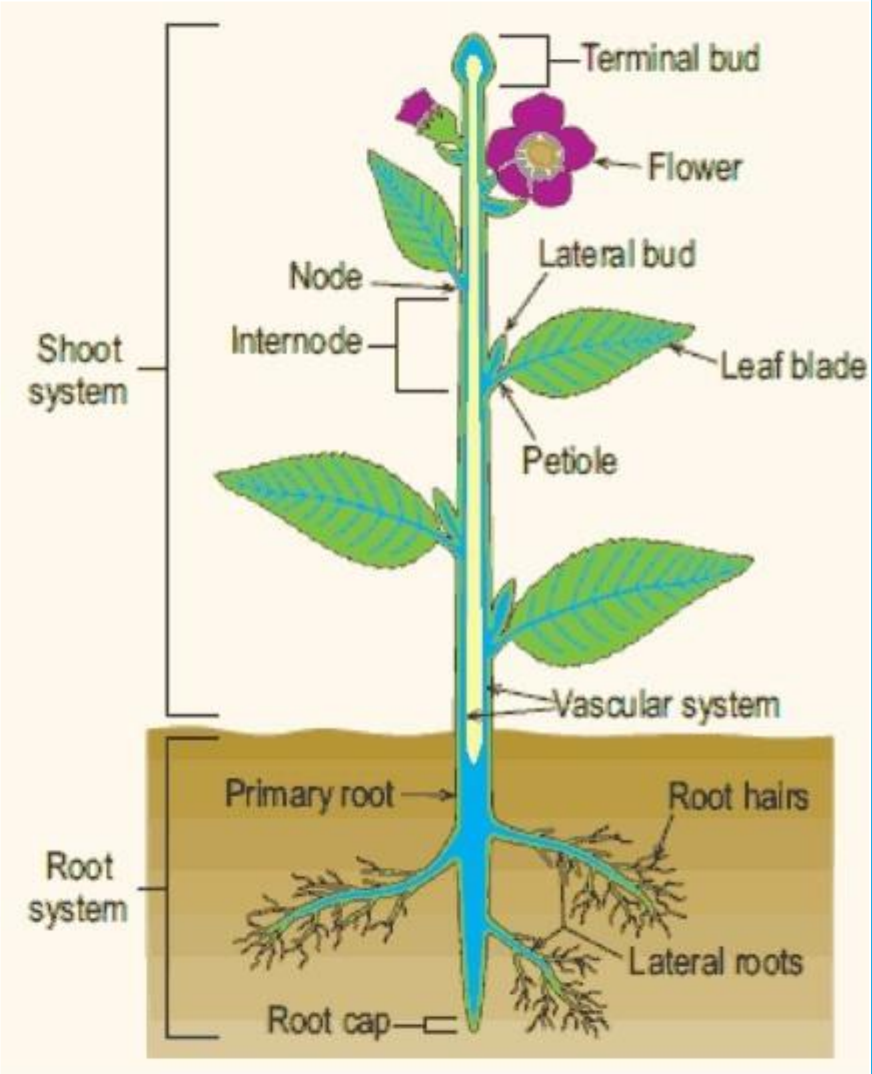
6. **Terrestial plants** lose water continously by evaporation and have mechanisms for avoiding desiccation.

7. **Terrestial plants** have mechanisms for moving water and minerals from the soil to the sites of photosynthesis and growth ***by xylem***, as well as mechanisms for moving the products of photosynthesis to non-photosynthetic organs and tissues ***by phloem***.

Plant Structure

- **1. All seed *(flowering)* plants have the same basic body plan.**
- **2. Vegetative body is composed of three organs: *Leaf*-primary function is photosynthesis, also respiration and transpiration; *Stem*-supporter; *Root*-anchorage, and absorb water and minerals.**
- **3. Leaves are attached to the stem at *nodes*, and the region of the stem between two nodes is termed *internode*, together with its leaves, stem is referred to as *shoot*.**



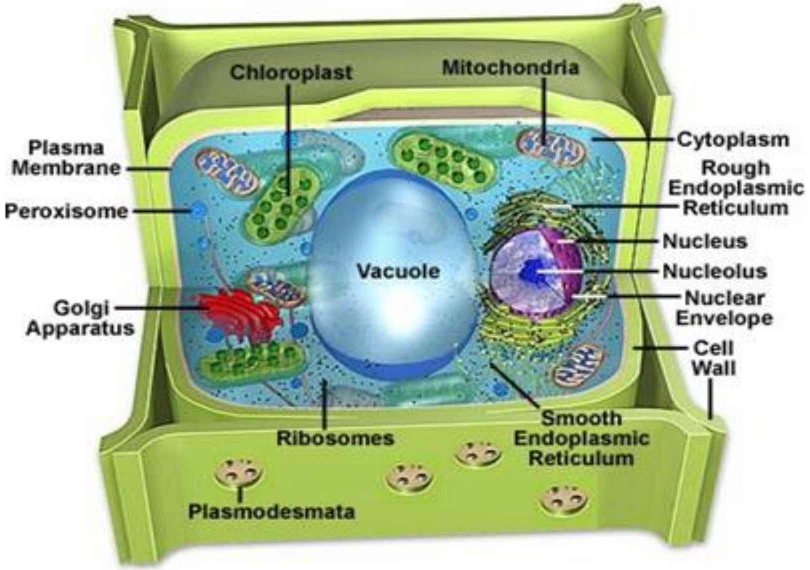


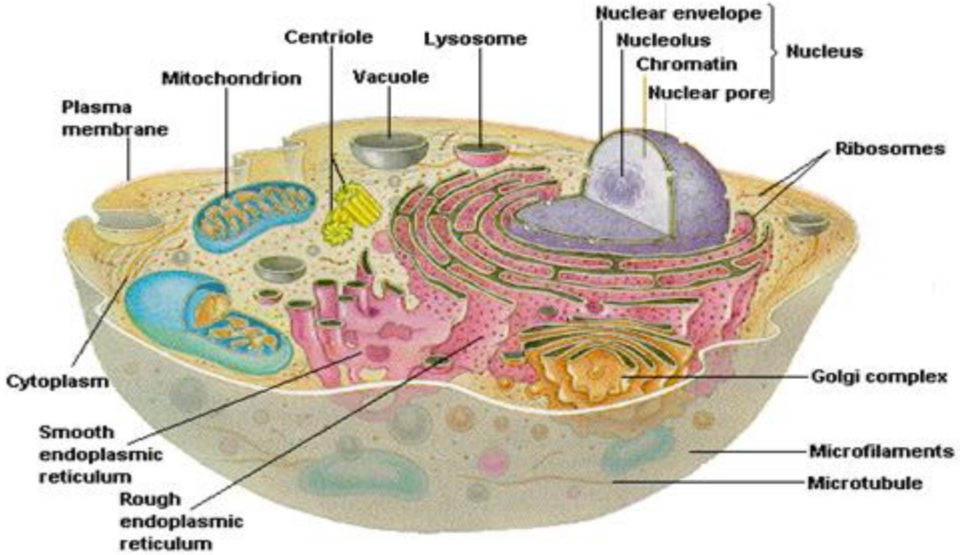

Spring
Summer
Fall
Winter

2.
Plant Cell & Structure

Comparison:

Plant cells | Animal cells





Plant cells:

- ❑ Large, central vacuole
- ❑ Chloroplasts
- ❑ Rigid cell wall outside of cell membrane

Animal cells:

- ❑ No large, central vacuole
- ❑ No chloroplasts
- ❑ No rigid cell wall

Plant Cell Types

1. ***Parenchyma***
primary walls thin and flexible; no secondary walls; large central vacuole; most metabolic functions of plant (chloroplasts)

2. ***Collenchyma***
unevenly thick primary walls used for plant support (no secondary walls ; no lignin)

3. ***Sclerenchyma***
support element strengthened by secondary cell walls with lignin (may be dead; xylem cells); fibers and sclereids for support

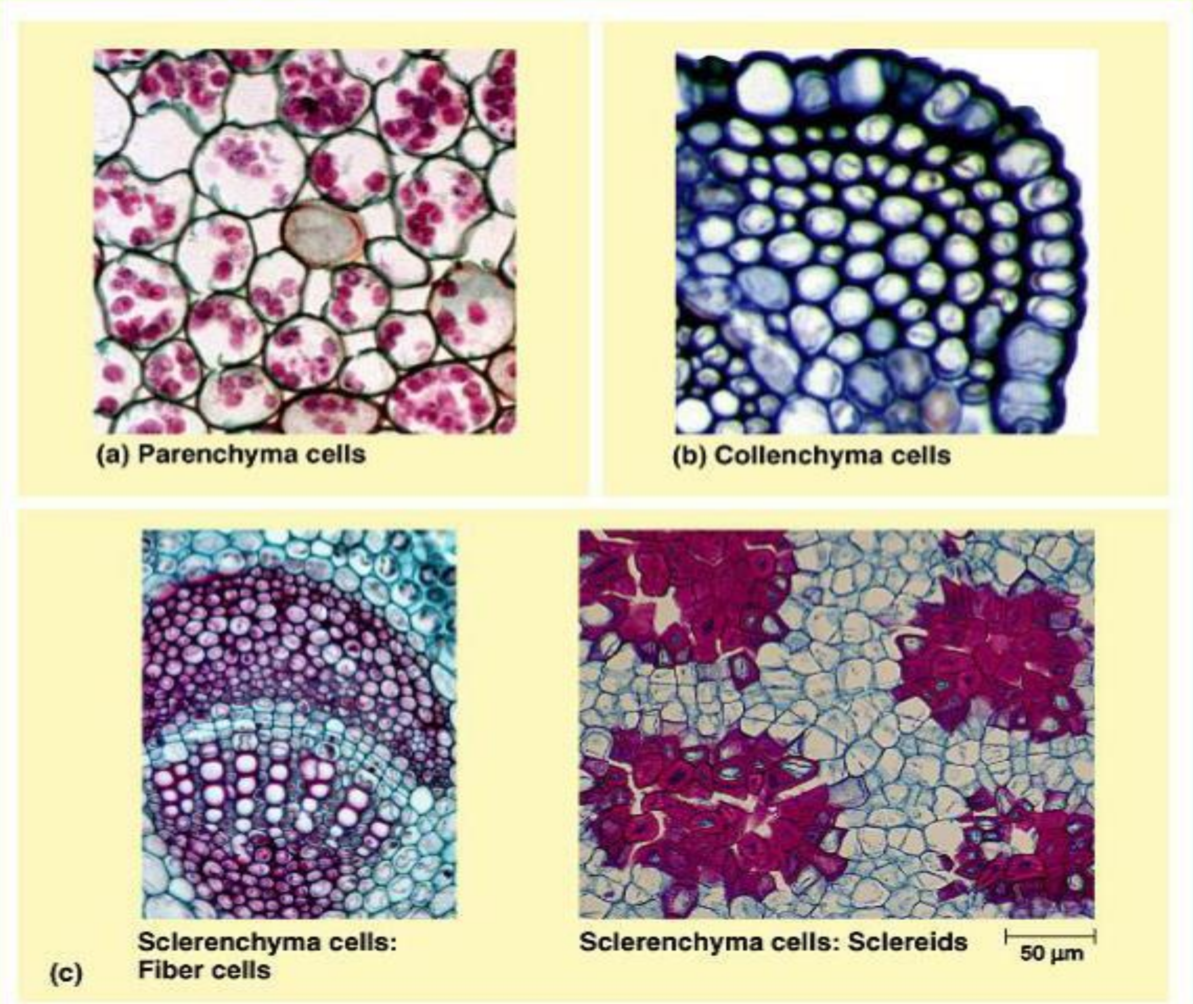


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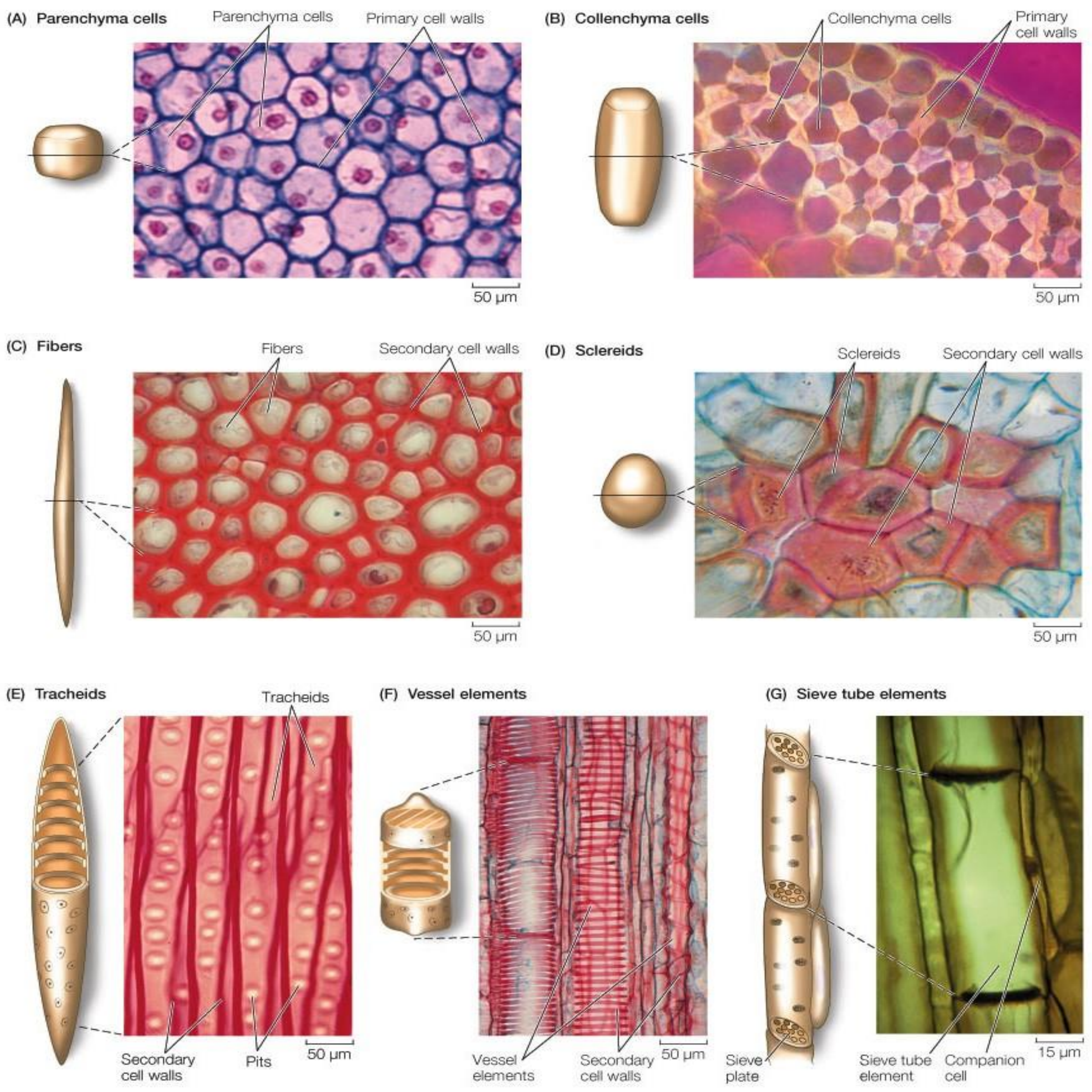
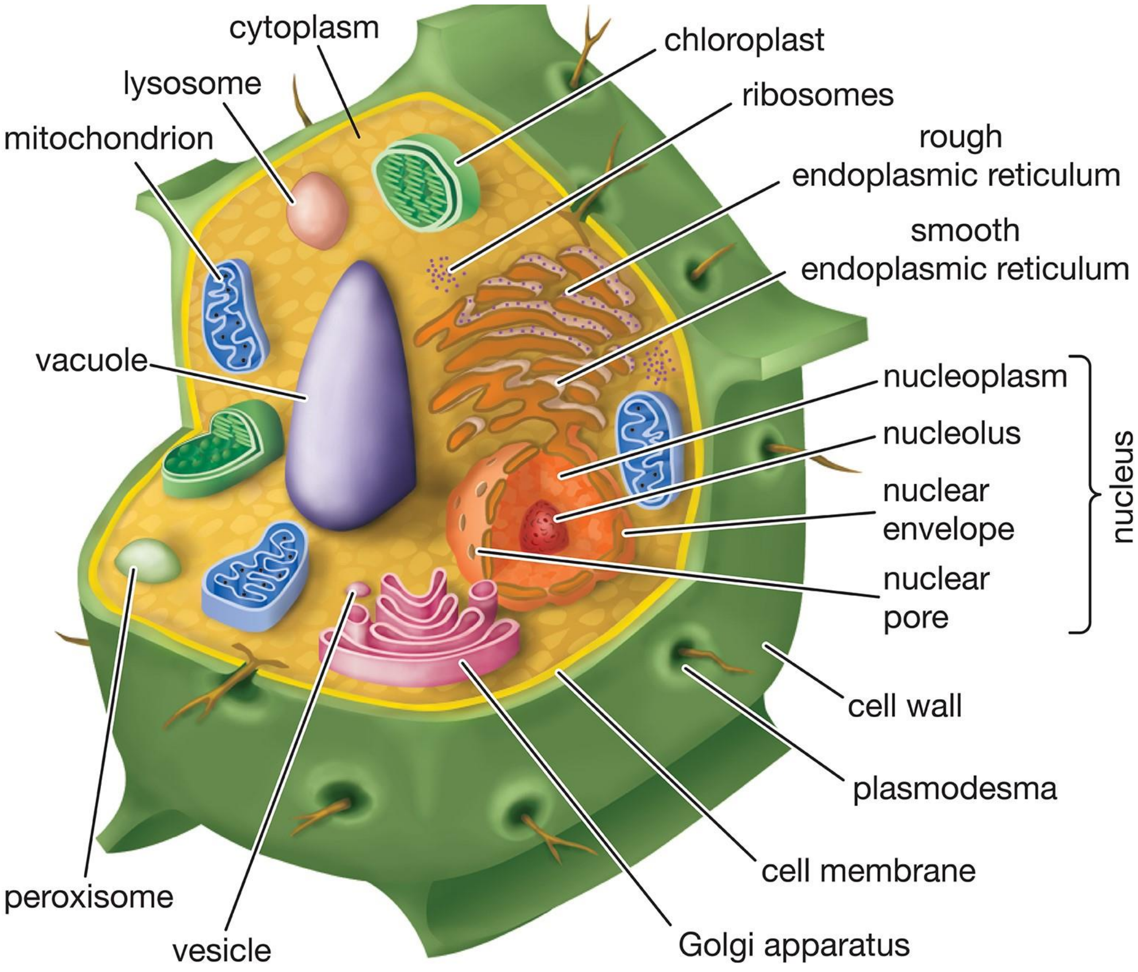
Table 1.2. Plant cell types and their function.

Cell type	Function(s)
Parenchyma	Storage of cellular metabolites Capable of meristematic activity
Collenchyma	Provide support Capable of meristematic activity
Sclerenchyma (sclereids and fibers)	Provide support
Tracheids	Lateral water and solute transport in xylem
Vessel elements	Lateral and longitudinal water and solute transport in xylem
Sieve elements	Transport of photosynthetic products
Companion cells	Provide energy to sieve elements for transport



Plant Cell Structure

- Cell is derived from the Latin ***cella***, meaning **storeroom** or **chamber**, first used in biology in **1665** by English botanist **Robert Hook.**
- Plants are multicellular organisms composed of millions of cells with specialized functions.
- All plant cells have the same basic eukaryotic organization:
- They contain **a nucleus, a cytoplasm,** and **subcellular organelles**, and they are enclosed in **a membrane**.



Cell Wall

- Each plant cell is surrounded by a rigid cell wall seperating the cytoplasm from external environment, also called **plasmalemma**.

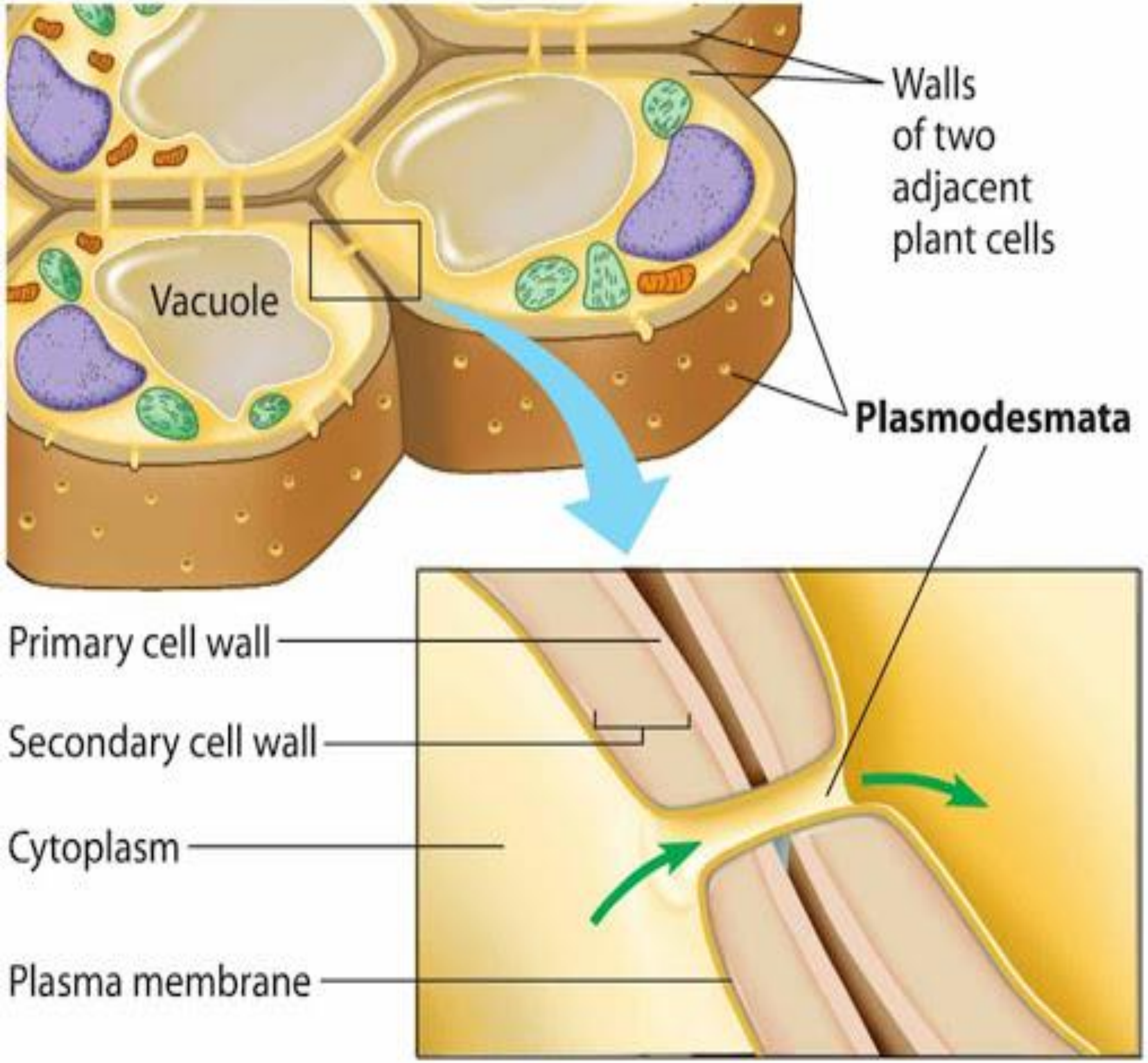
- Plant cells have two types of walls;

1. Primary cell walls: Composed of thin, and young growing cells.

2. Secondary cell walls: Thicker and stronger that owe their strength to lignin.

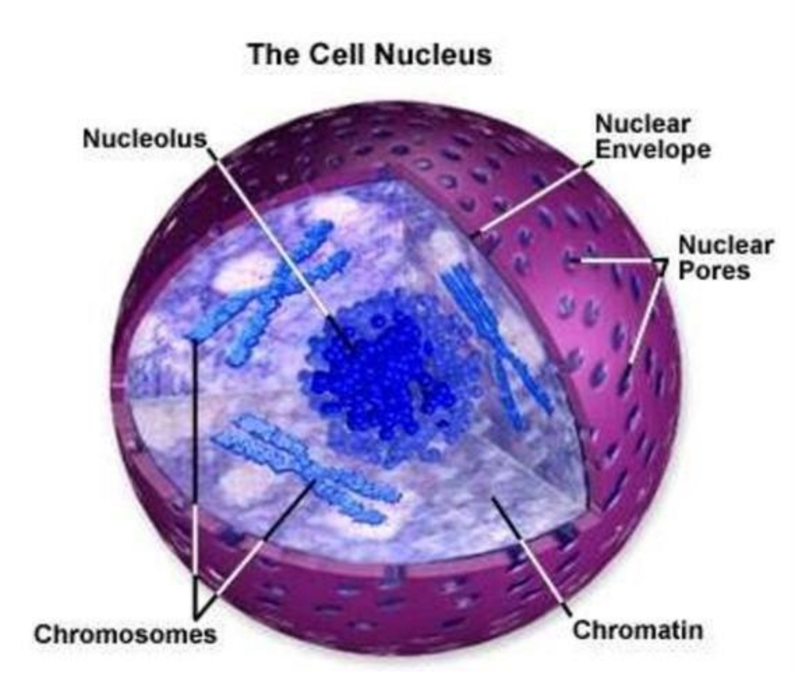
- Biological membranes are **phospolipid bilayers** that contain **proteins**.

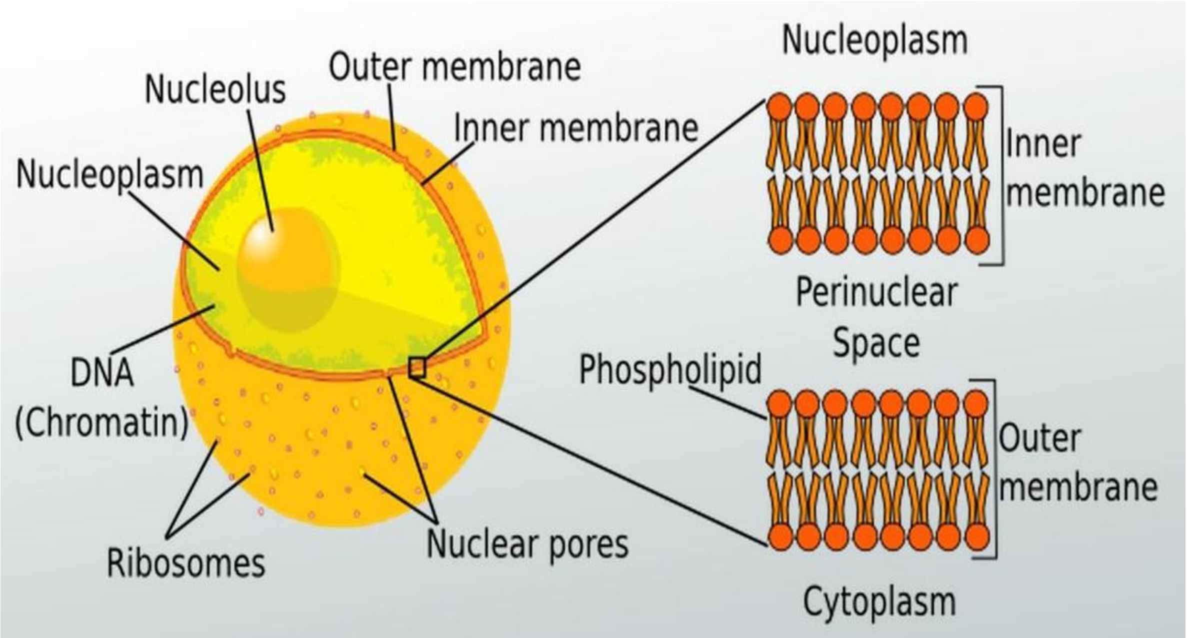
- **Plasmodesma** (Pl. *Plasmadesmata*) is a channel through the cell wall that allows molecules and substances to move back and forth as needed.



Nucleus

- **Nucleus** *(pl. Nuclei)* **is the organelle that contains the genetic information responsible for regulating the metabolism, growth and differentiation of the cell.**
- **All these genes and their intervening sequences are referred to as nuclear genome.**
- **Nucleus is surrounded by a double membrane called nuclear envelope.**
- **Nucleus is the site of storage and replication of the chromosomes, composed of DNA and its associated proteins. This DNA-protein complex is known as chromatin.**
- **Linear length of DNA within any plant genome is usually millions of times greater than the diameter of nucleus.**
- **During mitosis, the chromatin condenses, followed by further folding and packing processes, depend on interactions between proteins and nucleic acids.**





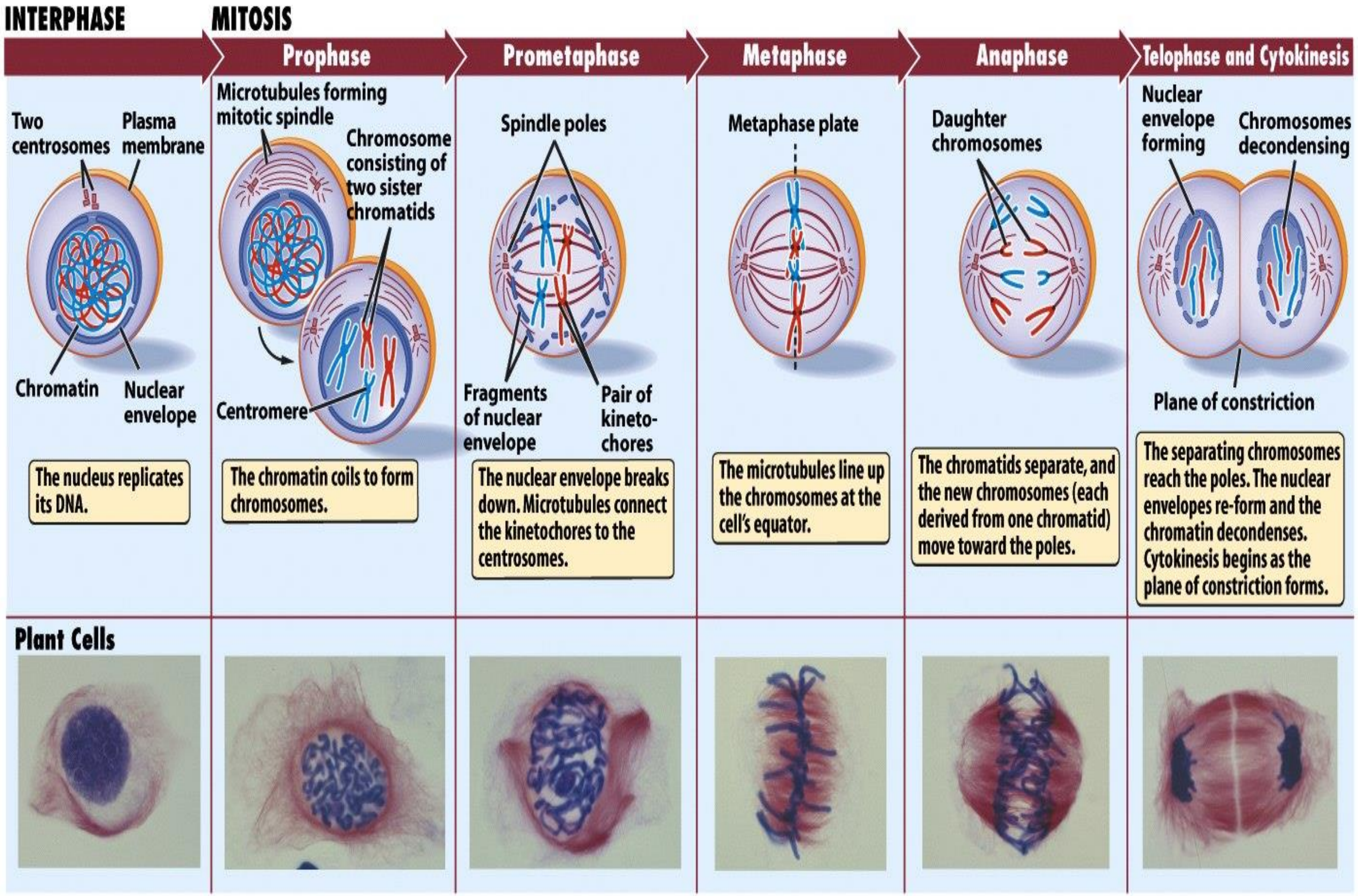
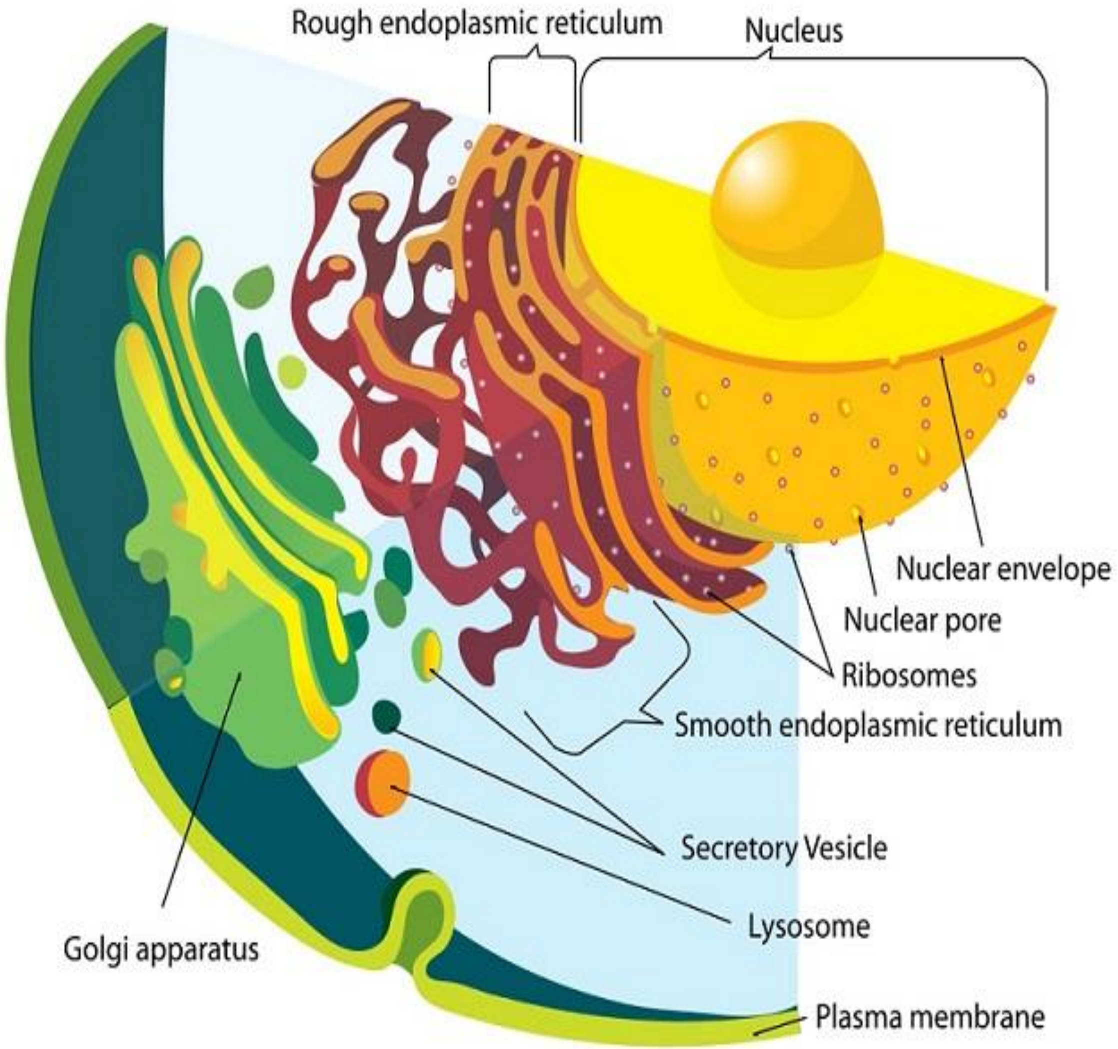


Figure 9-5 Discover Biology 3/e

Microtubules provide structure and shape to eukaryotic cells.
Centromere is the specialized DNA sequence of a chromosome that links a pair of sister chromatids.
Kinetochore is a disc-shaped protein structure associated with duplicated chromatids in eukaryotic cells.
Centrosome is an area in the cell where microtubules are produced.

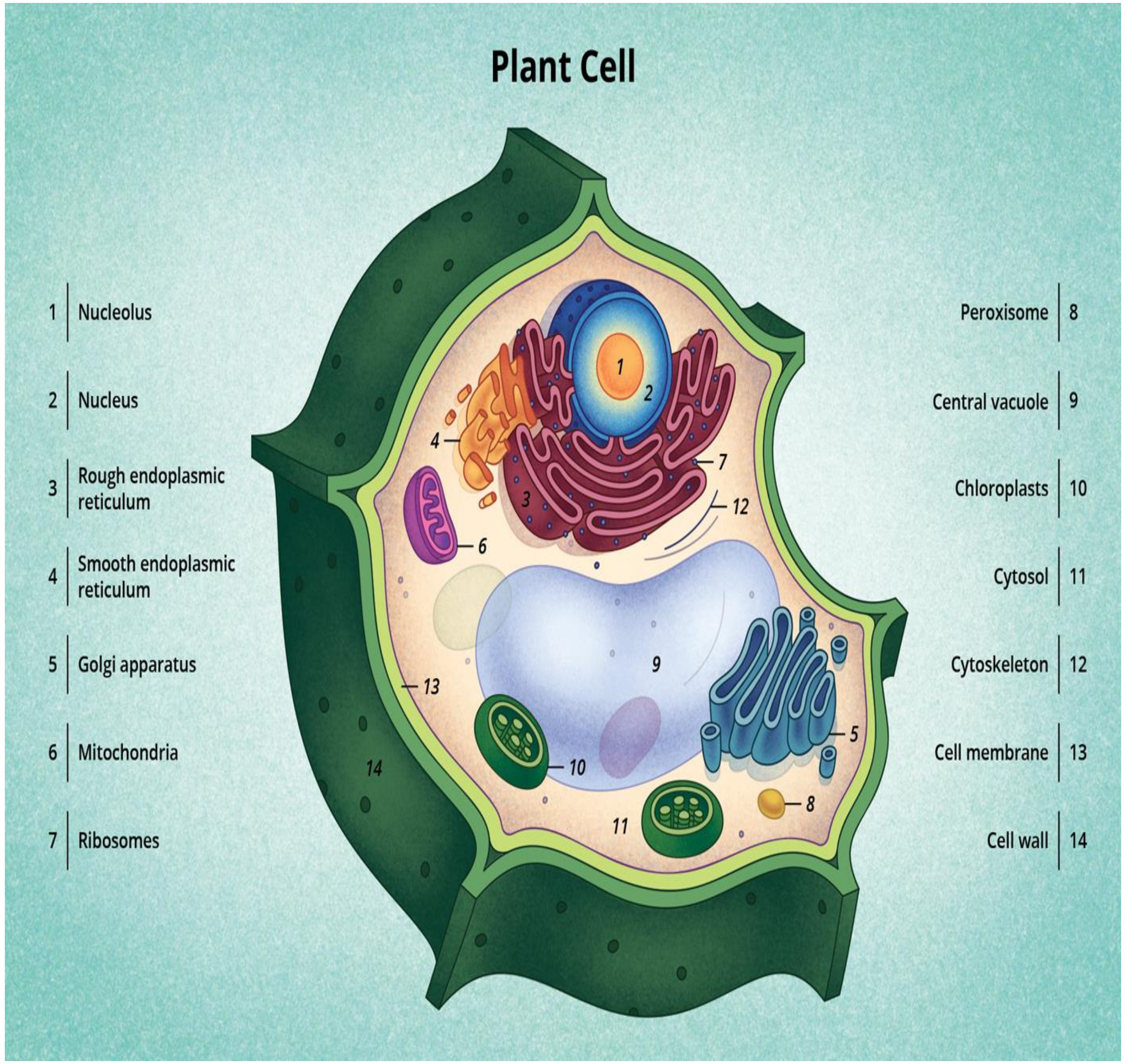
Endoplasmic Reticulum

- **ER is an elaborate *(detailed)* network of internal membranes.**
- **There are two types of ER, *smooth* and *rough*.**
- **Sections of proteins from cells begins with *rough ER*.**
- # Golgi Apparatus
- **A dynamic structure consisting of one or more stacks or three to ten flattened membrane sacs, or cisternae, and irregular network of tubules and vesicles.**
- **Golgi Apparatus play a key role in the synthesis and secretion of complex polysaccharides.**



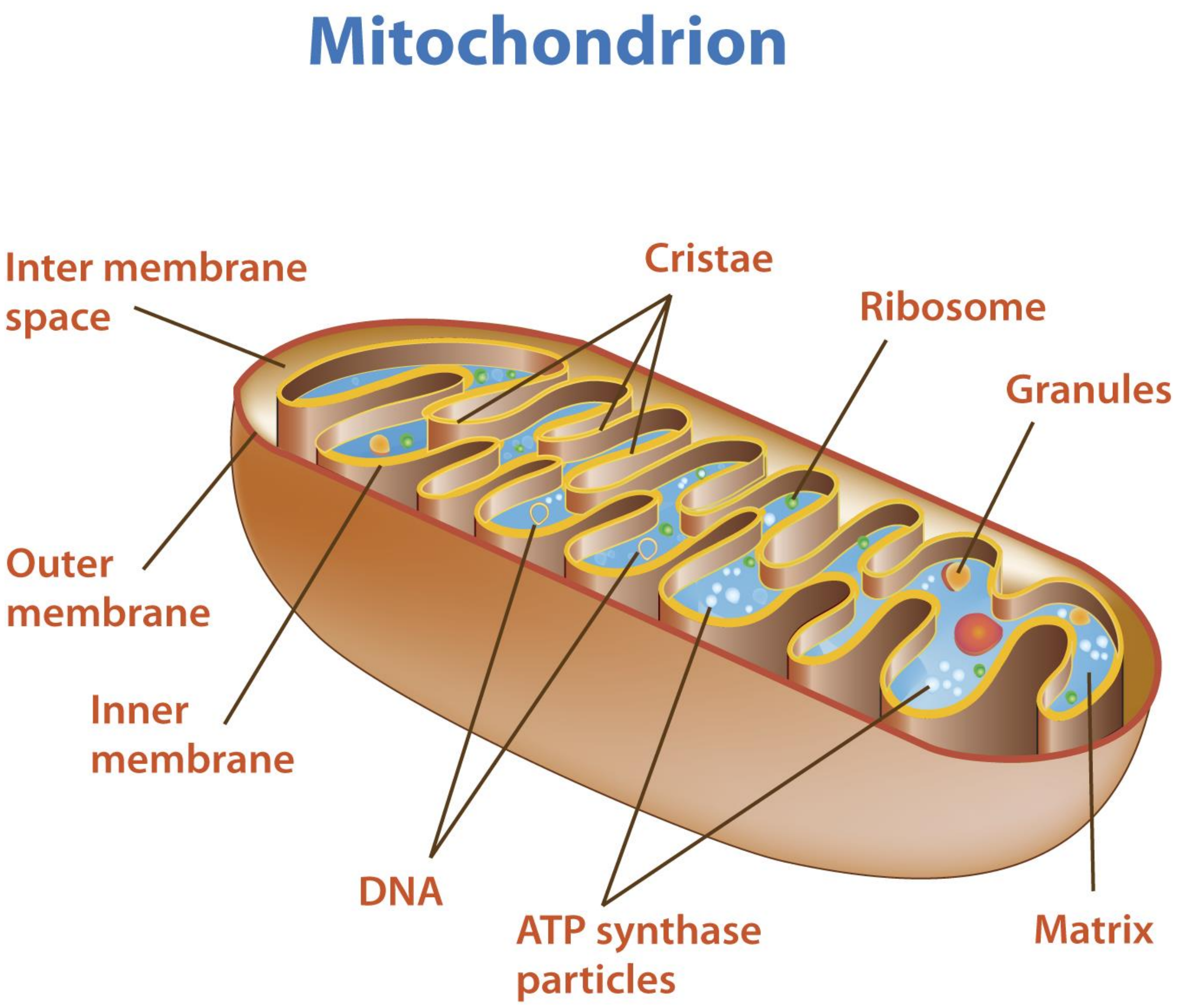
Central Vacuole

- Mature living plant cells contain large, water-filled **central vacuoles** that can occupy **80 to 90%** of total volume of cell.
- Each vacuole is surrounded by a vacuolar membrane, **tonoplast.**
- **Vacuole** contains *water* and *dissolved inorganic ions*, *organic acids*, *sugars*, *enzymes*, an a variety of *secondary metabolites*, which often play roles in **plant defense**.



Mitochondria

- **Energy-producing organelle, and cellular sites of respiration, that is a process in which energy released sugar metabolism is used for synthesis of *ATP (Adenosine Tri-Phosphate)* and *inorganic phosphate (Pi)*.**



Chloroplasts

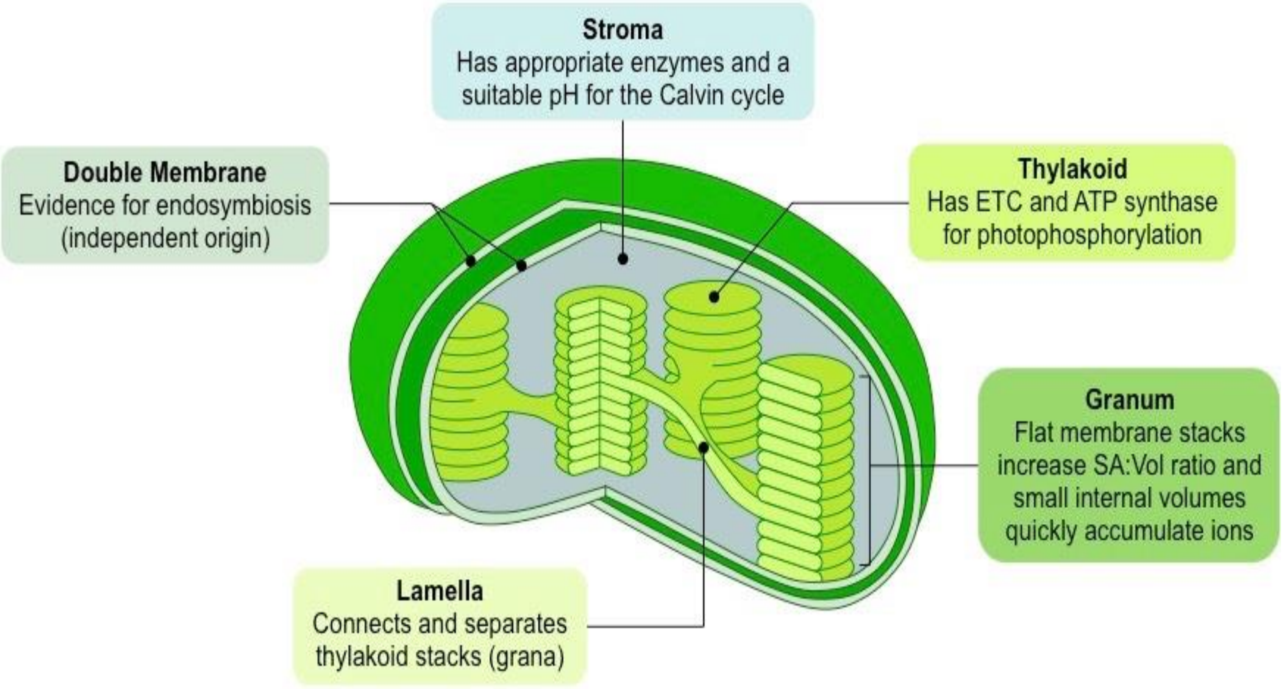
1. They are also energy-producing organelles.

2. They belong to another group of double membrane-enclosed organelles called **plastids**.

3. Chloroplast membranes are rich in *glycosylglycerides (Monogalactosyldiglyceride (MGDG) and digalactosyldiglyceride (DGDG) are two important biomolecules that are especially prevalent in chloroplast membranes and photosynthetic tissues. A proper ratio of MGDG and DGDG is critical for membrane function).*

4. Chloroplast membranes contain *chlorophyll* and its associated proteins and the *sites of photosynthesis*.

5. Chloroplasts possess a third system of membranes called *thylakoids*. A stack of thylakoids forms a *granum* (pl. Grana).

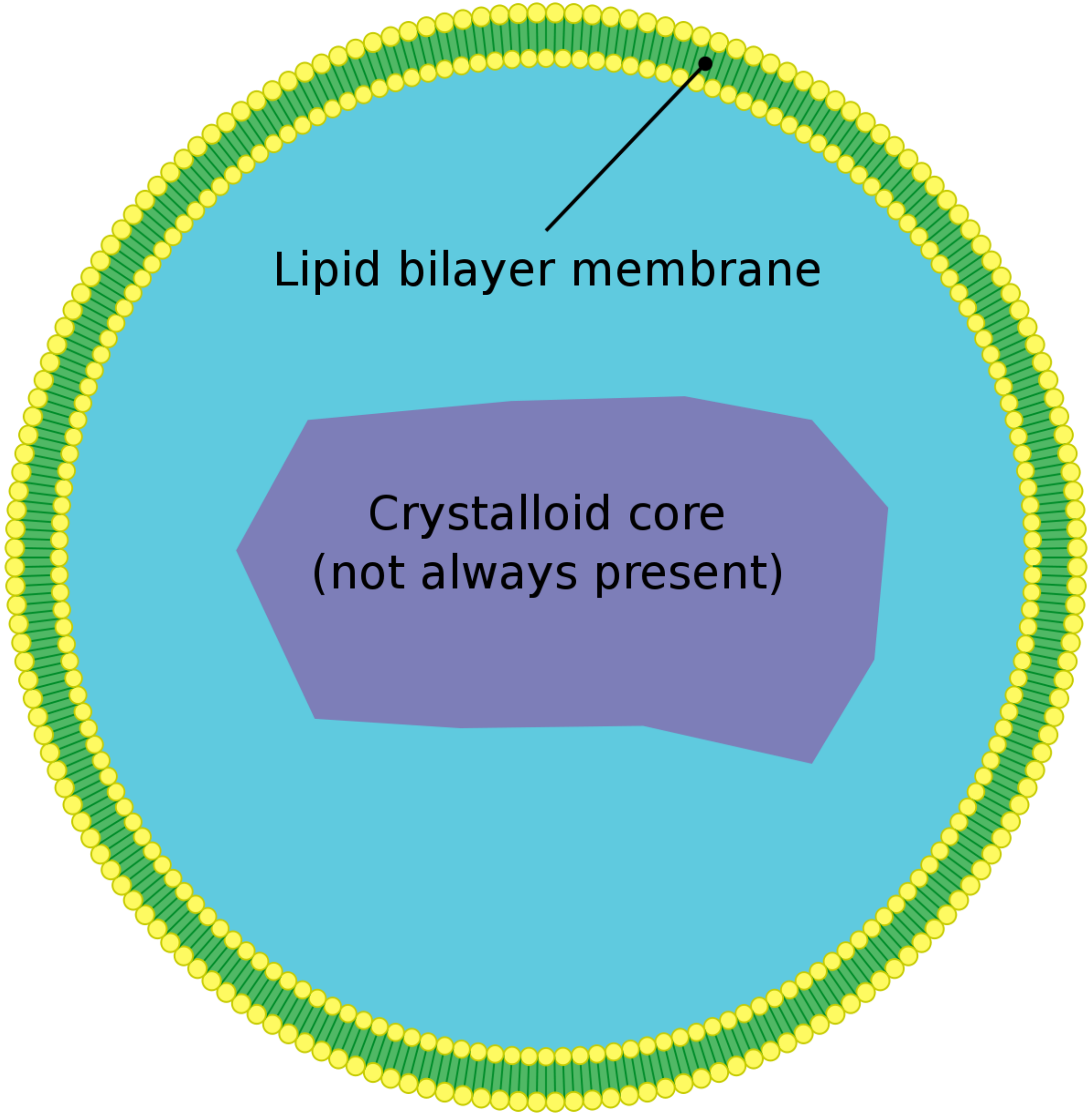


Chromoplasts & Leucoplasts

- **Chromoplasts :** They are plastids that contain high concentrations of carotenoid pigments rather than chlorophyll. They are one of the causes of yellow, orange, or red colors of many fruits and flowers, as well as autumn leaves.
- **Leucoplasts :** They are non-pigmented plastids. Most important type of leuocoplast is amyloplast, a starch storing plastid.

Microbodies

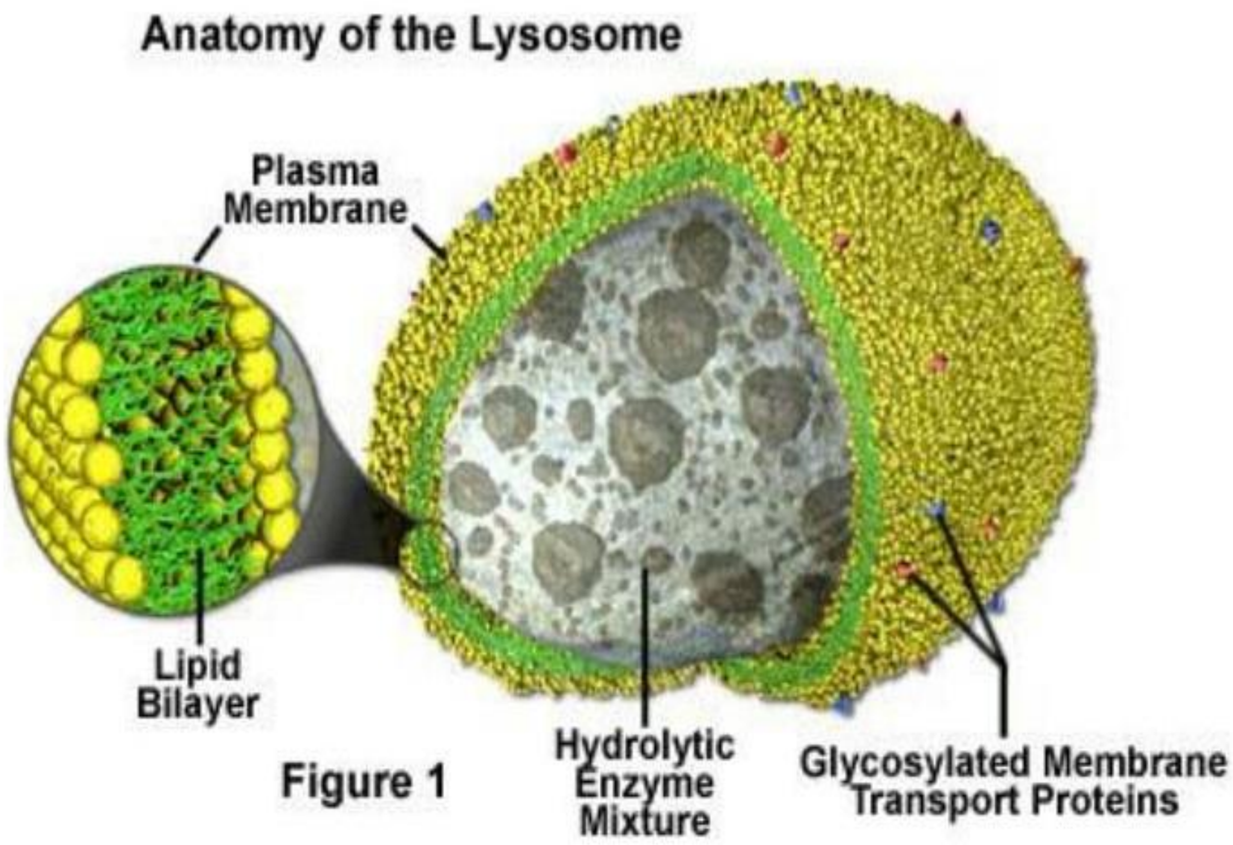
- A class of spherical organelles surrounded by a single membrane and specialized for one of several metabolic functions.
- The two main types of microbodies are peroxysomes and glyoxysomes.
- Peroxysomes are found in all eukaryotic organisms, and they are present in photosynthetic cells. They function in removal of hydrogens from organic substrates.
- Glyoxysomes which is present in oil-storing seeds, contain the *glyoxylate cycle enzymes*, help *convert stored fatty acids into sugars* that can be translocated throughout the young plant to provide energy for growth.



Oleosomes

- In addition to ***starch*** and ***protein***, many plants synthesize and store large quantities of ***triacylglycerol*** (*also known as triglycerides, are the simplest lipids formed by fatty acids. It is made up of three fatty acids ester linked to a single glycerol. Most triacylglycerols contain two or three different fatty acids. Triacylglycerols are nonpolar, hydrophobic, and insoluble in water.*) in the form of oil during seed development.

- These oil accumulate in **oleosomes**.



3.
Water & Plant Cells

Structure & Properties of Water

1. **Polarity of water *molecules*** *(an irregular distribution of electron density. Water has a partial negative charge near the oxygen atom due the unshared pairs of electrons, and partial positive charges near the hydrogen atoms)* **gives rise to hydrogen bonds.**

2. **Water molecule consists of an oxygen atom covalently *(eşdeğerlikli)* bonded to two hydrogen atoms. Two O-H bonds form an *angle of 105°.***

3. **Polarity of water makes it *an excellent solvent*. It dissolves greater amounts of a wider variety of substances than do other related solvents.**

4. **Thermal properties of water result from hydrogen bonding. Extensive hydrogen bonding between water molecules results in unusual thermal properties.**

5. **Cohesive and adhesive properties of water are also due to hydrogen bonding. Extensive hydrogen bonding in water give rise to a mutual attraction between molecules known as *cohesion*, and *adhesion* is the attraction of water to a solid phase such as a cell wall or glass surface.**

6. **Water has a high tensile strength. Cohesion gives water a high tensile strength, defined as the maximum force per unit area that a continuous column of water can withstand before breaking.**

Structure of Water Molecules

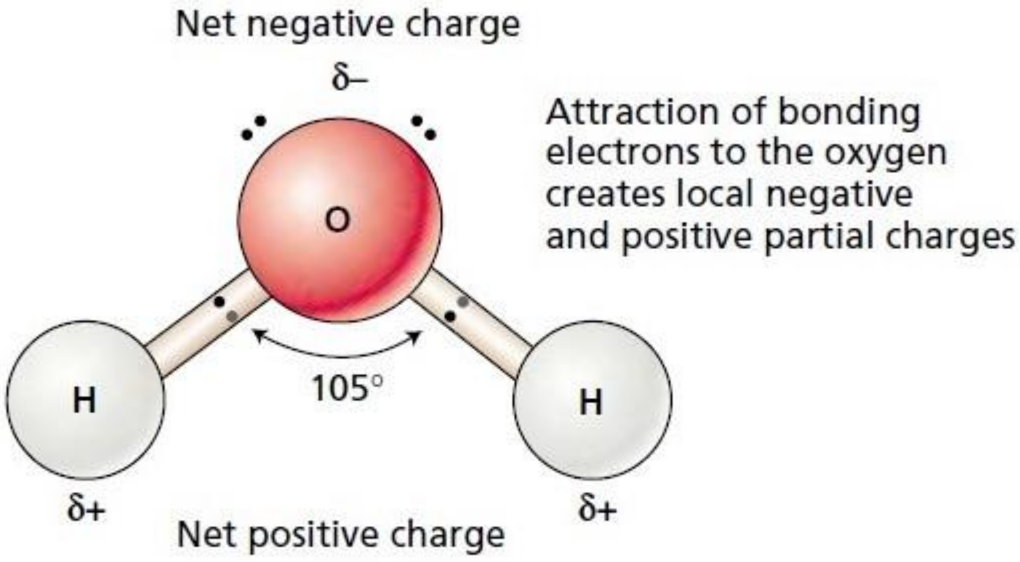
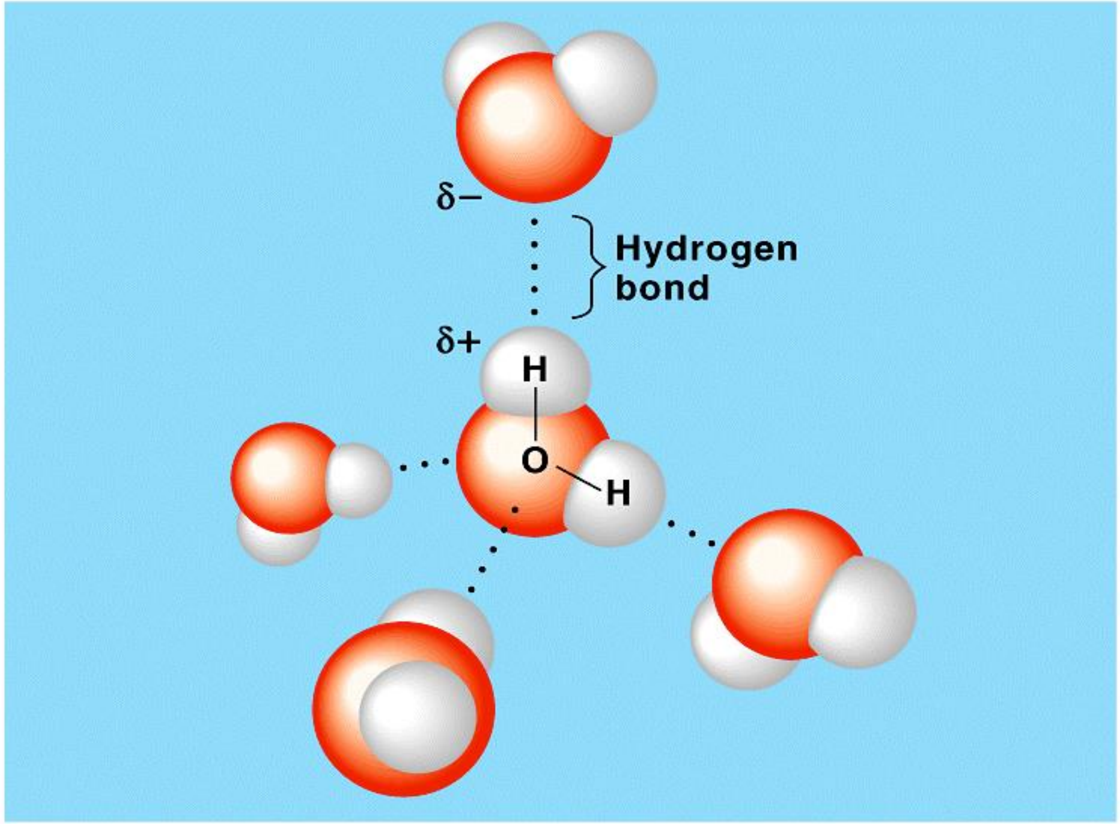


FIGURE 3.3 Diagram of the water molecule. The two intramolecular hydrogen–oxygen bonds form an angle of 105°. The opposite partial charges (δ– and δ+) on the water molecule lead to the formation of intermolecular hydrogen bonds with other water molecules. Oxygen has six electrons in the outer orbitals; each hydrogen has one.

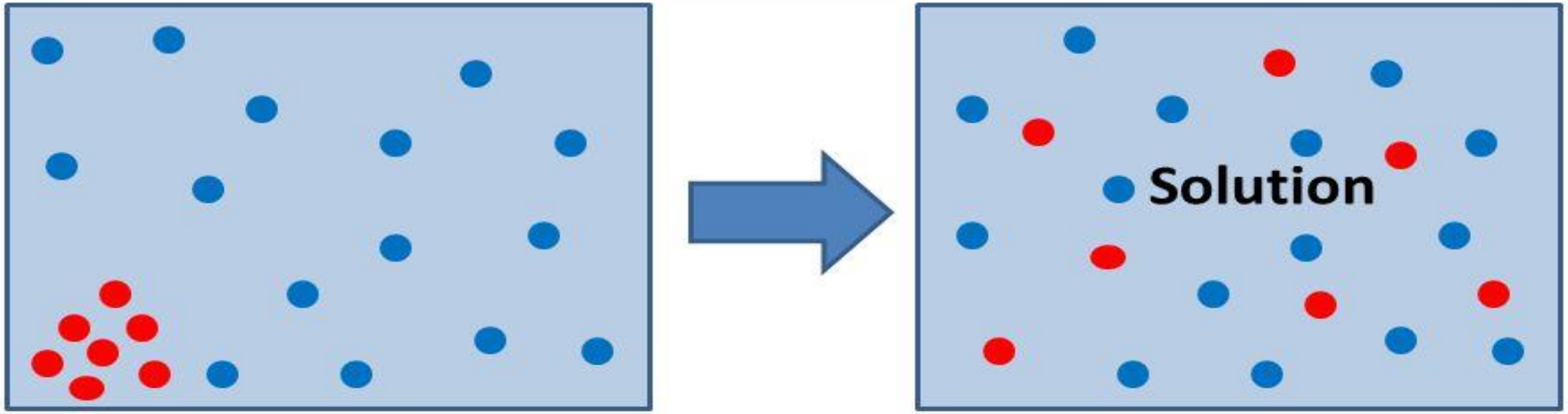


Water Transport Process- *Diffusion*

- **Water molecules in a solution are not static; they are in continuous motion, colliding with one another and exchanging kinetic energy.**
- **Molecules intermingle as a result of their random thermal agitation that is called *Diffusion*.**
- ***Diffusion* is *rapid* over short distances but extremely *slow* over long distances.**

Diffusion

Diffusion is the **passive movement** of particles from a **high concentration of particles** to a **lower concentration** until they are spread out evenly

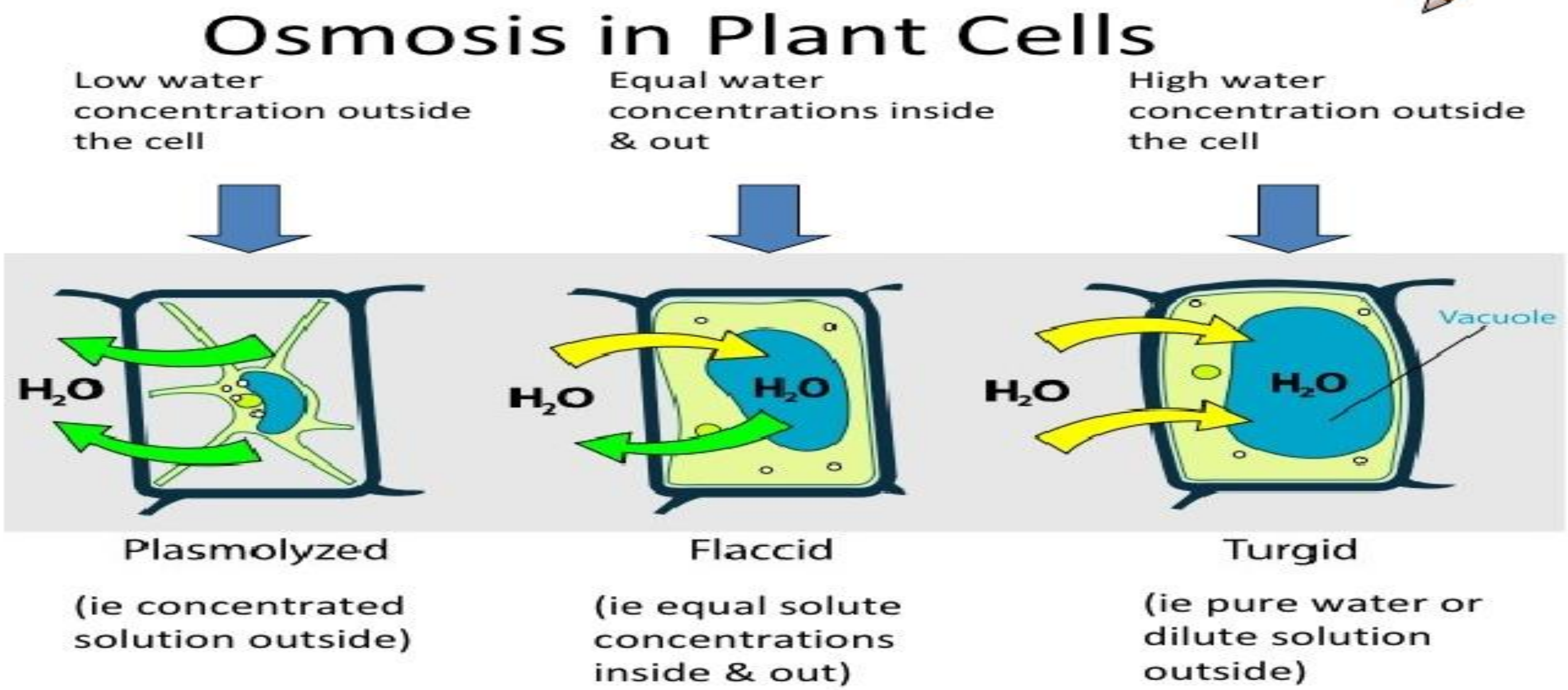


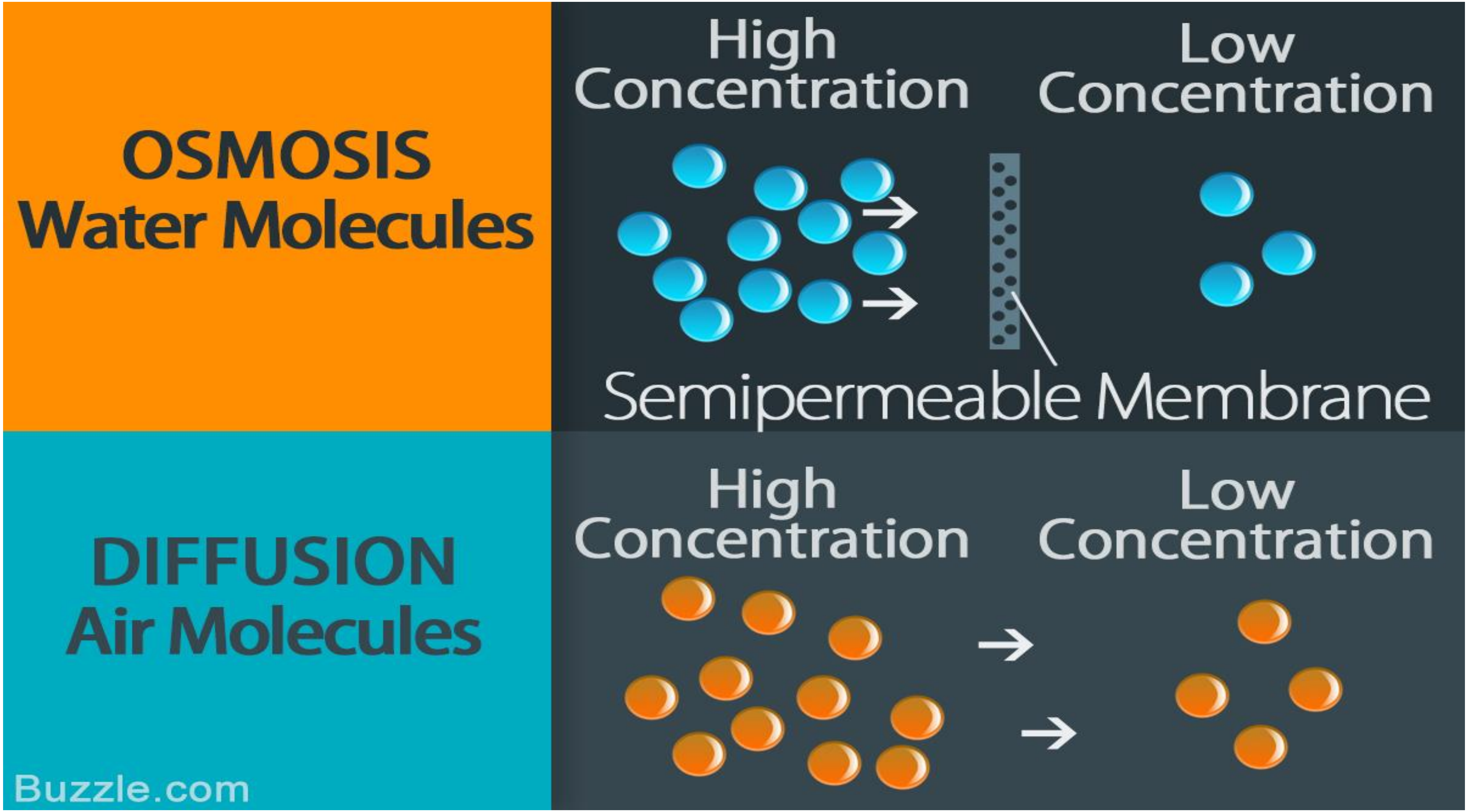
Smell Particles & Air Particles

Smell Particles diffused evenly into the Air Particles

Water Transport Process-*Osmosis*

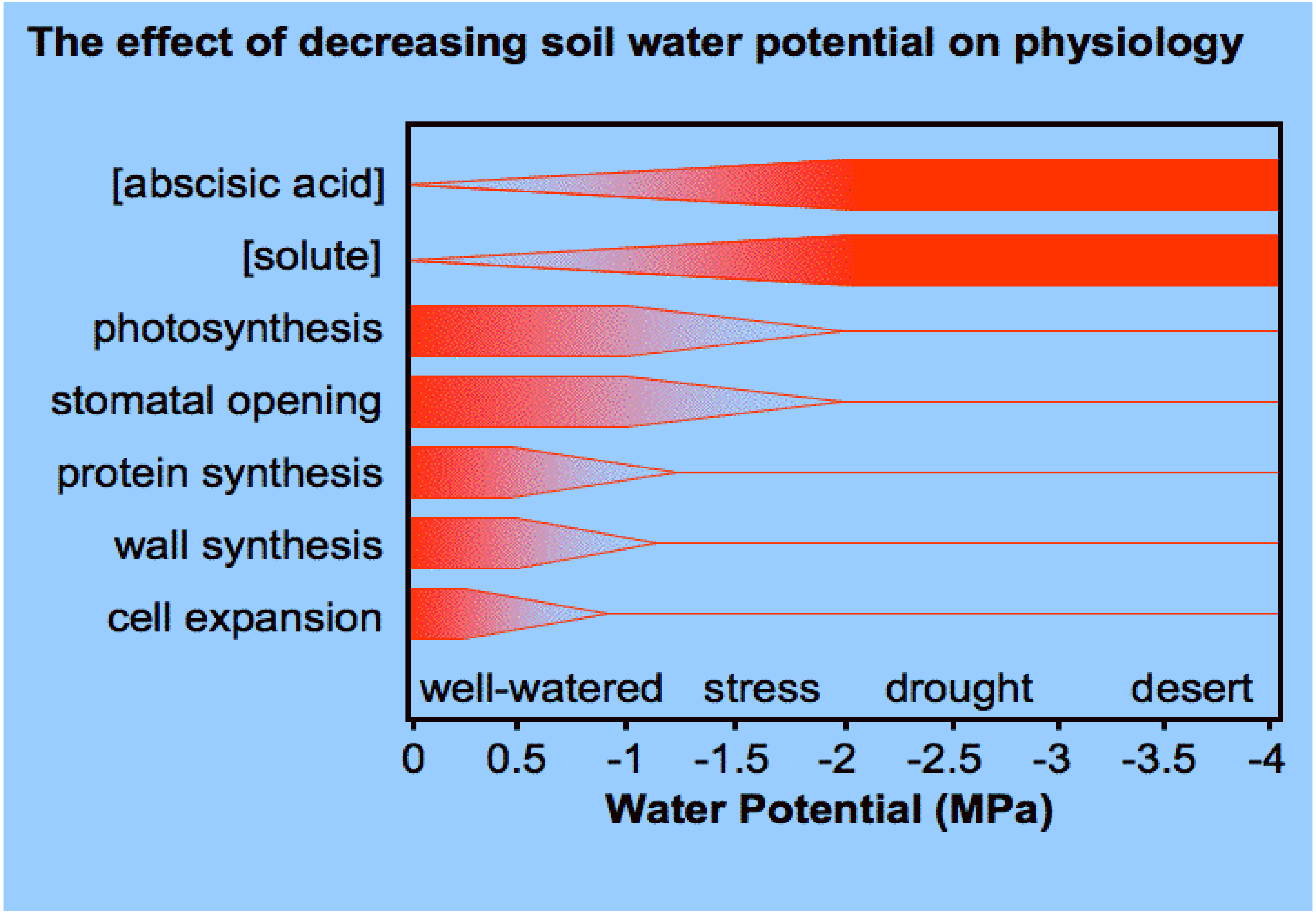
- **Membranes of plant cells are selectively permeable *(semipermeable)* that means they allow the movement of water and other small uncharged substances across them more readily than the movement of larger solutes and charged substances (Stein 1986). This type of molecular diffusion is called as *osmosis*.**




OSMOSIS
Water Molecules
High Concentration
Low Concentration
Semipermeable Membrane
DIFFUSION
Air Molecules
High Concentration
Low Concentration
Buzzle.com

Differences between Diffusion, Osmosis and Active transport

Process	Movement of	Condition	Additional requirements
Diffusion	Molecules/ ions	High conc. to low conc.	Down a conc. gradient
Osmosis	Water molecules	High water potential to low water potential	Across a partially permeable membrane
Active transport	Particles of substances	Low conc. to high conc.	Against a conc. Gradient; Energy required



- The soil water can only be extracted by expending energy.
- *Soil water potential* expresses how much energy is needed to expend to pull that water out of the soil sample

Water Balance of Plants – *Water in Soil*

- **Water content and rate of water movement in soils depend to on *soil type* and soil *structure*.**
- ***In sandy soils,* spaces between particles *(one mm or more in diameter)* are so large that water tends to drain from them and remain only on the particle surfaces and interstices *(gap)* between particles.**
- ***In clay soils,* the channels are small enough that water does not freely drain from them; it is hold more tightly.**
- ***Water Holding Capacity (WHC)* of soils is called *field capacity* that is water content of a soil after saturation with water.**

WHC of Soil Types *(inches water/foot of soil)*

Texture	Field Capacity	Wilting point	Available water
Coarse sand	0.6	0.2	**0.4**
Fine sand	1.0	0.4	0.6
Loamy sand	1.4	0.6	0.8
Sandy loam	2.0	0.8	1.2
Light sandy clay loam	2.3	1.0	1.3
Loam	2.7	1.2	1.5
Sandy clay loam	2.8	1.3	1.5
Clay loam	3.2	1.4	1.8
Clay	4.0	2.5	1.5
Self-mulching clay	4.5	2.5	2.0

Water Balance of Plants – ***Water Absorption by Roots***

- **Intimate *(close)* contact between the surface of the root and soil is essential for effective water absorption by the root.**
- ***Root hairs*** **are microscopic extension of root epidermal cells that greatly increase the surface area of the root, providing greater capacity for absorption of ions and water from the soil.**
- **Water moves in the root via the following pathways;**

-Apoplast Pathway: **Water moves exclusively through the cell wall without crossing any membranes.**

-Transmembrane Pathway: ***W*****ater enters the cell on one side, exists the cell on the other side, enters the next in the series.**

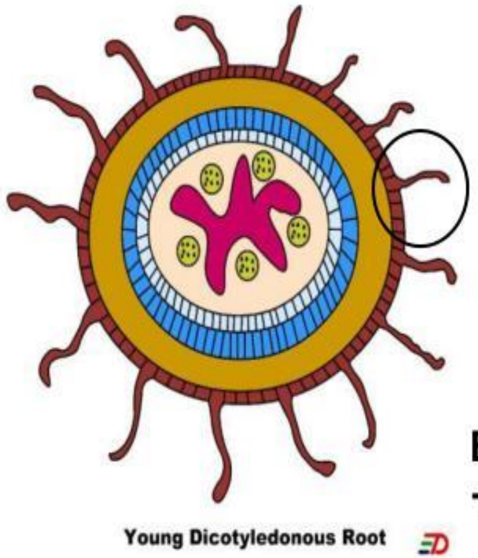
-Symplast Pathway: **Water travels from one cell to the next via *plasmodesmata*.**

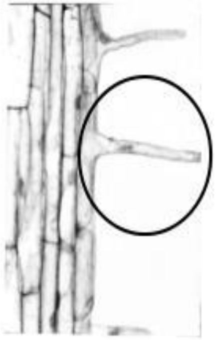
Water Absorption by Roots

Absorption of water by roots

Root hair cell has

Large surface area : volume ratio for efficient absorption

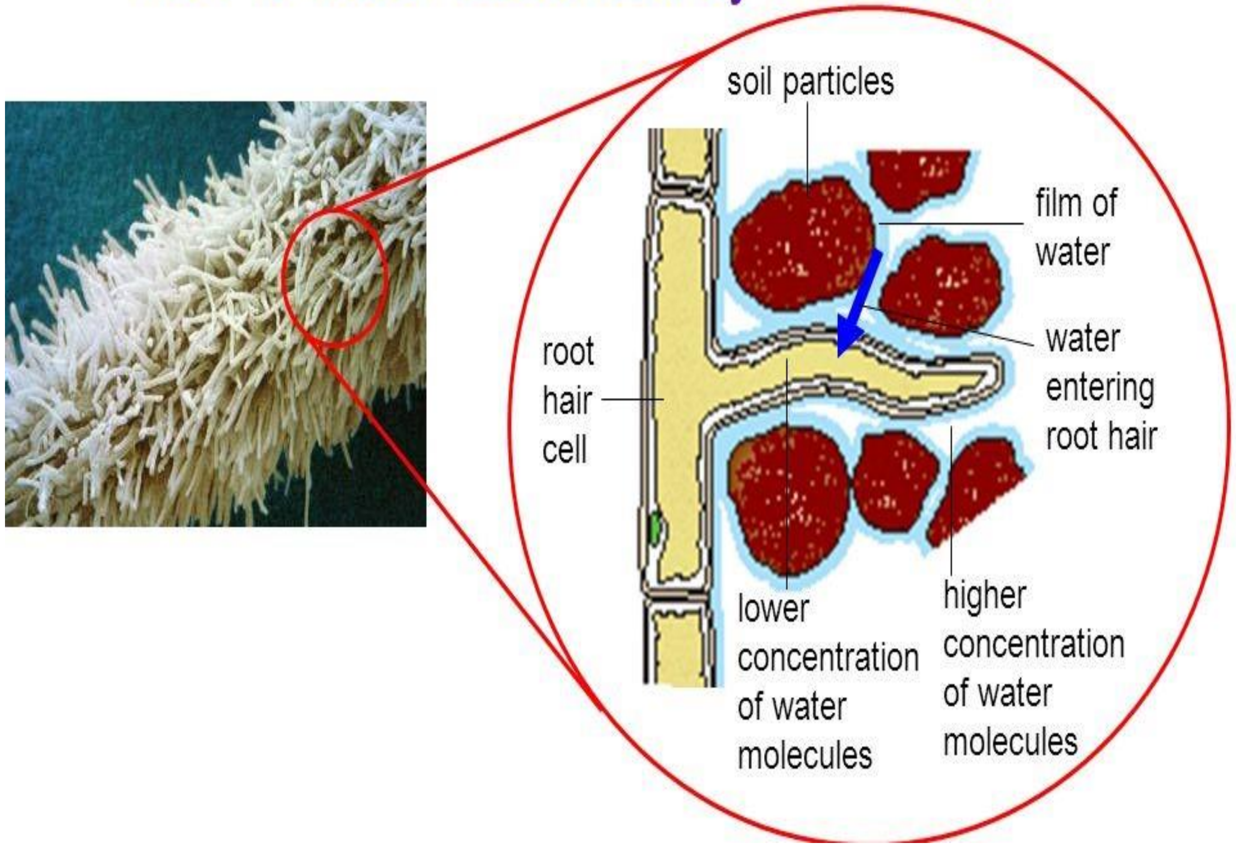




Root hair

Epidermal layer and root hair cell
→ Piliferous layer

- How is water absorbed by the roots?

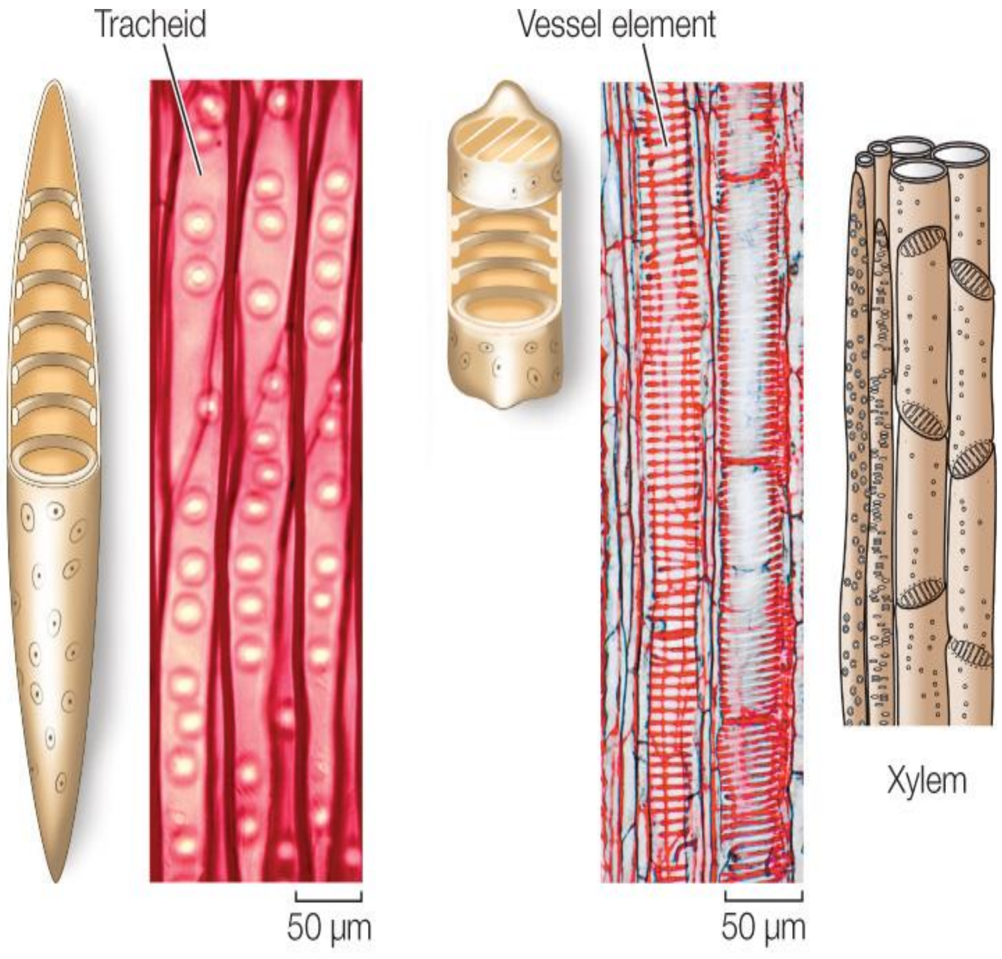


Water Transport Through the Xylem - 1

Xylem consists of two types of *tracheary elements*:

- *Tracheids*: They are present in both **angiosperms** and **gymnosperms**, as well as in ferns and other groups of vascular plants. Shape is elongated, spindle-shaped cells. Water flows between tracheids by means of numerous pits in their lateral walls.

- *Vessel elements*: They are found only in **angiosperms**, and a small group of gymnosperms (*Gnetales*). They are shorter and wider than tracheids with perforated end walls that form a *perforation plate*. Vessels also have pits on their lateral walls.



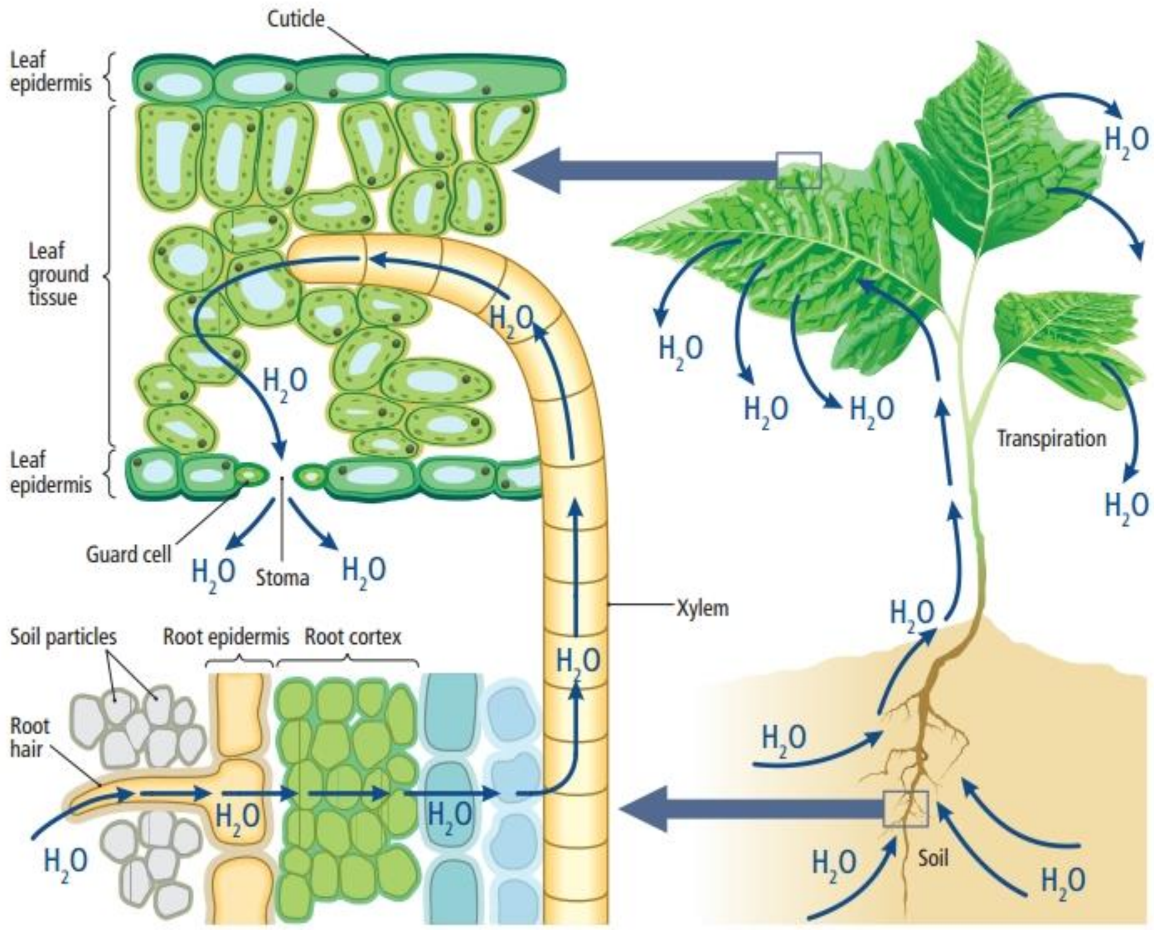
Tracheids: © Dr. John D. Cunningham/Visuals Unlimited, Inc.
Vessel elements: © J. Robert Waaland/Biological Photo Service.

Water Transport Through the Xylem - 2

- **Water movement through the xylem requires less pressure than movement through living cells.**
- **2 MPa pressure difference is needed to lift water 100 m to treetop.**
- ***Cohesion -Tension Theory* explains water transport in the xylem. So, water at the top of a tree develops a large tension *(a negative hydrostatic pressure)*, and this tension pulls water through the xylem. This mechanism is called the *Cohesion-Tension Theory* of sap ascent.**
- **Plants minimize the consequences of xylem cavitation *(sürtünme)*.**
- **Water evaporation in the leaf generates a negative pressure in the xylem.**

Water Movement from Leaf to Atmosphere-1

- **Only about *5% of the water loss from leaves* escapes through the cuticle, that means almost all of the water loss from leaves occures by diffusions of water vapor through the tiny *(very small)* pores of stomatal apparatus into the air spaces of the leaf, called as Transpiration.**
- **Water vapor diffuses quickly in air.**



Types of Transpiration

- **Stomatal** – from leaves through stomata
- **Cuticular** – through cuticle of leaf
- **Lenticular** – from lenticels (minute openings on the stem)

Stomatal Transpiration :

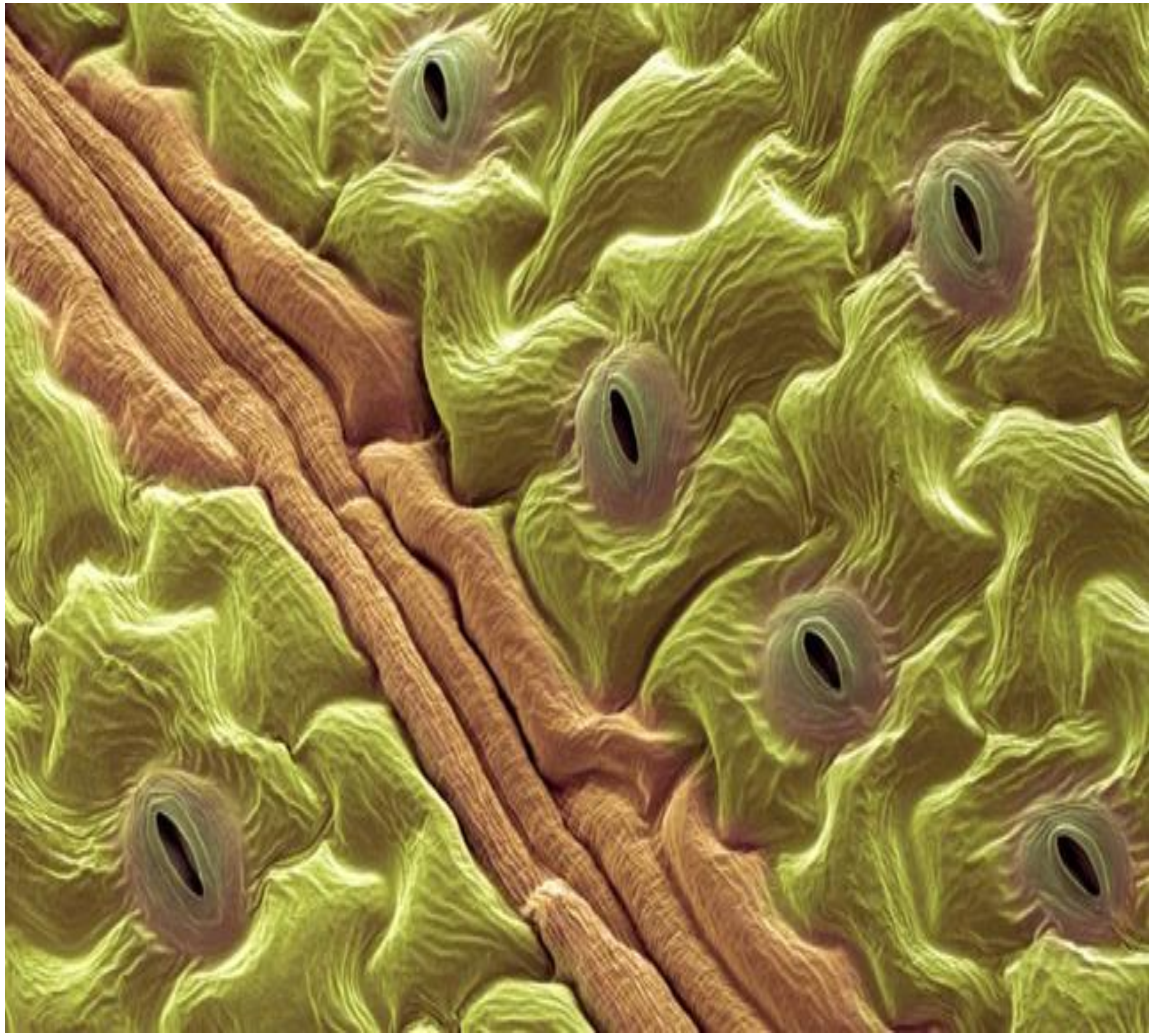
- Stomata are natural epidermal openings present on lower surface of leaf in dicots (rose, banyan) and on both surface in monocots (maize, grass)
- About 80 – 90% transpiration is through stomata
- Stomatal pores are guarded by two kidney-shaped cells called guard cells
- In daytime, stoma is open for intake of carbon dioxide
- Water vapor moves through stomata of leaf through veins

Water absorbed by roots reaches mesophyll cells in the surface of leaves → Surface of cells gives out water in the form of thin flim → Water Evaporates → Vapour formed saturates in intercelluar spaces → Diffuses, reaches substomatal space → Escapes through stomata

- Absence of stomata in submerged hydrophytes – hydrilla, vallisneria

Water Movement from Leaf to Atmosphere-2

- Cell walls of ***Guard Cells*** have specialized features. Guard cells are a pair of specialized epidermal cells which surround the stomatal pore that control the stomatal pore.
- An increase in guard cell turgor pressure opens the stomata.
- As water enters the guard cells, turgor pressure increases.
- Because of the elastic properties of their walls, guard cells can reversibly increase their volume **by 40 to 100%.**
- Such changes in cell volume lead to opening or closing of the stomatal pore.



Stomata

- Stomata (sing. stoma) = pores in a leaf, mostly on the undersurface
- Each pore is surrounded by a pair of guard cells
- Guard cells can change shape to open or close the stoma

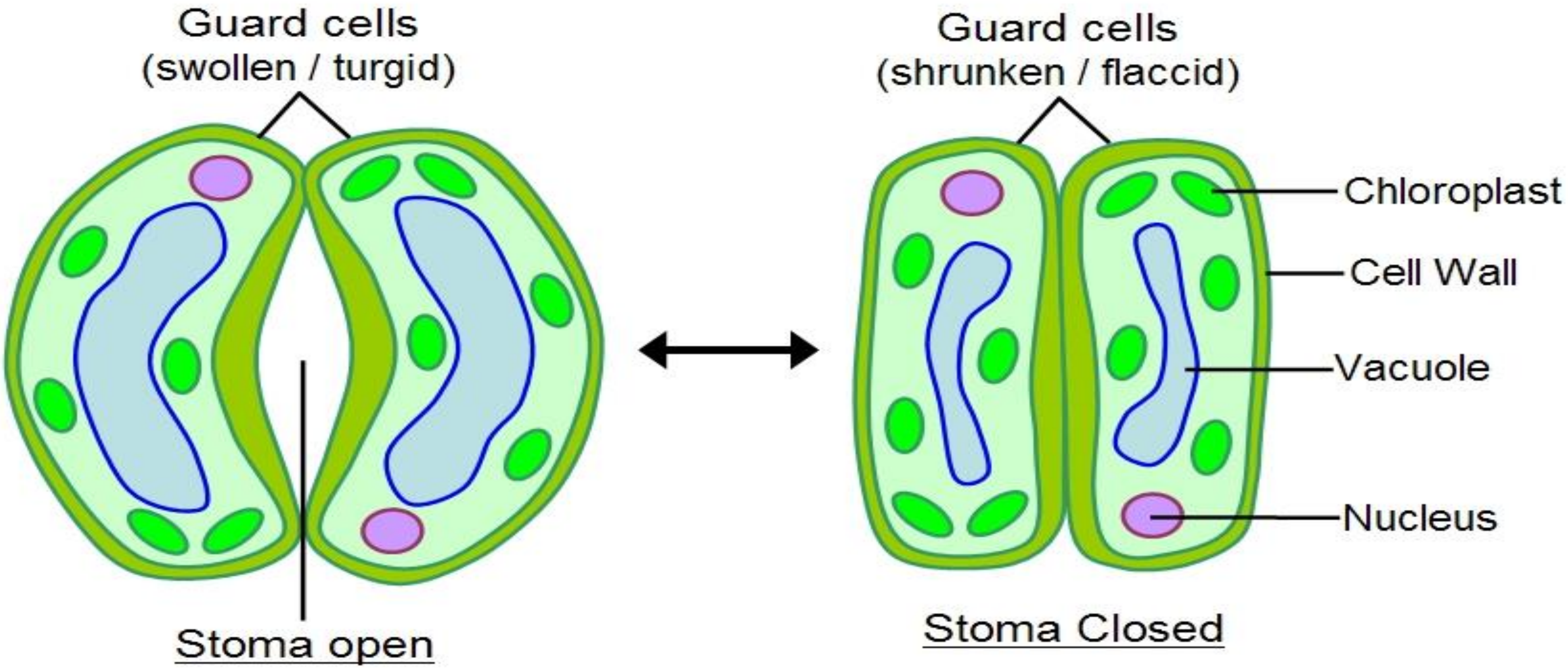


Table 7.1. Properties of water that make it important in horticulture.

Property	Value	Importance
Specific heat	1 cal/g/°C	Makes plants very resistant to sudden changes in the temperature of the surrounding environment
Heat capacity	Varies	Makes larger plants or tissues more resistant to frost injury
Heat of fusion	80 cal/g	Allows measurement of freezing point; frost protection using overhead irrigation
Heat of vaporization	540 cal/g	Provides cooling energy during transpiration
Density at 0°C		
Liquid	0.9998 g/cm^3	Allows ice to float and prevents bodies of water from freezing from the bottom up
Solid	0.931 g/cm^3	
Universal solvent		Provides medium for life as we know it
Hydroxyl bond		Absorbs infrared energy making water vapor a potent greenhouse gas

4.
Mineral Nutrition

THE 16 ESSENTIAL ELEMENTS REQUIRED FOR PLANT LIFE

Generally available to plants in sufficient quantities through air, soil, and water

BASIC NUTRIENTS

6 C	1 H	8 O
CARBON	HYDROGEN	OXYGEN

Available mostly through fertilizers

PRIMARY MACRONUTRIENTS

7 N	15 P	19 K
NITROGEN	PHOSPHORUS	POTASSIUM

Available through soil but usually not through fertilizers

SECONDARY MACRONUTRIENTS

20 Ca	12 Mg	16 S
CALCIUM	MAGNESIUM	SULFUR

MICRONUTRIENTS

26 Fe	25 Mn	30 Zn	29 Cu	5 B	42 Mo	17 Cl
IRON	MANGANESE	ZINC	COPPER	BORON	MOLYBDENUM	CHLORINE

Color-Coding Key: Elemental Classifications

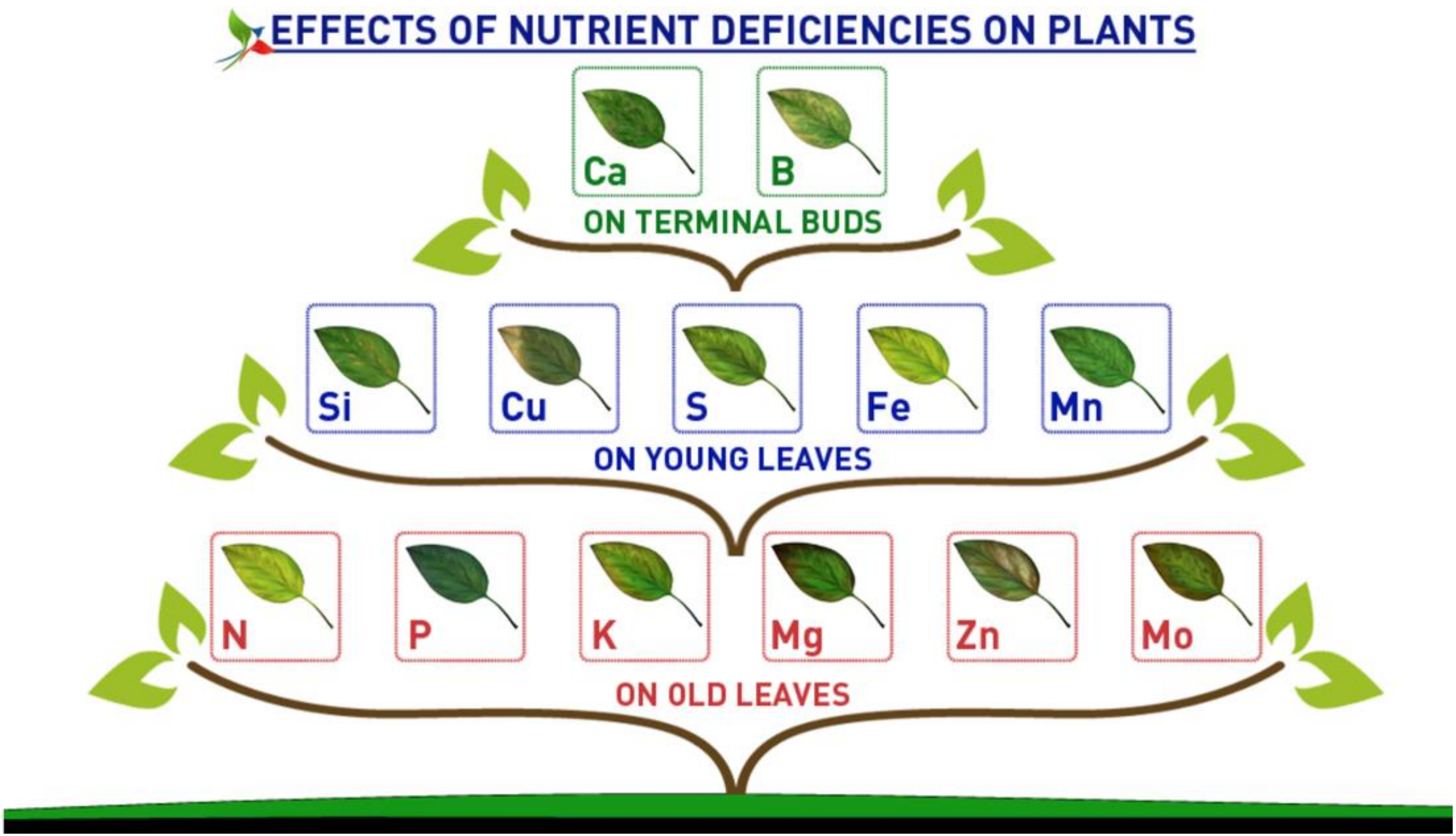
- NONMETALS
- ALKALI METALS
- ALKALINE EARTH METALS
- TRANSITION METALS

Table 37.1 Essential Elements in Plants

Element	Form Available to Plants	% Mass in Dry Tissue	Major Functions
Macronutrients			
Carbon	CO_2	45%	Major component of plant's organic compounds
Oxygen	CO_2	45%	Major component of plant's organic compounds
Hydrogen	H_2O	6%	Major component of plant's organic compounds
Nitrogen	NO_3^-, NH_4^+	1.5%	Component of nucleic acids, proteins, hormones, chlorophyll, coenzymes
Potassium	K^+	1.0%	Cofactor that functions in protein synthesis; major solute functioning in water balance; operation of stomata
Calcium	Ca^{2+}	0.5%	Important in formation and stability of cell walls and in maintenance of membrane structure and permeability; activates some enzymes; regulates many responses of cells to stimuli
Magnesium	Mg^{2+}	0.2%	Component of chlorophyll; activates many enzymes
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	0.2%	Component of nucleic acids, phospholipids, ATP, several coenzymes
Sulfur	SO_4^{2-}	0.1%	Component of proteins, coenzymes
Micronutrients			
Chlorine	Cl^-	0.01%	Required for water-splitting step of photosynthesis; functions in water balance
Iron	Fe^{3+}, Fe^{2+}	0.01%	Component of cytochromes; activates some enzymes
Manganese	Mn^{2+}	0.005%	Active in formation of amino acids; activates some enzymes; required for water-splitting step of photosynthesis
Boron	$H_2BO_3^-$	0.002%	Cofactor in chlorophyll synthesis; may be involved in carbohydrate transport and nucleic acid synthesis; role in cell wall function
Zinc	Zn^{2+}	0.002%	Active in formation of chlorophyll; activates some enzymes
Copper	Cu^+, Cu^{2+}	0.001%	Component of many redox and lignin-biosynthetic enzymes
Nickel	Ni^{2+}	0.001%	Cofactor for an enzyme functioning in nitrogen metabolism
Molybdenum	MoO_4^{2-}	0.0001%	Essential for symbiotic relationship with nitrogen-fixing bacteria; cofactor in nitrate reduction

Mineral Deficiencies

- **Inefficient supply of an essential element results in a nutritional disorder with characteristic deficiency symptoms.**
- ***Nitrogen, Phosphorus and Potassium* (N-P-K) *as primary macronutrients*** **can readily move from** ***leaf to leaf called*** **mobile; others, such as** ***Iron, Boron and Calcium*** **are relatively** ***immobile*****.**
- **If an essential element is** ***mobile*****, deficiency symptoms appear** ***first in older leaves*****.**
- **Deficiency of an** ***immobile*** **essential element will become evident first** ***in younger leaves*****.**


EFFECTS OF NUTRIENT DEFICIENCIES ON PLANTS
Ca
B
ON TERMINAL BUDS
Si
Cu
S
Fe
Mn
ON YOUNG LEAVES
N
P
K
Mg
Zn
Mo
ON OLD LEAVES

Deficiency Symptoms of Nutrient Elements

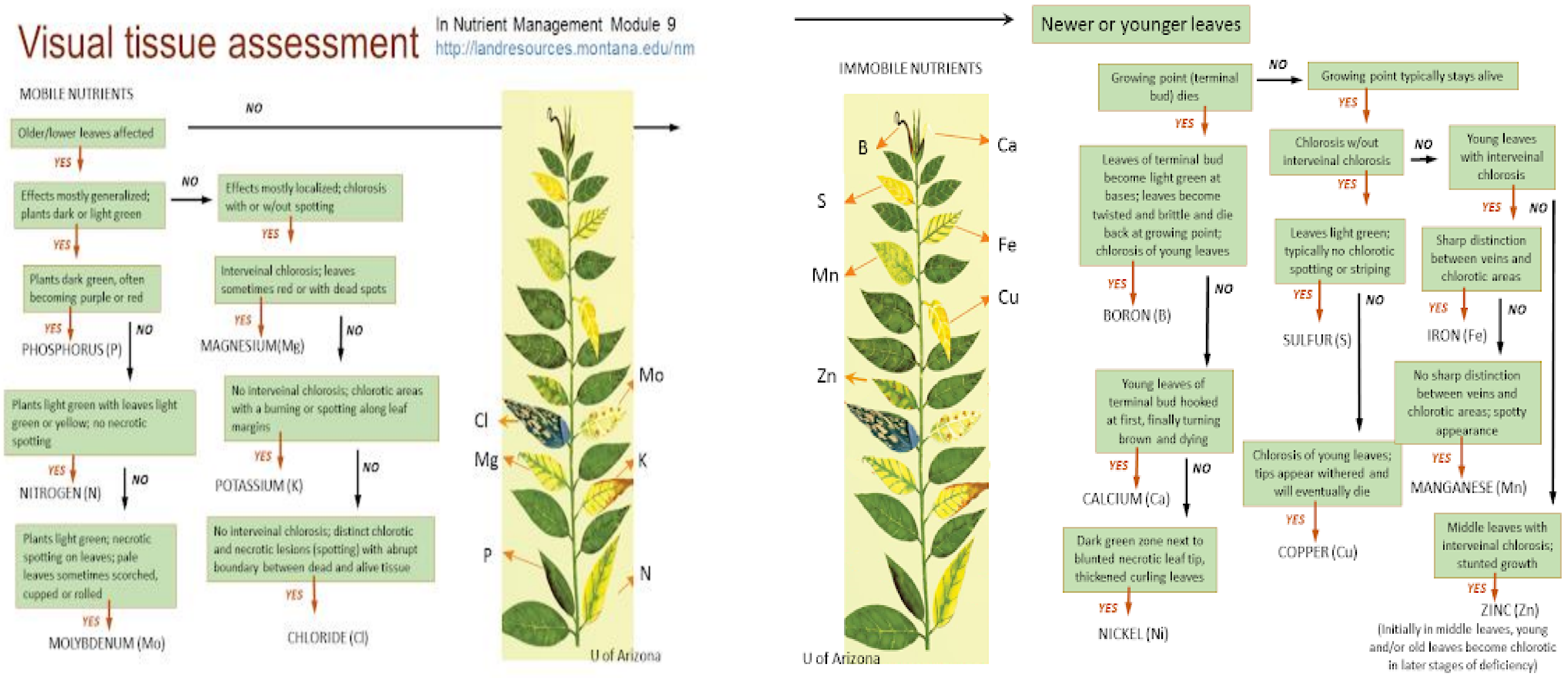
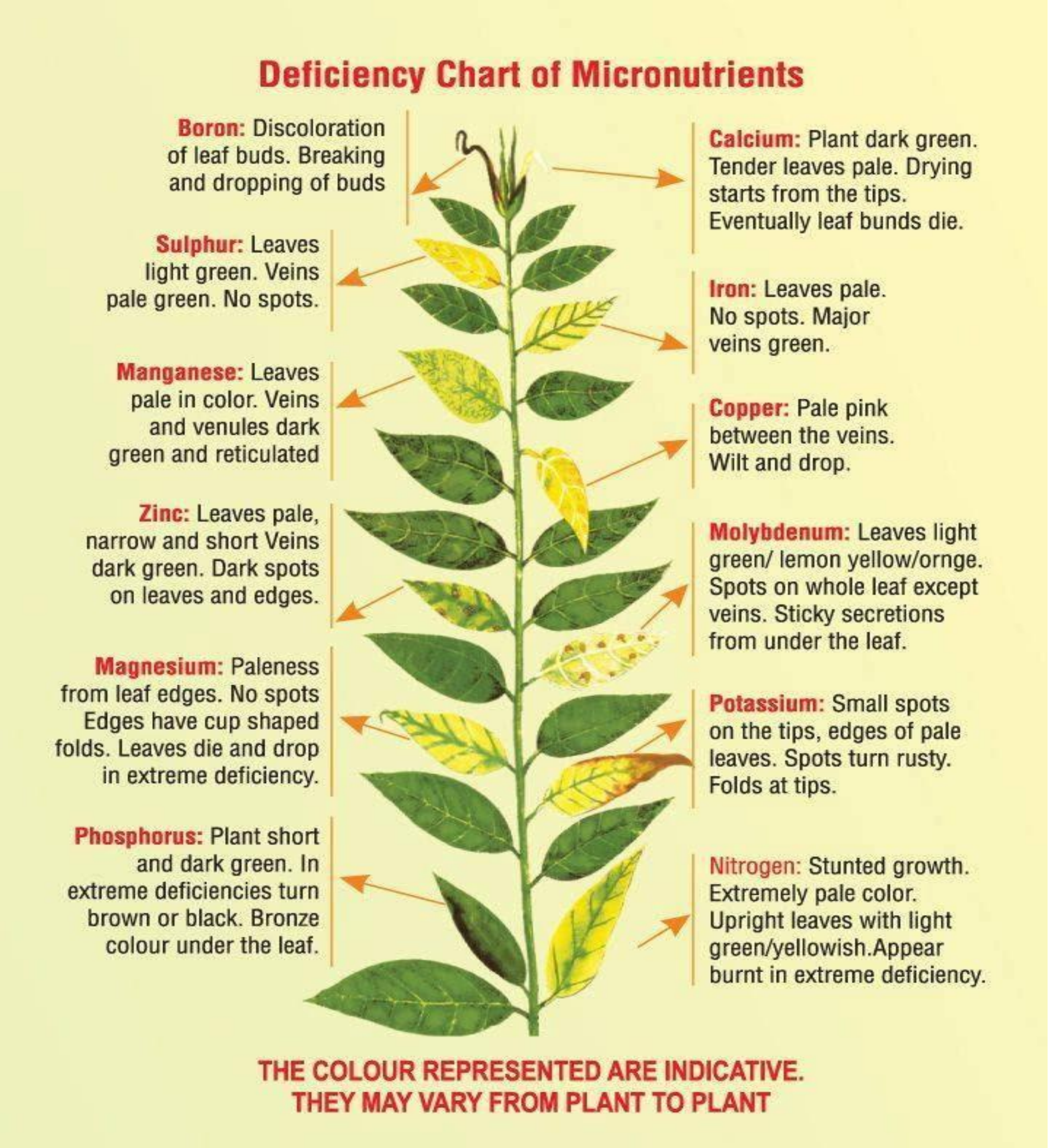


TABLE 5.4
Mineral elements classified on the basis of their mobility within a plant and their tendency to retranslocate during deficiencies

Mobile	Immobile
Nitrogen	Calcium
Potassium	Sulfur
Magnesium	Iron
Phosphorus	Boron
Chlorine	Copper
Sodium	
Zinc	
Molybdenum	

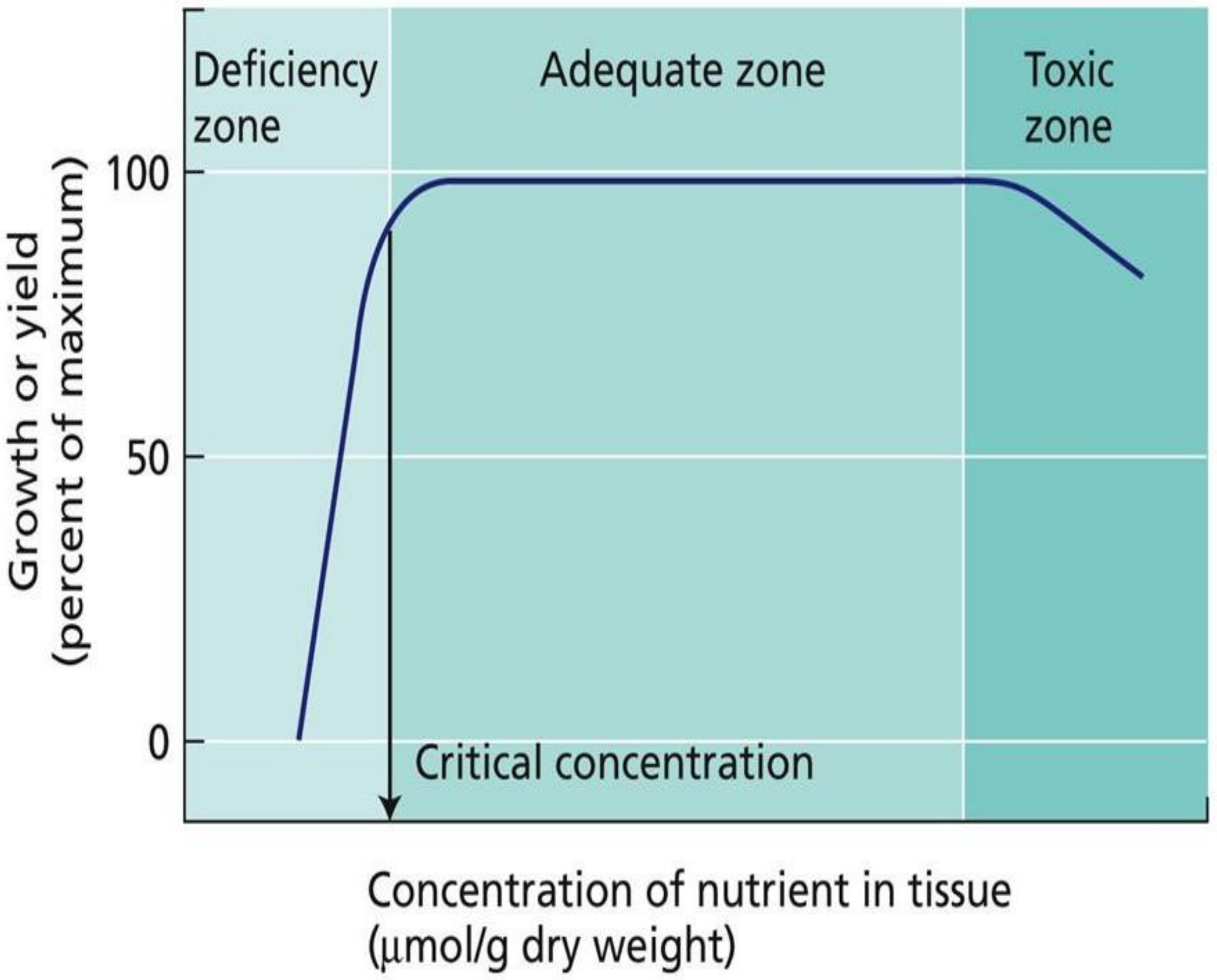
Note: Elements are listed in the order of their abundance in the plant.

Mobile – deficiency seen in old leaf
Immobile – deficiency seen in young leaf



Analyses of Plant Tissues to Reveal Mineral Deficiencies

- Proper use of plant tissue analysis can aid to understand the relationship between plant growth (or yield) and mineral concentration of plant tissue samples.
- Three zones may be defined in this relationship called as *deficiency zone*, *adequate zone*, and *toxic zone*.
- Plant analysis *(petiole and leaf blade)* is useful in establishing *fertilizer schedules* to ensure sustainable yields and crop quality of many crops.



Fertilization & Fertilizers

Fertilization

- Many traditional and commercial farms promote the recycling of mineral elements.
- Crop plants first absorb the mineral nutrients from the soil, then humans and animals consume grown plants, and finally crop residues and manu from humans and animals return to the soil *(Nutrient Cycle)*.
- Main losses of nutrients occur from leaching that carries dissolved ions away with drainage water particularly in acidic soils.
- In acid soils, leaching may be decreased by addition of lime-a mix of CaO, $CaCO_3$, and $CaSO_4.2H_2O$ *(gypsum)* to make the soil *more alkaline* near to neutral pH.

Mineral/Chemical Fertilizers

- They contain inorganic salts of *nitrogen, phosphorus, and potassium.*
- Fertilizers that contain only one of these three macronutrients are termed "*Straight Fertilizers*", such as *Superphosphate (45% P_2O_5), Ammonium Nitrate (33%).*
- Fertilizers that contain two or more macroelements are called "*Composed or Mixed Fertilizers*" such as *DAP, MAP, KNO_3, K_2SO_4, 15-15-15, 20-20-0.*
- Soil pH affects the availability of all mineral nutrients.
- Addition of *Lime* can raise *pH of acidic soils*.
- Addition of *Elemental Sulfur* can lower pH of *alkaline soils*.

Nutrient Solutions

- Over the years, many formulations have been used for nutrient solutions.
- A modified *Hoagland* solution contains all of the known mineral elements needed for rapid plant growth.
- The concentrations of these elements are set at the highest possible levels without producing toxicity symptoms or salinity stress.
- A significant problem with nutrient solutions is maintaining the *availability of iron.*
- *Precipitation of the iron* out of solution makes it physically unavailable to the plant, unless iron salts are added at frequent intervals.
- Modern nutrient solutions use chemicals such as *EthylenDiamineTetraacetic Acid (EDTA) or DiethlyleneTriaminePentaacetic Acid (DTPA) "also known as pentetic acid" as "Chelating" agents that* are chemical compounds that react with metal ions to form a stable, water-soluble complex.

TABLE 5.3
Composition of a modified Hoagland nutrient solution for growing plants

Compound	Molecular weight	Concentration of stock solution	Concentration of stock solution	Volume of stock solution per liter of final solution	Element	Final concentration of element	
	g mol^{-1}	mM	g L^{-1}	mL		µM	ppm
Macronutrients							
KNO_3	101.10	1,000	101.10	6.0	N	16,000	224
$Ca(NO_3)_2 \cdot 4H_2O$	236.16	1,000	236.16	4.0	K	6,000	235
$NH_4H_2PO_4$	115.08	1,000	115.08	2.0	Ca	4,000	160
$MgSO_4 \cdot 7H_2O$	246.48	1,000	246.49	1.0	P	2,000	62
					S	1,000	32
					Mg	1,000	24
Micronutrients							
KCl	74.55	25	1.864	2.0	Cl	50	1.77
H_3BO_3	61.83	12.5	0.773		B	25	0.27
$MnSO_4 \cdot H_2O$	169.01	1.0	0.169		Mn	2.0	0.11
$ZnSO_4 \cdot 7H_2O$	287.54	1.0	0.288		Zn	2.0	0.13
$CuSO_4 \cdot 5H_2O$	249.68	0.25	0.062		Cu	0.5	0.03
H_2MoO_4 (85% MoO_3)	161.97	0.25	0.040		Mo	0.5	0.05
NaFeDTPA (10% Fe)	468.20	64	30.0	0.3–1.0	Fe	16.1–53.7	1.00–3.00
Optional[a]							
$NiSO_4 \cdot 6H_2O$	262.86	0.25	0.066	2.0	Ni	0.5	0.03
$Na_2SiO_3 \cdot 9H_2O$	284.20	1,000	284.20	1.0	Si	1,000	28

Source: After Epstein 1972.

Note: The macronutrients are added separately from stock solutions to prevent precipitation during preparation of the nutrient solution. A combined stock solution is made up containing all micronutrients except iron. Iron is added as sodium ferric diethylenetriaminepentaacetate (NaFeDTPA, trade name Ciba-Geigy Sequestrene 330 Fe; see Figure 5.2); some plants, such as maize, require the higher level of iron shown in the table.

Organic Fertilizers

- **They originate from the residues of plant and animal, including *vermicompost*** *(can be defined as the biological breakdown (decomposition) of organic wastes, via the joint action of earthworms and microorganisms. It is a term that can be used interchangeably with **worm composting**)*.
- **Plant and animal residues contain organic forms of many nutrient elements.**
- **Before using these fertilizers, organic compounds must be broken down, usually by the action of soil microorganisms through a process called *mineralization*.**
- ***Mineralization* depends on *temperature, humidity* and *oxygen availability*, and the *type and number of microorganisms* present in the soil.**
- **Organic fertilizers *improve the physical soil structure, water retention capacity* during drought, *drainability* in wet soils.**

Foliar Nutrition

- Some mineral nutrients, *particularly micro nutrients* can be applied to the leaves as sprays *(foliar application).*
- This method can have following agronomic advantages over the application to the soil.

1. They can reduce the lag *(delay)* time between application and uptake,
2. They can also solve the problem of restricted uptake of a nutrient from the soil *(micronutrients such as Fe, Zn, Mn, Cu).*

- Nutrient uptake by leaves is most effective when nutrient solution remains on the leaf as a thin film by using surfactant chemicals such as *STARWET, TARWET, NU-FILM-17, TWEEN-20.*
- Spraying on cool days or in the evening helps to alleviate burning or scorching problems.
- Foliar nutrition can be combined with regular spraying programmes against pests & diseases.

5.
Soils, Roots and Microorganisms

Soil Phases

- Soil is a complex *physical*, *chemical*, and *biological* substrate that contains *solid*, *liquid*, and *gaseous* phases.
- Inorganic particles of the *solid phase* provide a reservoir of *potassium*, *calcium*, *magnesium* and *iron*, also organic compounds containing *nitrogen*, *phosphorus* and *sulfur*.
- *Liquid phase* of the soil constitutes the soil solution which contains *dissolved mineral ions*.
- *Gases* such as *oxygen*, *carbon dioxide* and *nitrogen* are dissolved in soil solution.

Inorganic Soil Particles

- ***Gravel*** **has particles** ***larger than 2 mm.***
- ***Coarse sand*** **has particles** ***between 0,2-2 mm.***
- ***Fine sand*** **has particles** ***between 0,02-0,2 mm.***
- ***Silt*** **has particles** ***between 0,002-0,02 mm.***
- ***Clay*** **has particles** ***smaller than 0,002 mm.***

Negatively Charged Soil Particles

- ***Inorganic and organic soil particles have predominantly negative charges on their surfaces.***
- **Many *inorganic soil particles* are crystal lattices *(structure)* that are *tetrahedral* *(with four faces)* arrangements of the cationic forms of *aluminum (Al^{+3})* and *silicon (Si^{+4})*.**
- **When cations of lesser charge *(NH_4^{+1}, K^{+1}, Ca^{+2}, Mg^{+2})* replace *Al^{+3}* and *Si^{+4}*, inorganic soil particles become *negatively charged*.**
- ***Organic soil particles* originate from the residues of microbial decomposition of dead plants, animals and microorganisms.**
- ***Negative charges of organic particles* result from *dissociation of hydrogen ions from carboxylic acid and phenolic groups* present in this component of the soil.**

Adsorption of Mineral Nutrients-*Cations*

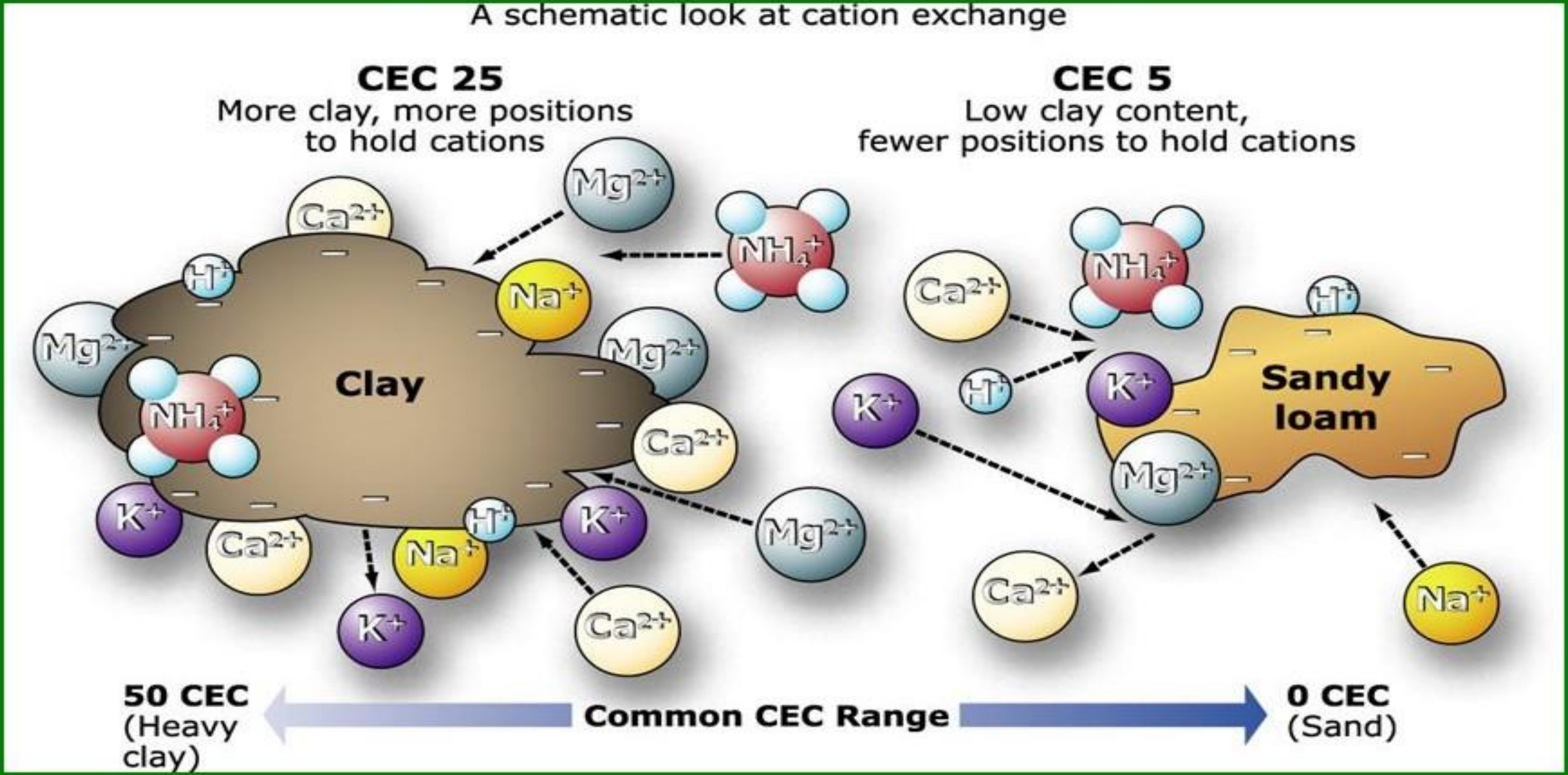
- Mineral cations such as ***ammonium (NH_4^+)*** and ***potassium (K^+)*** adsorb to the negative surface charges of inorganic or organic soil particles.
- This cation adsorption is an important factor in soil fertility. Because, mineral cations adsorbed on the surface of soil particles are not easily lost when the soil is leached by water, and they provide a nutrient reserve available to plant roots.

- Mineral nutrients adsorbed in this way can be replaced by other cations known as ***cation exchange***.
- The degree that a soil can absorb and exchange ions is termed its ***Cation Exchange Capacity (CEC)***, and is highly dependent on the soil type.
- A soil with ***higher CEC*** generally has larger reserve of mineral nutrients.

CEC of Soil Types

Soil & Soil Components	CEC value (meq/100g)
Soil Texture	
Pure Sand	1-5
Fine Sandy Loam	5-10
Loam	5-15
Clay Loam	15-30
Organic Rich Soils	50-100
Pure Organic Matter	200-400
Clay Type	
Kaolinite	3-15
Illite	15-40
Montmorillonite	80-100

Cation Exchange Capacity



Adsorption of Mineral Nutrients-*Anions*

- Mineral anions such as nitrate *(NO_3^-)* and chloride *(Cl^-)* are naturally repelled *(itilmek)* by the negative charge on the surface of soil particles and remain dissolved in soil solution. So, the *Anion Exchange Capacity (AEC)* of most agricultural soils is of minor importance.

- Among anions, ***nitrate*** remains mobile in the soil solution, where it is susceptible to leaching by water moving through the soil.

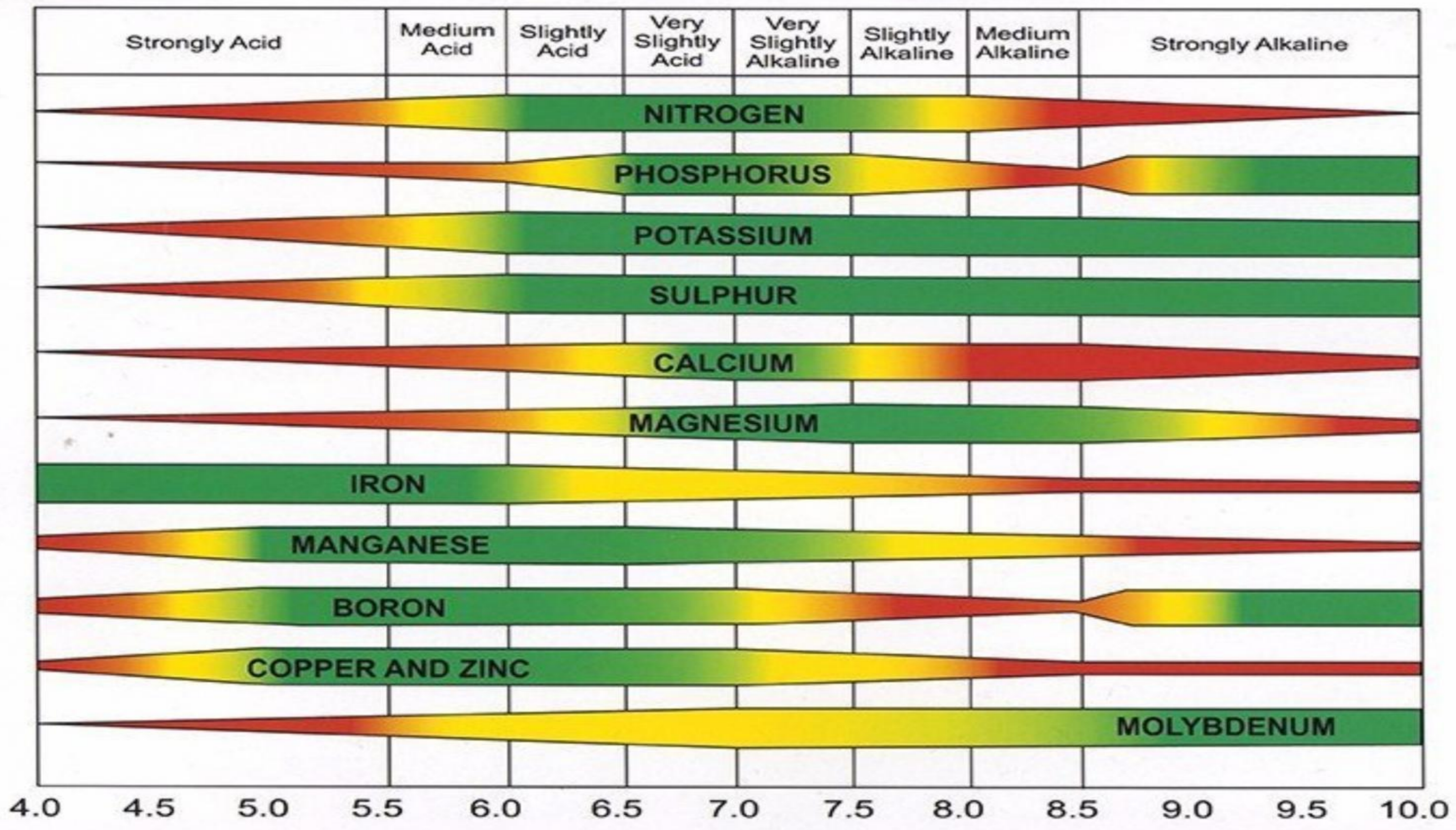
- ***Phosphate ions ($H_2PO_2^{-2}$)*** may bind the soil particles ***containing aluminium or iron***, because the ***positively charged iron (Fe^{+2},Fe^{+3})*** and ***aluminium ions (Al^{+3})*** have ***hydroxyl (OH^-)*** groups that ***exchange with phosphate***. As a result, ***phosphate*** can be tightly bound, and its mobility and availability in soil can limit plant growth.

- ***Sulfate (SO_4^{-2})*** in the presence of calcium ***(Ca^{+2})*** forms ***gypsum ($CaSO_4.2H_2O$)***. ***Gypsum*** is only slightly soluble, but it ***releases sufficient sulfate*** to support plant growth. Since most alkaline soils contain substantial amounts of calcium, sulfate mobility in these soils is low, so ***sulfate*** is not highly susceptible to leaching.

Soil pH

- Hydrogen ion concentration (pH) is an important property of soils.
- pH affects the growth of plant roots and soil microorganisms.
- Root growth is generally favored in *slightly acidic soils (pH: 5,5-6,5).*
- While *fungi* generally predominate in *acidic soils*; *bacteria* become more prevalent in *alkaline soils*.
- Soil pH determines the availability of soil nutrients.
- Acidity promotes the weathering of rocks that releases *K^+, Mg^{++}, Ca^{++}, and Mn^{++}* and increases the *solubility of phosphates (H_2PO_2), carbonates ($CO_3{}^{-2}$), and sulfates ($SO_4{}^{-2}$).*
- Increasing the solubility facilitates their availability to roots.

How soil pH affects availability of plant nutrients.



SOURCE: https://www.emporiumhydroponics.com/what-is-ph-1-to-14

Excessive Amounts of Minerals in the Soil

- Excess minerals in soils can be a major problem in arid and semi-arid regions, where is insufficient to leach the mineral ions.
- ***Sodium chloride*** **(NaCl)** and ***sodium sulfate*** **(Na_2SO_4)** are most common salts in saline soils.
- Irrigation increases soil salinization if insufficient water is used.
- In saline soils, plants encounter ***salt stress***.
- Plants can be divided in three groups for their adaptations to ***saline soil*** conditions;

1. ***Sensitive***, 2. ***Salt-tolerant***, 3. ***Halophytes.***

- Mechanism of salinity tolerance are complex, involving ***molecular synthesis***, ***enzyme induction***, and ***membrane transport***.
- Another important problem with excess minerals is the ***accumulation of heavy metals***, including ***zinc*** *(65)*, ***copper*** *(63)*, ***cobalt*** *(59)*, ***nickel*** *(59)*, ***mercury*** *(200)*, ***lead*** *(207)*, ***cadmium*** *(112)*, ***silver*** *(108)* ***and chromium*** *(52)* which can cause severe toxicity in plants as well as humans.

Plants Can Develop Extensive Root System

- Ability of plants to obtain water and mineral nutrients from the soil is related to their capacity to develop an extensive root system.
- **Roots of annual crop plants** can grow between *0,1 and 2,0 m* in depth and extend laterally to distances of *0,3-1,0 m*.
- Major **root systems of fruit trees** planted *1 m apart* reach a *total length of 12 to 18 km per tree*.
- In natural ecosystems, annual production of roots may easily surpass *(exceed)* the shoots.
- Root growth depends on the availability of water and minerals in microenvironment of the root, so called ***rizosphere.***
- If *rizosphere* is poor in nutrients and too dry, root growth is slow.

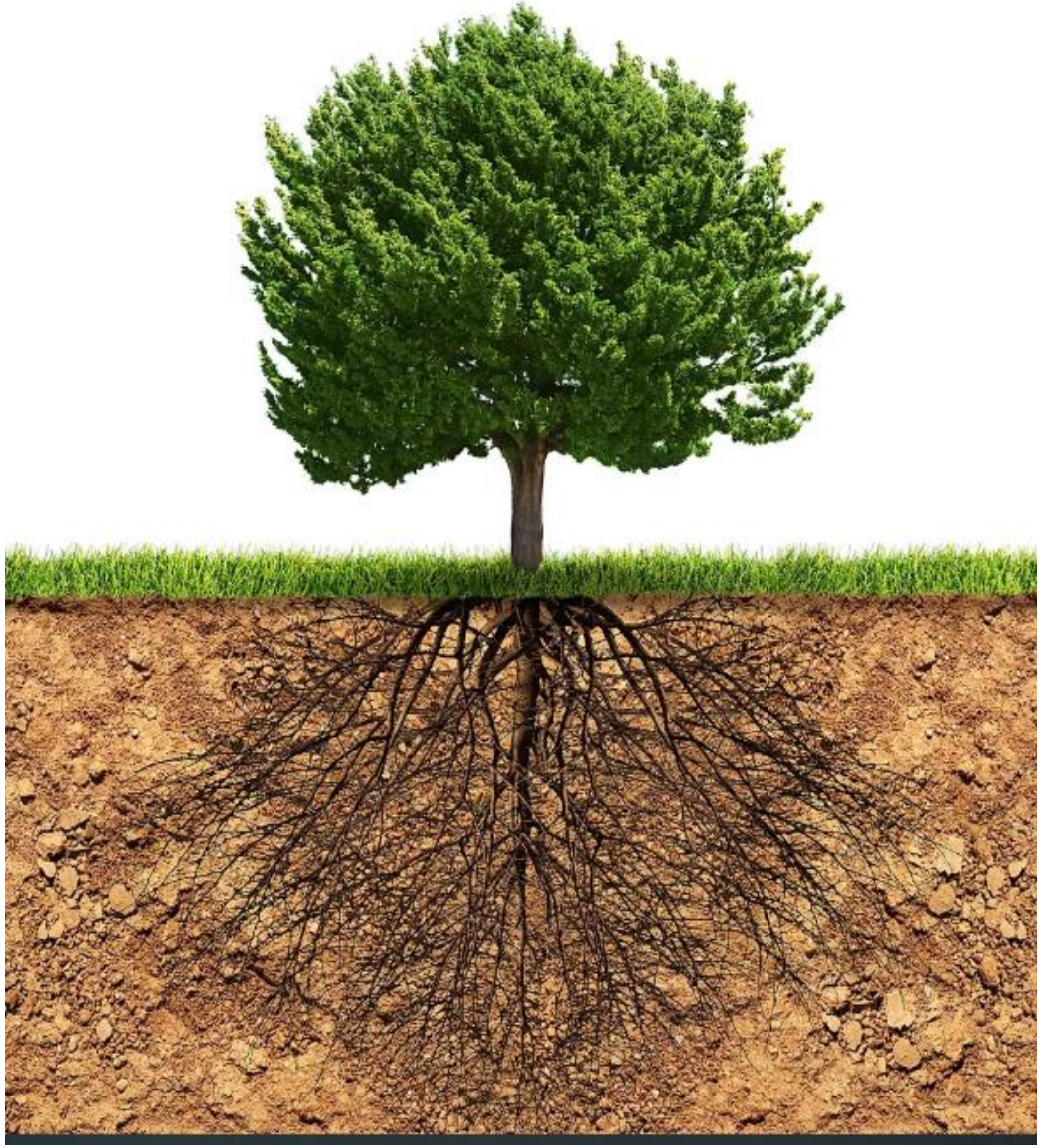
Root Systems of *Monocots*

- **Form of root system differ greatly among plant species.**
- **In *monocots,* root development starts with the emergence of *3-6 primary root axes* from germinated seeds.**
- **With further growth, plant extends new adventitious roots called *nodal roots*.**
- **Over time, primary and nodal root axes grow and branch extensively to form a *complex fibrous root system.***
- ***In fibrous root systems*, all the roots generally have the same diameter, so it is difficult to distinguish a main root axes.**

Root Systems of *Dicots*

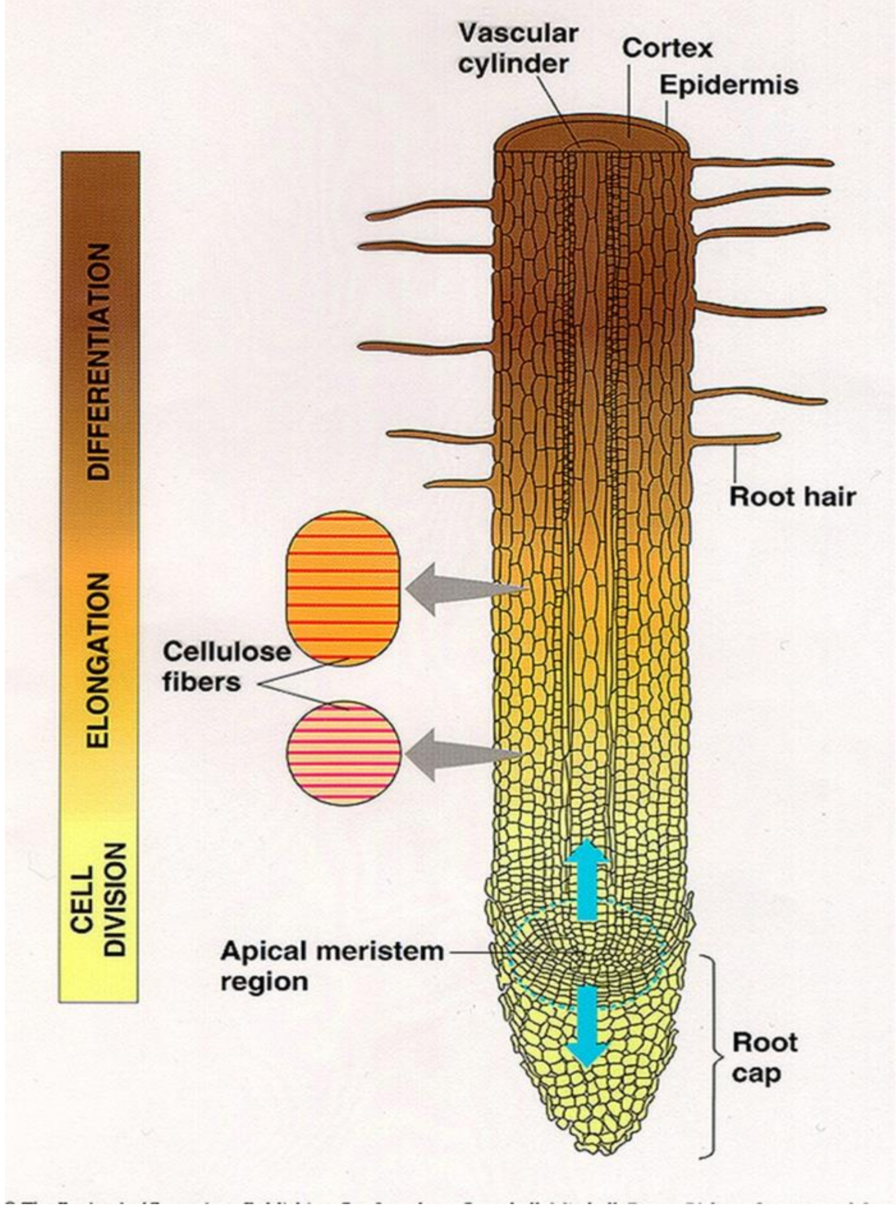
- ✓ In contrast to monocots, *dicots* develop a main single root axis, called *taproot* which may thicken as a result of secondary cambial activity.

- ✓ *Lateral roots* develop from this main root axis to form an extensively branched root system.



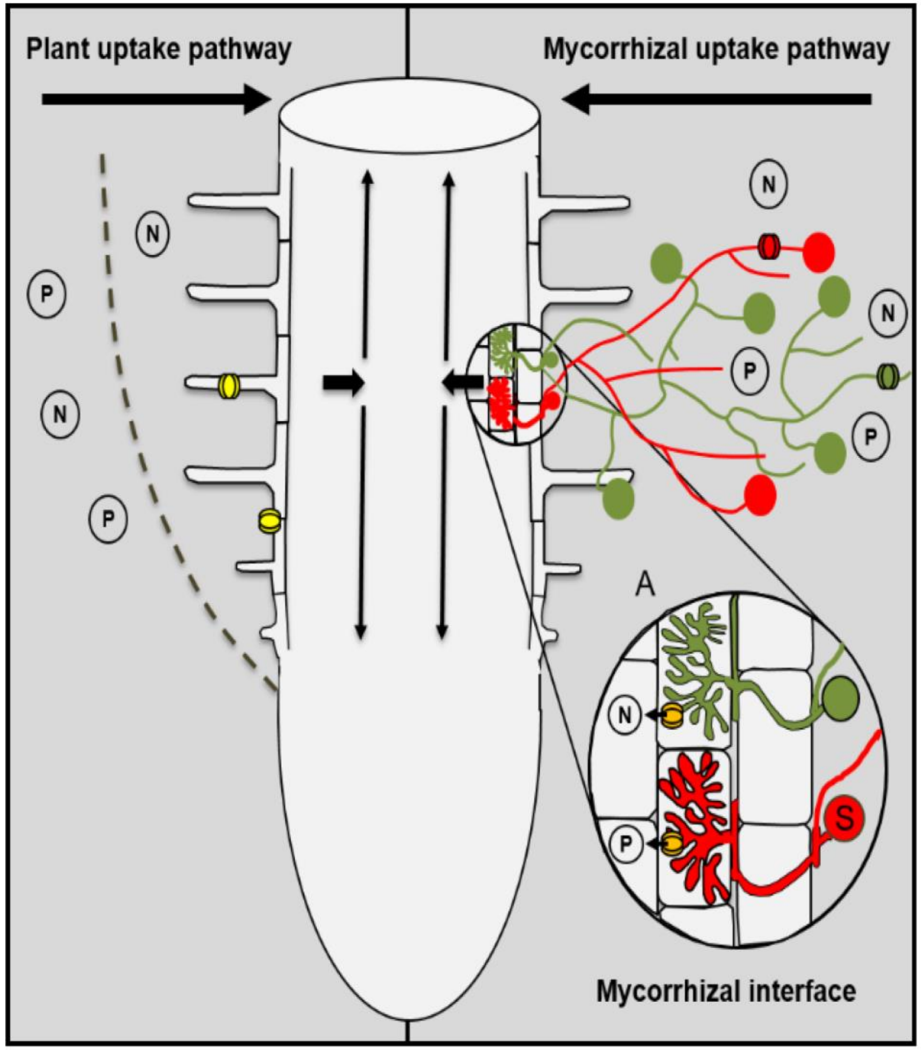
Apical Region of a Plant Root

- ***Meristematic (Cell Division) Zone:*** Cells in this zone divide both in direction of root base to form ***older tissues*** and root apex to form ***root cap*** which protects the delicate meristematic cells. Root cap also secretes a gelatinous material called ***mucigel*** which commonly surrounds the root tip.
- ***Elongation Zone:*** Begins ***0,7-1,5 mm*** from apex. In this zone, cells elongate rapidly to produce a central ring of the cells called ***endodermis*** which divides the roots into two regions as ***cortex*** toward the outside and ***stele*** toward the inside. ***Stele*** contains the vascular elements; ***phloem*** transport metabolites from the shoot to the roots, and ***xylem*** transport water and solutes to the shoot.
- ***Maturation (Differentiation) Zone:*** This is the region of ***root hairs*** which absorbing of water and solutes. After first appear of root hairs, the ***xylem*** develops the capacity to translocate of water and solutes to the shoot.



Mycorrhizal Fungi Facilitate Nutrient Uptake

- Roots of much of the world’s vegetation associated with *mycorrhizal fungi*.
- Plants from families *Cruciferae* (*cabbage*), *Chenopodiaceae* (*spinach*) and *Proteaceae* (*macademia nuts*), and *aquatic plants* rarely have *mycorrhiza*.
- *Mycorrhiza* are also absent from roots in *very dry, saline, or flooded soils*, or where soil fertility is exteremly high or low.
- *Mycorrhizal fungi* are composed of fine, tubular filaments called *hyphae*. Mass of hypae forms the body of fungus, called *mycelium*.
- There are two major classes of mycorrhizal fungi; 1. Ectotrophic, 2. Vesicular orbiscular *((küresel kesecikli).*
- Nutrients move from *mycorrhizal fungi to the root cells*.
- Mycorrhizal association in well-fertilized soils may shift from a symbiotic relationship to a parasitic one in that fungus still obtains carbohydrates from the host plant, but host plant no longer benefits from improved nutrient uptake efficiency.



Key Benefits of Mycorrhizal Fungi

Root System Growth

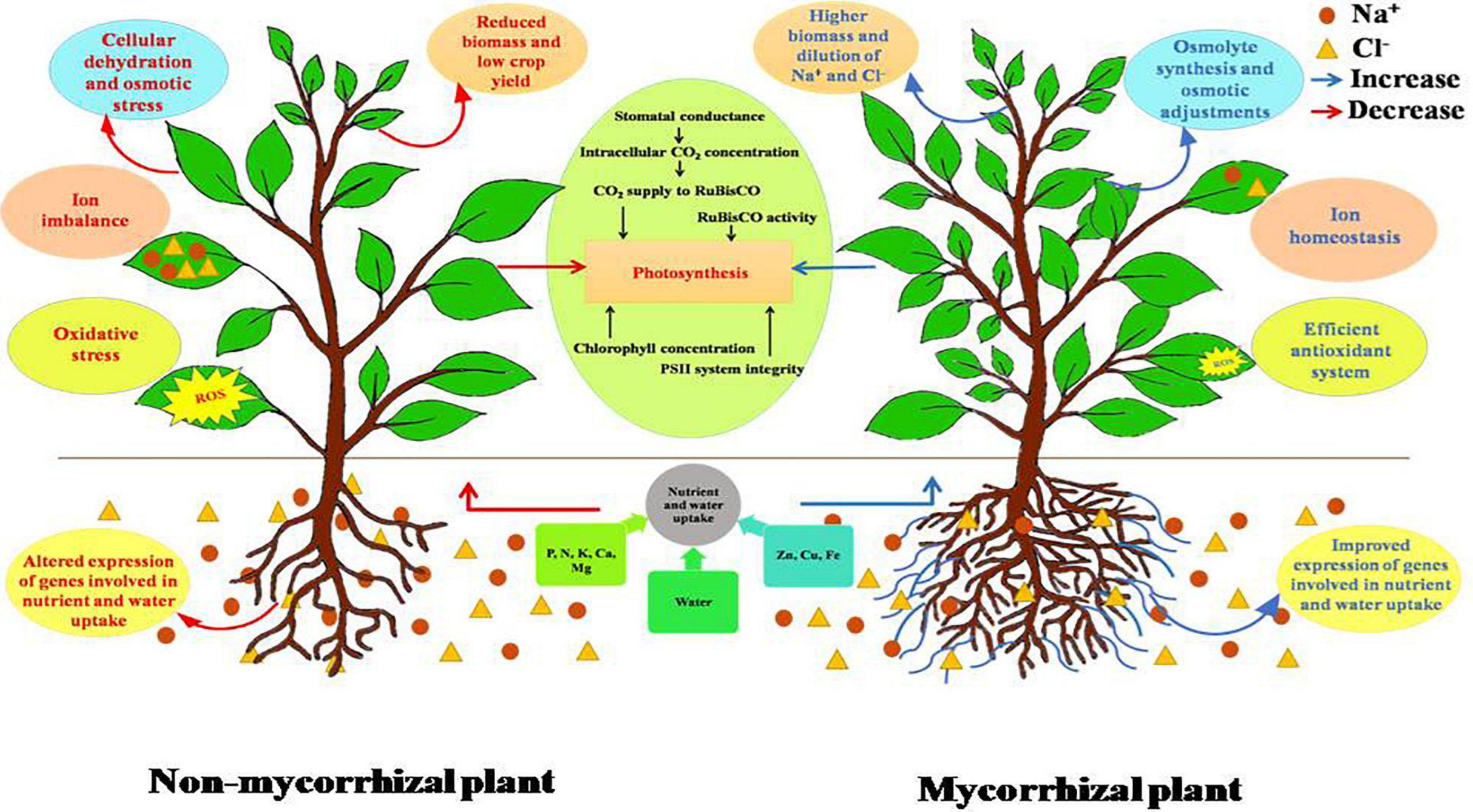
- Mycorrhizal fungi support faster plant establishment
- Mycorrhizal hyphae access water and nutrients beyond the root zone and deliver them to the plant's vascular network
- Increases absorption area by as much as 50 times
- Increases overall root biomass

Nutrient Efficiency

- Mycorrhizal hyphae absorb and actively deliver nutrients directly to the roots
- Improves utilization of soil nutrients including:
  - Nitrogen
  - Phosphorus
  - Potassium
  - Micronutrients

Water Absorption

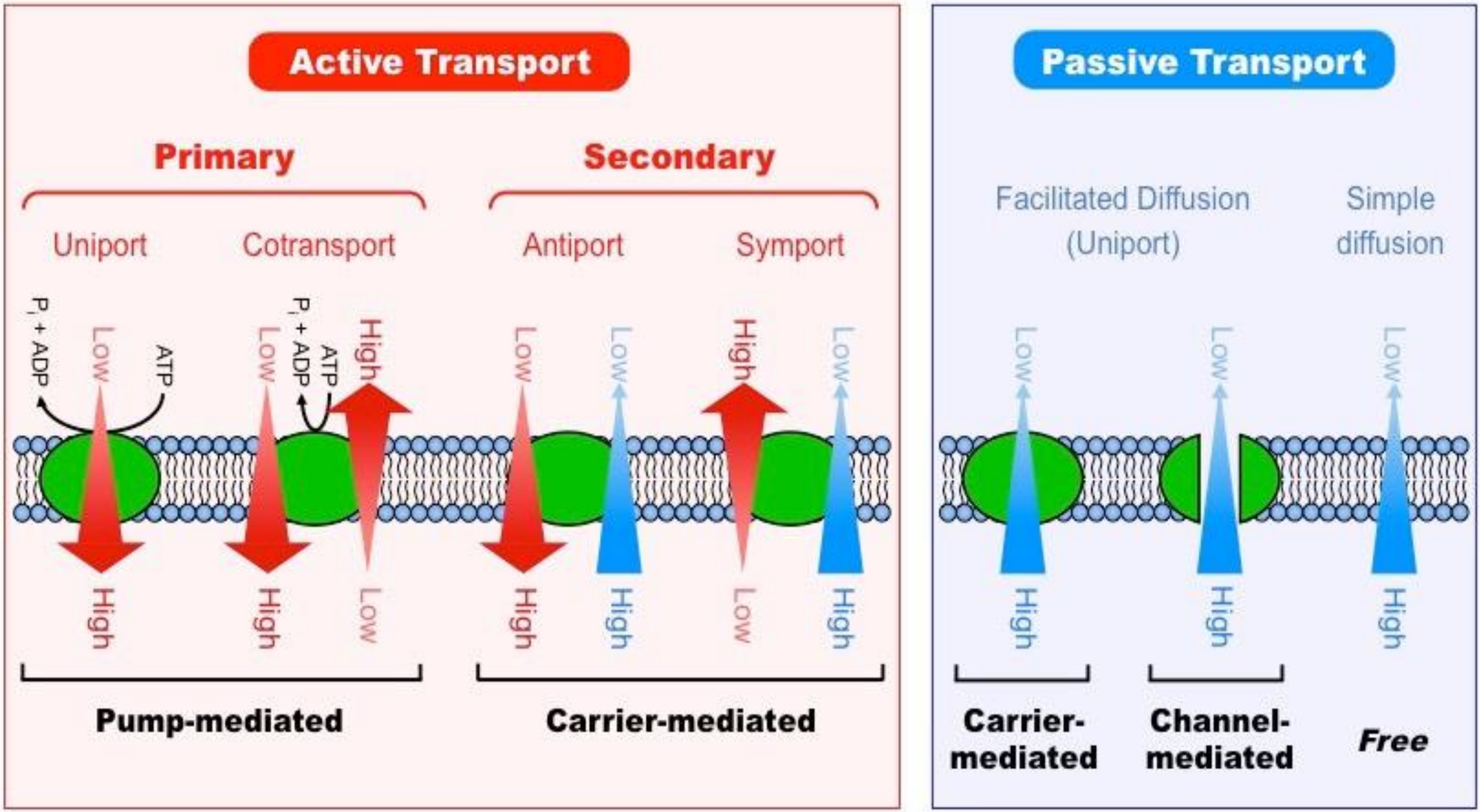
- Mycorrhizal hyphae absorb and transport soil moisture from beyond the root zone to the plant's roots
- The mycorrhizal symbiosis increases the plant's effective water utilization capability:
  - Improved tolerance to stress
  - Greater resistance to drought



Cellular dehydration and osmotic stress
Reduced biomass and low crop yield
Ion imbalance
Oxidative stress
ROS
Stomatal conductance
Intracellular CO_2 concentration
CO_2 supply to RuBisCO
RuBisCO activity
Photosynthesis
Chlorophyll concentration
PSII system integrity
Higher biomass and dilution of Na^+ and Cl^-
Osmolyte synthesis and osmotic adjustments
Ion homeostasis
Efficient antioxidant system
ROS
Na^+
Cl^-
Increase
Decrease
Nutrient and water uptake
P, N, K, Ca, Mg
Water
Zn, Cu, Fe
Altered expression of genes involved in nutrient and water uptake
Improved expression of genes involved in nutrient and water uptake
Non-mycorrhizal plant
Mycorrhizal plant

Passive & Active Transport of Solutes

- Movement of molecules by diffusion always proceeds spontaneously, ***down a gradient of concentration or chemical potential***, until equilibrium is reached.
- This spontaneous ***downhill*** movement of molecules is termed ***passive transport***.
- Movement of substances ***against up a gradient of chemical potential*** is termed ***active transport***.
- It is not spontaneous, and requires an application of cellular energy ***(ATP).***



Active Transport
Primary
Secondary
Uniport
Cotransport
Antiport
Symport
P_i + ADP
ATP
Low
High
Pump-mediated
Carrier-mediated
Passive Transport
Facilitated Diffusion (Uniport)
Simple diffusion
Carrier-mediated
Channel-mediated
Free

6. Photosynthesis

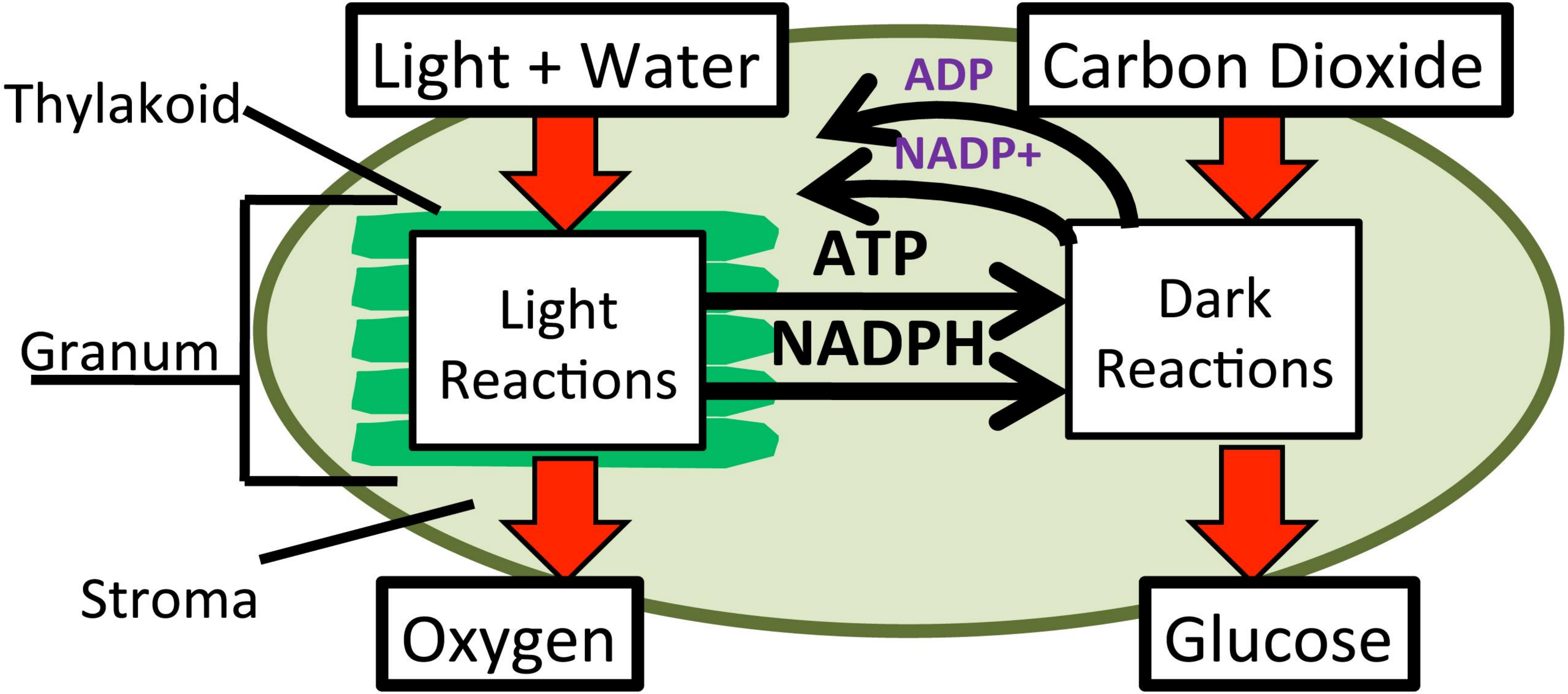
What is Photosynthesis?

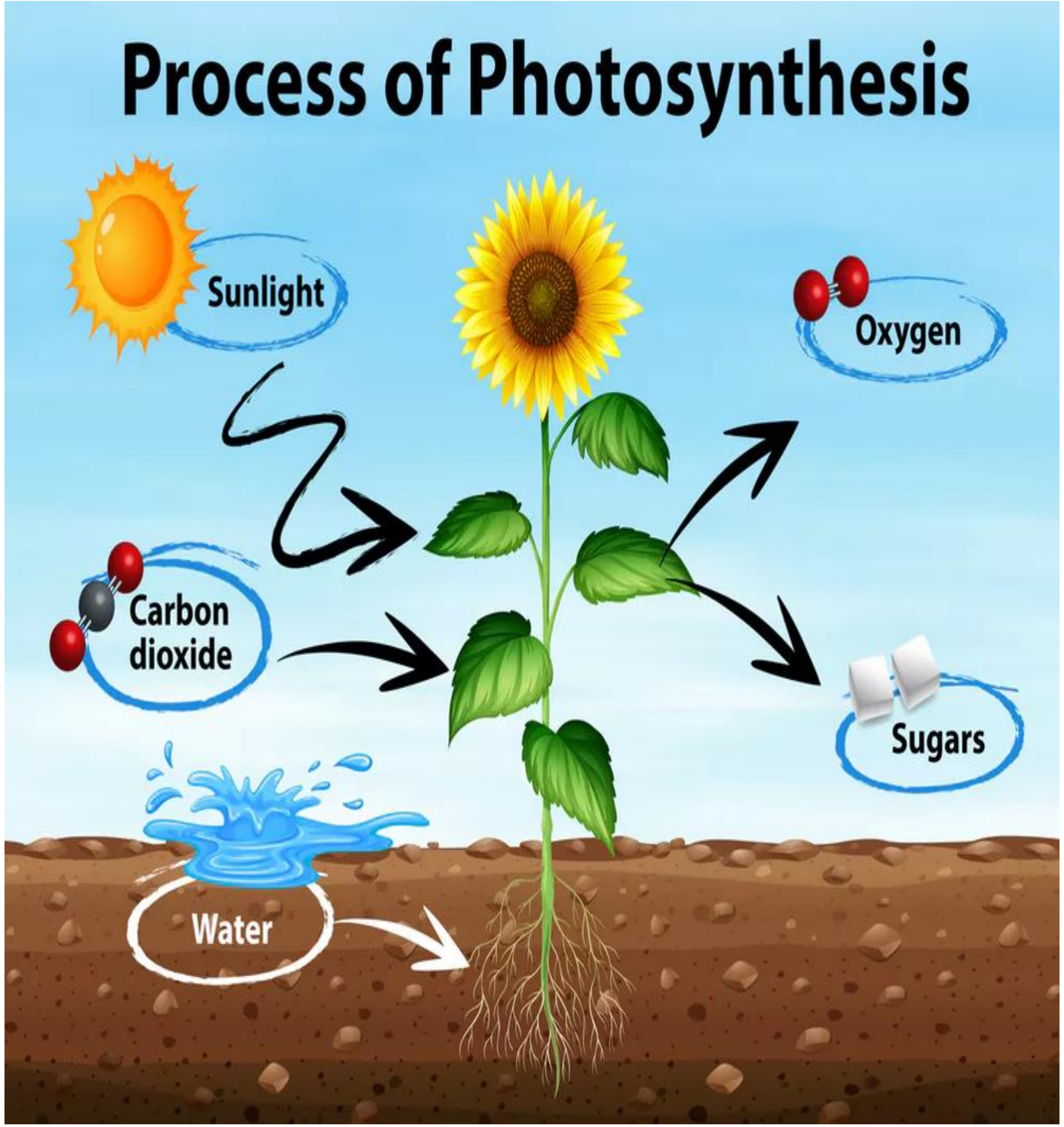
- **Photosynthesis is a process performed by *green plants* to form carbohydrates in the presence of *light, water and carbon dioxide*.**
- **Photosynthesis is represented by the following overall chemical reaction:**

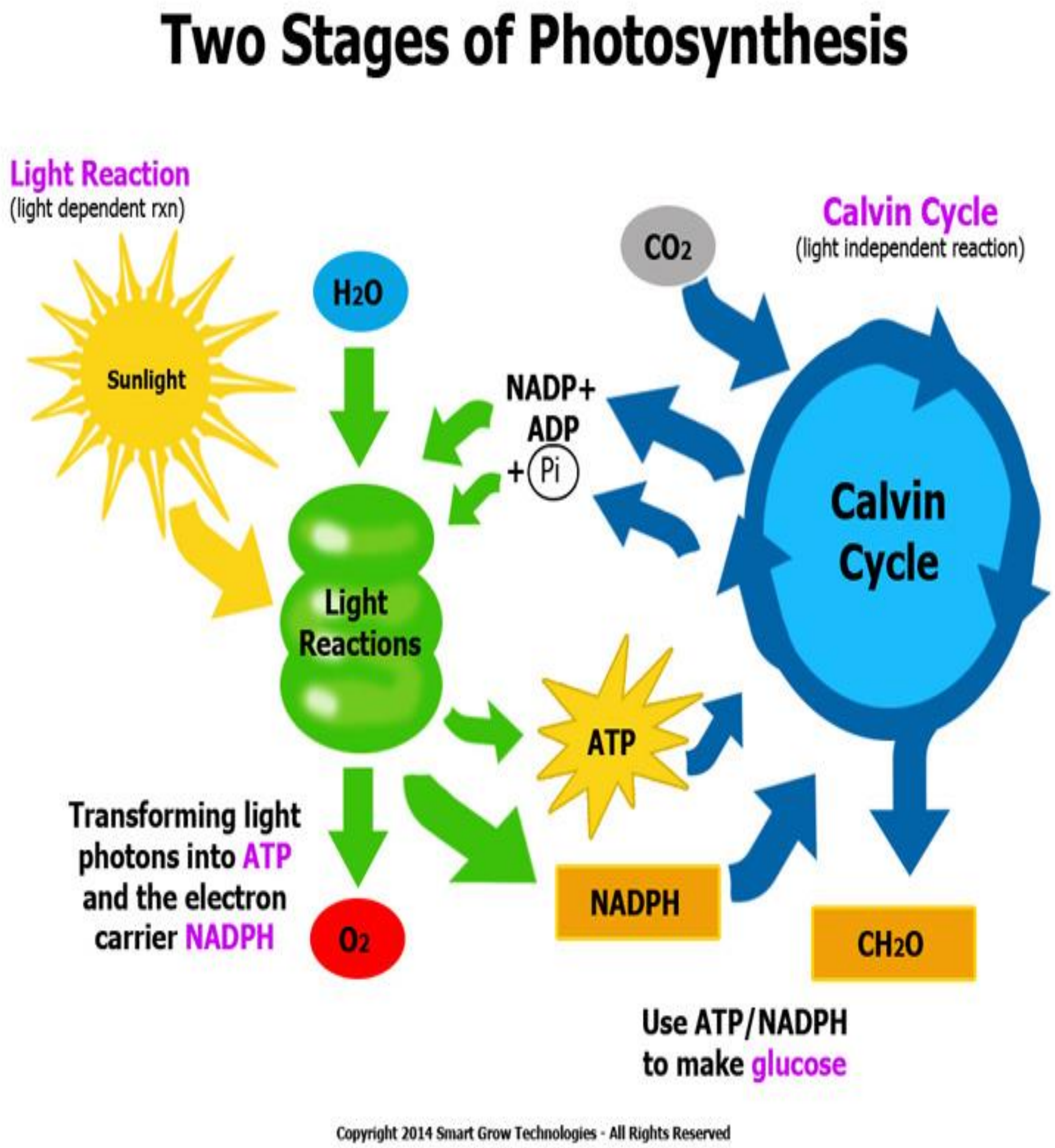
$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

- **In photosynthesis, *CO_2* is fixed *(reduced)* to carbohydrates *($C_6H_{12}O_6$ = Glucose),* water is split in the presence of light, called *photolysis of water* to release *O_2*.**
- ***O_2* is released *from water molecule, not from CO_2*.**

$$CO_2 + H_2O + \text{Energy} \rightarrow O_2 + C_6H_{12}0_6$$




Process of Photosynthesis
Sunlight
Oxygen
Carbon dioxide
Sugars
Water


Two Stages of Photosynthesis
Light Reaction
(light dependent rxn)
Calvin Cycle
(light independent reaction)
CO_2
H_2O
Sunlight
NADP+
ADP
+ Pi
Light Reactions
Calvin Cycle
ATP
NADPH
CH_2O
O_2
Transforming light photons into ATP and the electron carrier NADPH
Use ATP/NADPH to make glucose
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Significance of Photosynthesis

1. Green plants posses chlorophyll *(green pigment)* which can capture, transform, translocate and store energy that is readily available for all forms of life on this planet.

2. Photosynthesis is a process in which light energy is converted into chemical energy.

3. Except *green plants*, no other organism can directly utilize solar energy to synthesize food, hence all other organisms are dependent on green plants for their survival.

4. *Green plants* which can prepare organic food from simple inorganic elements are called *autotrophic*, while all other organisms are called *heterotrophic.*

5. During photosynthesis, oxygen liberated into the atmosphere makes the environment livable for all aerobic organisms.

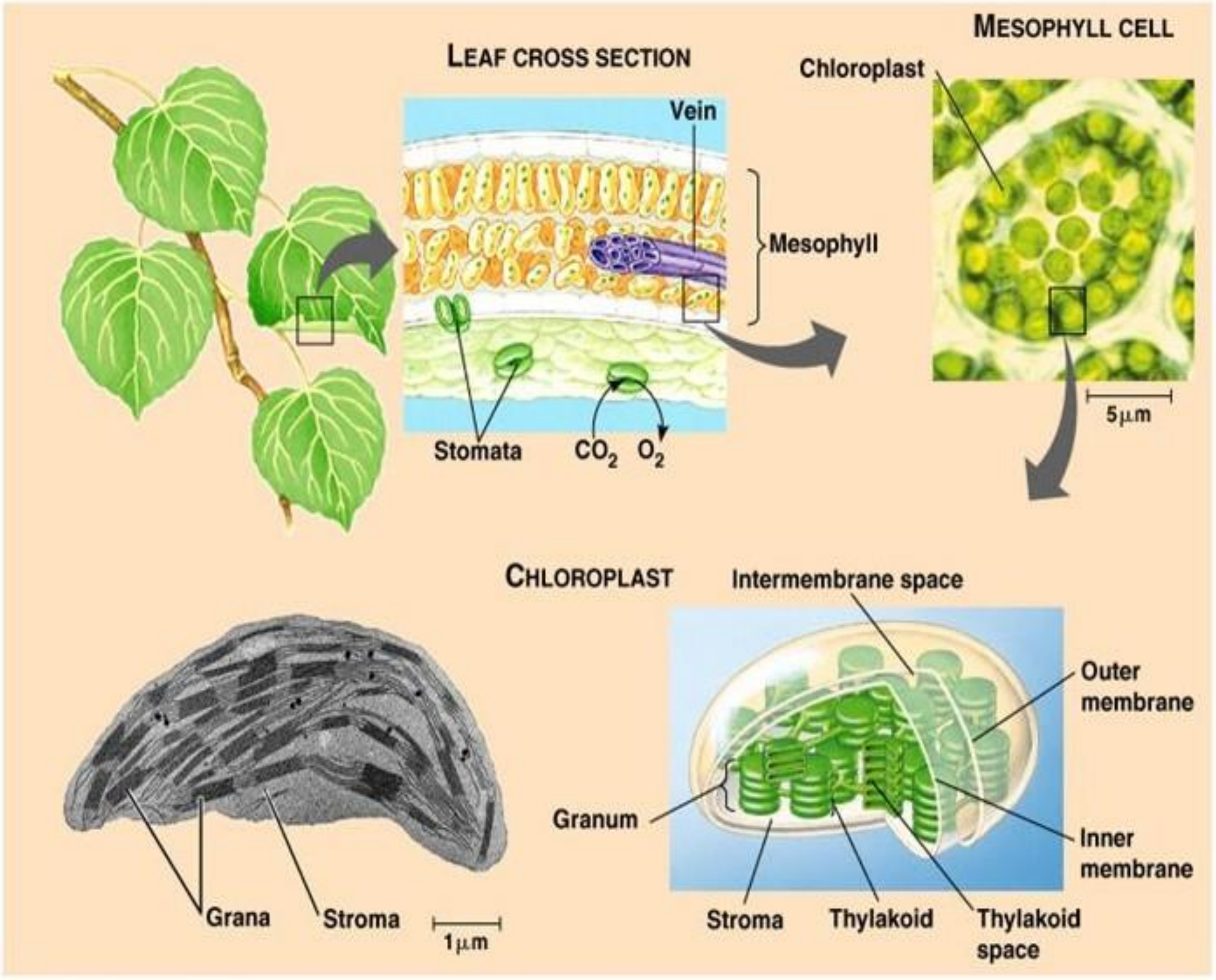
6. Simple carbohydrates produced in photosynthesis are transformed into *lipids*, *proteins, nucleic acids* and *other organic molecules*.

7. Plants and their products are the major food sources of almost all organisms on the earth.

8. Fossil fuels like *coal, gas and oil* represent the photosynthetic products of the plants belonging to early geological periods.

Where Does Photosynthesis Occur?

- **Photosynthesis occurs in the *green parts* of the plants, mostly the leaves, sometimes the green stems, and floral buds.**
- **Leaves contain specialised cells called *mesophyll* cells which contain the *chloroplast* – the pigment containing organelle.**
- ***Chloroplasts* are the actual sites for photosynthesis.**



Photosynthetic Pigments

- ***Thylakoids of the*** **chloroplast contain the pigments which absorb light of different wavelengths and carry out the photochemical reaction of photosynthesis.**
- **The role of the pigments is to absorb light energy, thereby converting it to chemical energy.**
- **Chloroplasts located *on the thylakoid membranes* are at right angles to the light source for maximum absorption.**
- **The photosynthetic pigments of higher plants are *chlorophyll* and *carotenoid*.**
- ***Chlorophyll* is the principal pigment involved in photosynthesis. It is a large molecule and absorbs light maximally in the *violet blue* and in the *red region* of visible spectrum and reflects *green light*, thus leaves appear *green in colour*.**
- ***Carotenoids* (*carotene or xanthophyll*) absorb the light in the regions of the spectrum not absorbed by the *chlorophylls* and transfer the energy to *chlorophyll* to be used in photosynthesis.**
- ***Chlorophyll-a* (*a special type of chlorophyll*) is the main pigment that traps solar energy and convert it into chemical energy which is present in all autotrophic plants except photosynthetic bacteria.**
- ***Chl-a* is the essential photsynthetic agent called "*Reaction Centre*", all other pigments including *Chl-b* and *carotenoids* are called accesory pigments or "*Harvesting Centre*".**

Photosystems

- Chlorophyll-a (*Reaction Centre*) and Accessory Pigments (*Harvesting Centre*) are called ***Photosystems*** that are of two types as ***PS I*** and ***PS II***.
- *250-400 of Chl-a* molecules constitute ***a single photosystem***.

Differences of Photosystems

PS I

1. **PS I has a *Reaction Centre* of *Chlorophyll-a* molecule with max. light absorbance at 700 nm. This *Reaction Centre* is referred to as P_{700}.**

2. **Primary electron acceptor is an *iron protein (Fe-S-protein)*.**

3. **A set of electron carriers are *plastocyanin*, *ferredoxin* and *cytochrome*.**

PS II

1. **PS II has a *Reaction Centre* of *Chlorophyll-a* molecule with max. light absorbance at 680 nm. This reaction centre is referred to as P_{680}.**

2. **Primary electron acceptor is *pheophytin* which is a modified *Chl-a* molecule with 2 H^+ atoms in place of Mg^{++}.**

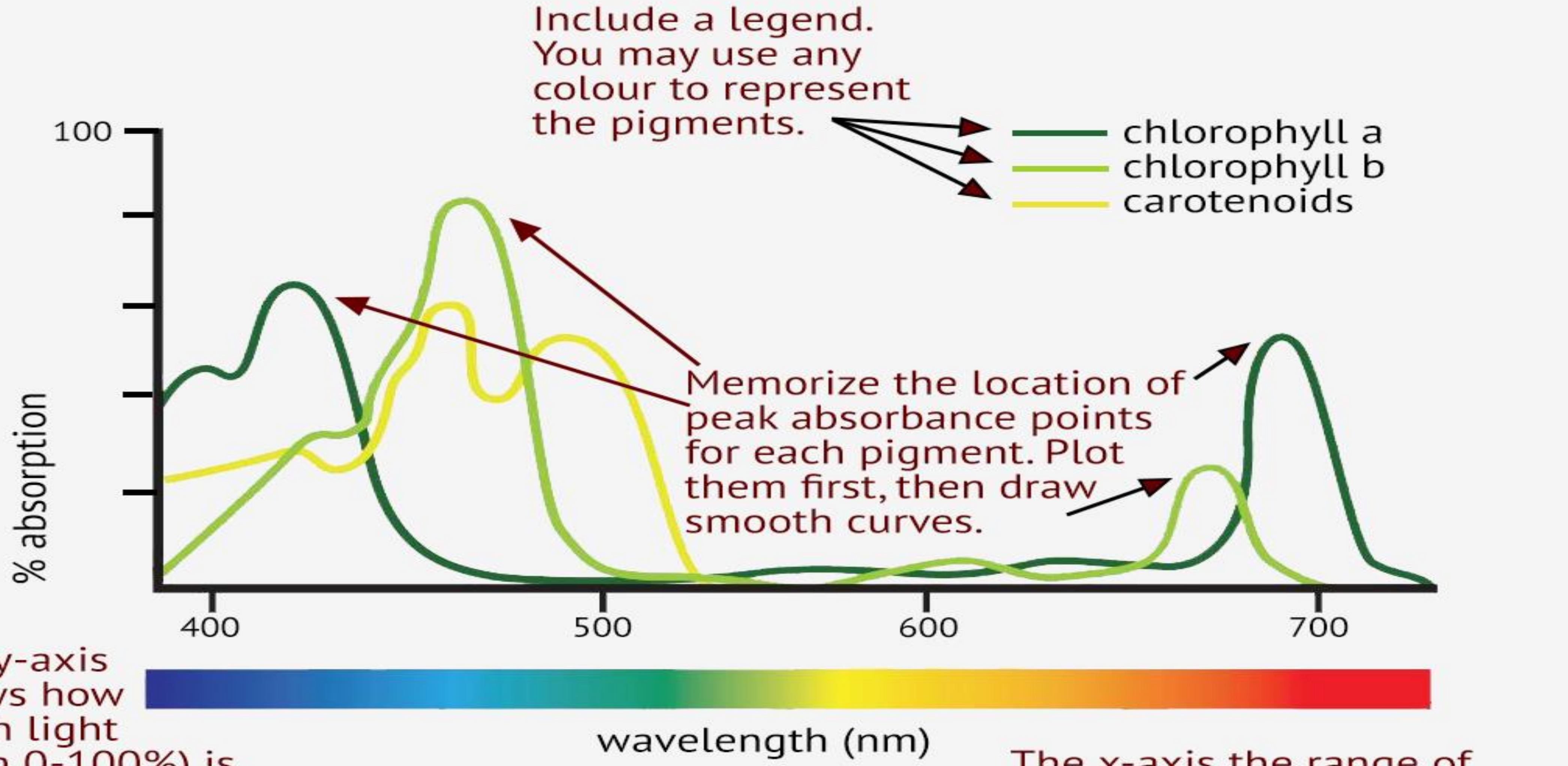
3. **A set of electron carriers are *pheophytin*, *plastoquinone*, and *cytochrome*.**

Role of Sunlight in Photosynthesis

- Light consists of small particles or packages of energy called ***photons***, a single photon is called ***quantum.***
- ***Chlorophyll molecules*** absorb light energy and get into an ***excited state*** losing ***an electron*** to the outer orbit. But no substance can remain in an excited state for long, so the excited chlorophyll molecule comes down to a low energy state known as ***ground state***, and releases the extra amount of energy. This energy can be lost as ***heat***, or as ***light*** *(florescence)* or can be used for ***some work***.
- In **photosynthesis**, this released energy is used for ***splitting water*** molecule to produce **H^+** and **OH^-** ions.
- ***Carotene*** is *orange-yellow* pigment present along with chlorophylls ***in thylakoid membrane***. A carotene molecule breaks down into ***vitamin A*** molecules. This pigment gives *carrot* its colours.

Light Absorption and Action Spectra

- ***Action spectrum*** is a graph showing the effectiveness of different wavelengths of light in stimulating the process of photosynthesis, where the response could be measured in terms of oxygen produced in different wavelengths.
- ***Absorption spectrum*** is a graph representing the relative absorbance of different wavelengths of light by a pigment.
- Close similarity of both spectra indicates that the pigments (***chlorophyll-a in particular***) are responsible for absorption of light used in photosynthesis.
- Photosynthesis occurs maximum in ***blue*** and ***red*** regions of ***visible spectra***.



The y-axis shows how much light (from 0-100%) is absorbed by the pigment at each wavelength.

The x-axis the range of wavelengths in nanometers (from 400 to 700nm) absorbed by each pigment.

Photochemical & Biosynthetic Phase of Photosynthesis

- Entire process of photosynthesis takes place inside the ***chloroplast.***
- ***Light dependent (Light Reaction)*** and ***light independent (Dark Reaction)*** reactions take place at different sites in the ***same organelle***.
- ***Thylakoids*** have the same pigments and other necessary components to absorb light and transfer electrons to carry out the light reaction or ***Electron Transfer Chain (ETC).***
- In ***ETC***, the electrons from **PS II** and **PS I** are excited to a higher energy level,i.e the electrons acquire ***excitation energy***.

Photophosphorylation

- Reduction of ***CO_2*** also requires ***ATP*** which are generated via ***ETC.***
- As the energy-rich electrons pass down the ***Electron Transport System***, it releases energy which is sufficient to bind ***inorganic phosphate (P_i)*** with **ADP** to form **ATP.**
- This process is called ***Photophosphorylation*** due to its takes place in the presence of light.

Biosynthetic Pathway *(Dark Reaction)*

- **These reactions are independent of light, i.e. light is not necessary, but can continue in light if products of the light reaction are available.**
- ***Carbon Fixation Reactions (CFR)*** **produce sugar in the leaves of the plant from where it is exported to other tissues of the plant as a source of both organic molecule and energy for growth and metabolism.**
- **There are two major pathways by which *CO_2 fixation* *(Dark Reaction)*, *C3* and *C4*.**

C3 Cycle *(Calvin Cycle)*

- ***Atmospheric CO_2*** is initially accepted by a 5-carbon sugar ***Ribulose BiphosPhate (RuBP)*** resulting in the generation of two molecules of ***3-carbon compound***, called as ***3-PhosphoGlyceric Acid (PGA).***
- ***This 3-carbon molecule*** is the first stable product of this pathway. Formation of ***PGA*** is called ***carboxylation.***
- This reaction is catalysed by an enzyme called ***Ribulose BiphosPhate Carboxylase/Oxygenase*** or **Rubisco** (*An enzyme involved in the first major step of carbon fixation, a process by which the atmospheric carbon dioxide is converted by plants and other photosynthetic organisms to energy-rich molecules such as glucose. In chemical terms, it catalyzes the carboxylation of ribulose-1,5-bisphosphate (also known as RuBP). It is probably the most abundant enzyme on Earth*).
- Most of these molecules are then diverted from the C3 cycle and used for synthesis of other carbohydrates such as ***glucose*** and ***sucrose.***

C4 Cycle ***(Hatch Slack Cycle)***

- ***C4 Cycle*** **seems to be an adaptation for plants growing under *dry hot environment*. Such plants can photosynthesize even in conditions of *very low CO_2 concentration* and under *partial closure of stomata*.**

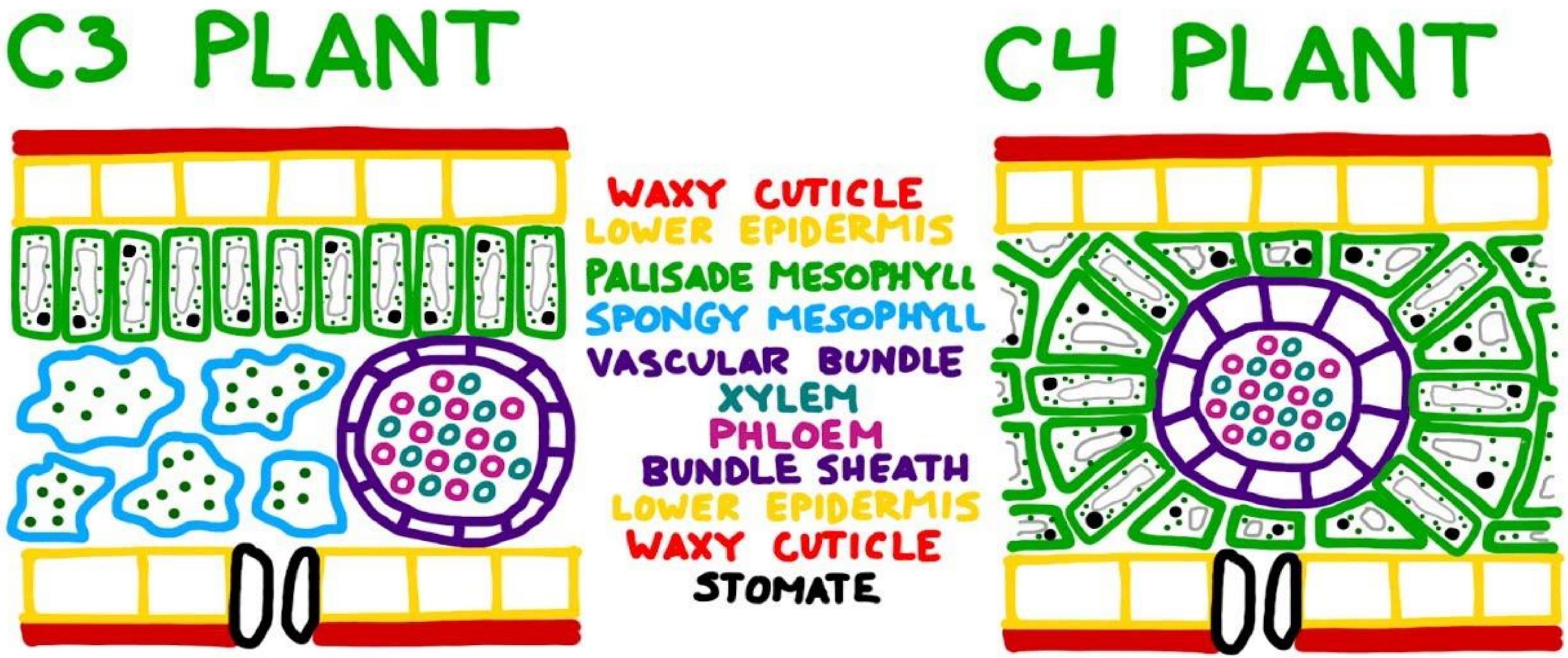
- **Such plants can also grow at *low water content*, *high temperature* and *high light intensity* *(maize, sugarcane, sorghum).***

- **Photorespiration *(oxidation of RuBP in presence of O_2)* is absent in these plants. So, the photosynthetic rate is high.**

- **Leaves of C4 plants show presence of *dimorphous chloroplasts*, called *'Kranz anatomy'*.**

- ***In C4 Plants*, the initial acceptor of CO_2 is *PhosphoEnol Pyruvic Acid (PEP)*, a 3-carbon compound. It combines with CO_2 in presence of an enzyme *phosphoenol pyruvate carboxylase (PEP carboxylase)* and *forms a C4 acid*, *OxaloAcetic Acid (OAA).* This fixation of CO_2 occurs in cytosol of mesophyll cells of the leaf.**

- ***OAA* is the first stable product of this cycle which is 4-carbon compound and hence the name is *C4 Pathway*.**


C3 PLANT
C4 PLANT
WAXY CUTICLE
LOWER EPIDERMIS
PALISADE MESOPHYLL
SPONGY MESOPHYLL
VASCULAR BUNDLE
XYLEM
PHLOEM
BUNDLE SHEATH
LOWER EPIDERMIS
WAXY CUTICLE
STOMATE

Differences Between C3 and C4 Plants

Feature	C3 Plants	C4 Plants
CO_2 fixation	Occurs once	Occurs twice
CO_2 acceptor	Only one acceptor *(RuBP)*	Two acceptors *(PEP and RuBP)*
CO_2 fixing enzymez	RuBP carboxylase	PEP *(Phosphoenol Pyruvic Acid)* carboxylase
First product of PS	*3-C*, phosphoglyceric acid (PGA)	*4-C*, oxaloacetic acid (OAA)
Conc. of CO_2	Higher CO_2 concentration promotes PS	PS efficiency is high even if CO_2 concentration is low
Leaf anatomy	Only one type of chloroplast, Kranz Anatomy is absent	Two types of chloroplasts *(dimorphic)* or *Kranz Anatomy*
Photorespiration	Occurs	Absent
Efficiency	Less efficient PS	More efficient PS

Factors Affecting Rate of PS- *Internal Factors*

1. Chlorophyll:

- Amount of chlorophyll has a direct relationship with the rate of ***PS***. Because this pigment is directly involved in trapping light energy responsible for the light reactions.

2. Leaf Age and Anatomy:

- New expanding leaves show gradual increase in rate of ***PS*** and max. is reached at full size.
- Chloroplast functions decline as the leaves age.
- Rate of ***PS*** is also influenced by *(i) number, structure and distribution of stomata, (ii) size and distribution of intercellular spaces, (iii) relative proportion of palisade and spongy tissues, (iv) thickness of cuticle.*

3. Demand for Photosynthates:

- Rapidly growing plants show increased rate of ***PS*** in comparison to mature plants. When demand for ***PS*** is lowered due to poor meristematic activity, photosynthetic rate declines.

Factors Affecting Rate of PS-*External Factors-I*

1. Light:

- Rate of ***PS*** is directly proportional to light intesity.
- Except on a cloudy day and at night, light is never a limiting factor in ***PS*** in nature.
- At a certain light intensity, amount of CO_2 used in ***PS*** and amount of CO_2 produced in respiration are the same. This point of light intensity is known as ***compensation point***.
- Wavelength of light absorbed by ***PS pigments*** affects ***rate of PS***. ***Red light*** and to some extend ***blue light*** has an enhancing influence on ***PS***.
- Proportion of absorbed light by green plants is a limiting factor. Only about **1-2% of total incident** light reaching the green plants is actually absorbed, but **70%** is transmitted ***(transferred)*** *(Light that has passed through an object, as distinguished from light reflected from a surface)*, and **28-29%** is reflected back into atmosphere.

Factors Affecting Rate of PS-*External Factors-II*

2. Temperature:

- Very high and very low temperatures affect the ***rate of PS***, adversely.
- ***Rate of PS*** will rise with temperature from 5°-37°C beyond which there is a rapid fall.
- Enzymes involved into the process of dark reaction are denaturated at high temperature.
- Between 5°-35°C, with every 10°C rise in temperature, ***rate of PS doubles*** or slightly less.

3. Carbon Dioxide:

- Its concentration affects the ***rate of PS***, markedly.
- Because of its very low conc. (300 ppm) in atmosphere, it acts as limiting factor in natural ***PS***.
- At optimum temperature and light intensity, if CO_2 is supplied, ***rate of PS*** is increased until CO_2 concentration is as high as 3000 ppm means ***10 times higher than in atmosphere***.

Factors Affecting Rate of PS-External Factors-III

4. Water:

- Water has an indirect effect on the *rate of PS*.
- Loss of water in the soil is immediately felt by the leaves, which get wilted and their stomata close down, thus preventing the absorption of CO_2 from atmosphere. This causes decline in PS.

5. Oxygen:

- Conc. of oxygen is never a limiting factor for PS, because it is a by-product of PS, and easily diffuses into the atmosphere from the leaf.
- Excess of oxygen surrounding a green plant, reduces photosynthetic rate by promoting the rate of aerobic respiration.

6. Mineral Elements:

- Some mineral elements like ***magnesium, copper, manganese and chloride*** ions, which are components of photosynthetic enzymes, and ***magnesium*** as a component of chlorophylls are important.
- Their deficiency would effect *rate of PS* indirectly, by affecting the synthesis of photosynthetic enzymes and chlorophyll, respectively.

Chemosynthesis

- **There are some bacteria which can utilise chemical energy released during biological oxidation of certain inorganic substances to reduce CO_2 to carbohydrate.**
- ***These bacteria*** **are called** ***chemosynthetic autotrophs*****.**
- **There are many colorless bacteria which use chemical energy to reduce CO_2. This process is known as** ***chemosynthesis*****.**
- **Chemosynthesis may be defined as the** ***method of carbon assimilation*** **when the reduction of CO_2 is carried out in darkness, utilising the energy obtained from oxidation of inorganic substances such as** ***H_2S*** **and** ***NH_3*****.**

Common Chemosynthetic Bacteria

Nitrifying bacteria :

Nitrosomonas and *Nitrobacter* oxidise *NO_3 to NO_2*.

Sulphur bacteria :

React with *sulphur (S^{+2})* to produce *sulphates (SO_4^{-2})* useful to plants.

Iron bacteria :

Drive their energy to grow from oxidation of *soluble Ferrous* iron to *insoluble Ferris* form which hazardous to water wells and pipes.

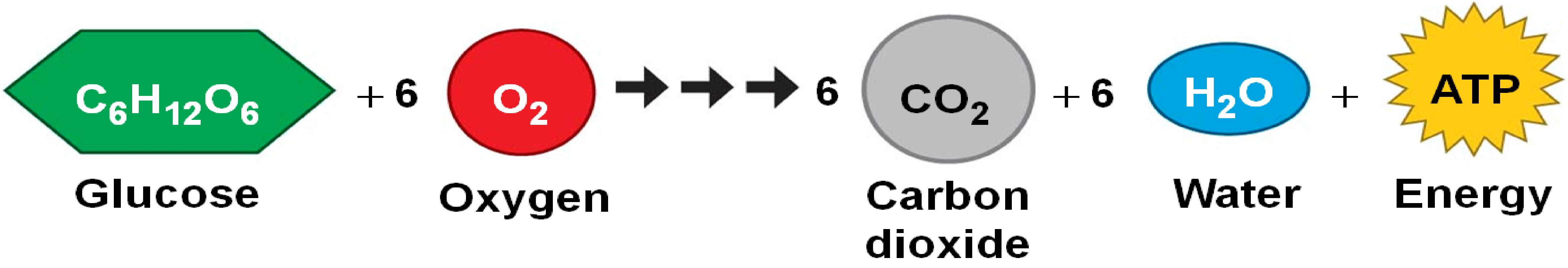
Hydrogen (H^+) and Methane (CH_4) producing bacteria :

Two types of anaerobic *chemolithotrophs* *(certain groups of prokaryotes that obtain their energy from reduced inorganic compounds such as sulfide -S^{-2}, ammonia-NH_4 and hydrogen-H^+)*, oxidize hydrogen with carbon dioxide as electron acceptor; *methanogens* (*microorganisms that produce Methane-CH_4*) and homoacetogens *(anaerobic gram-positive bacteria-without an outer cell membrane)*, producing *methane* and acetate, respectively.

7.
Respiration

General Concept

- **Respiration is the oxidation of complex organic molecules and release of energy as *ATP* for various cellular metabolic activities.**
- **Respiration involves exchange of gases between the organism and the external environment.**
- **This exchange of gases is known as *External Respiration*.**
- **Biochemical respiratory process which occurs within cells and oxidises food to obtain energy, is known *Cellular Respiration*.**
- **Various enzymez *(biocatalysts)* catalyze this process.**
- **Respiration is termed *Aerobic* when oxygen is utilized, and *Anaerobic* when oxygen is not utilized.**



Glucose	→	Ethanol	+	Carbon dioxide
$C_6H_{12}O_6$	→	C_2H_5OH	+	$2CO_2$

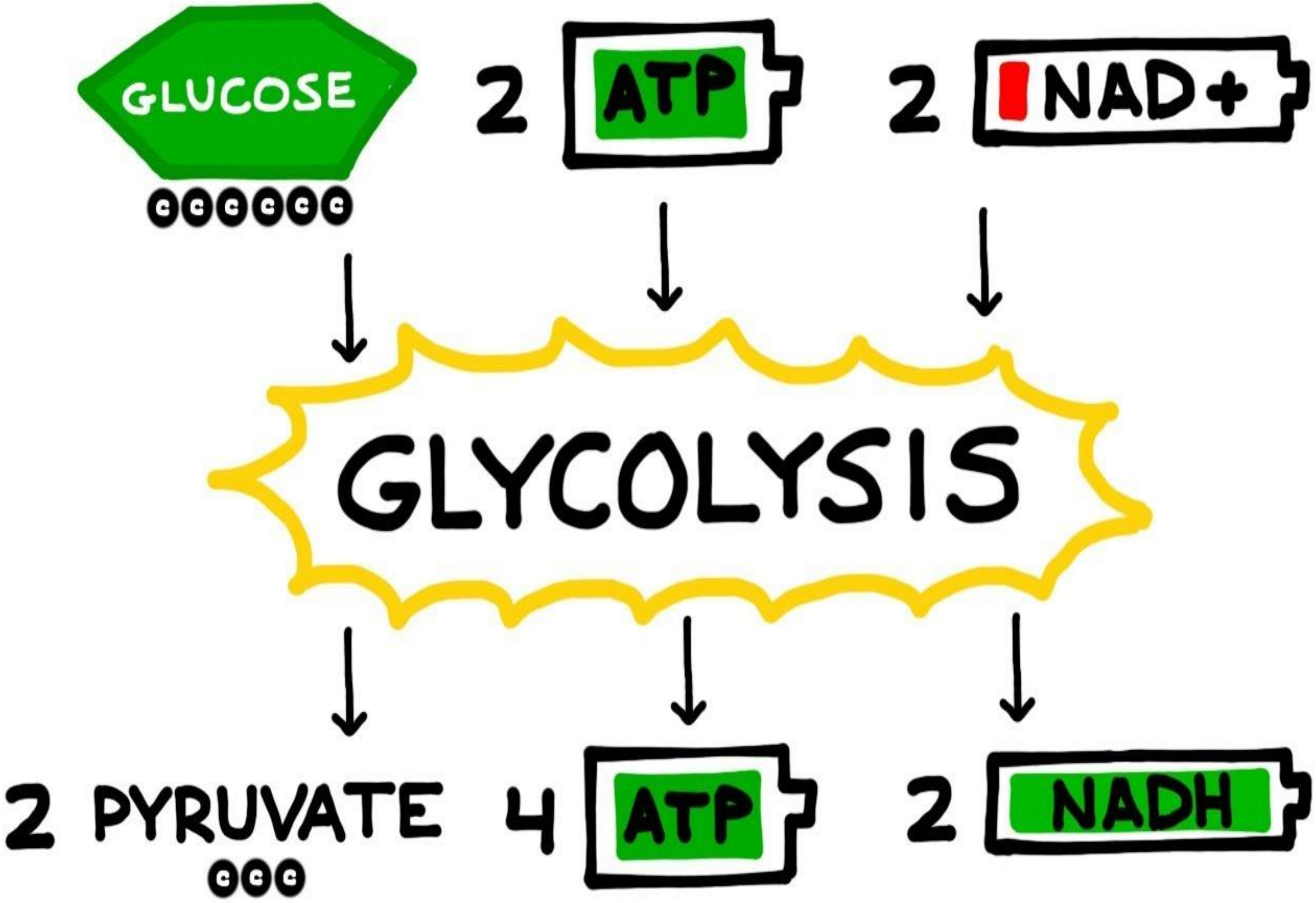
(You might also see ethanol with the formula C_2H_6O. It's the same thing.)

Differences Between *Aerobic* and *Anaerobic* Respiration

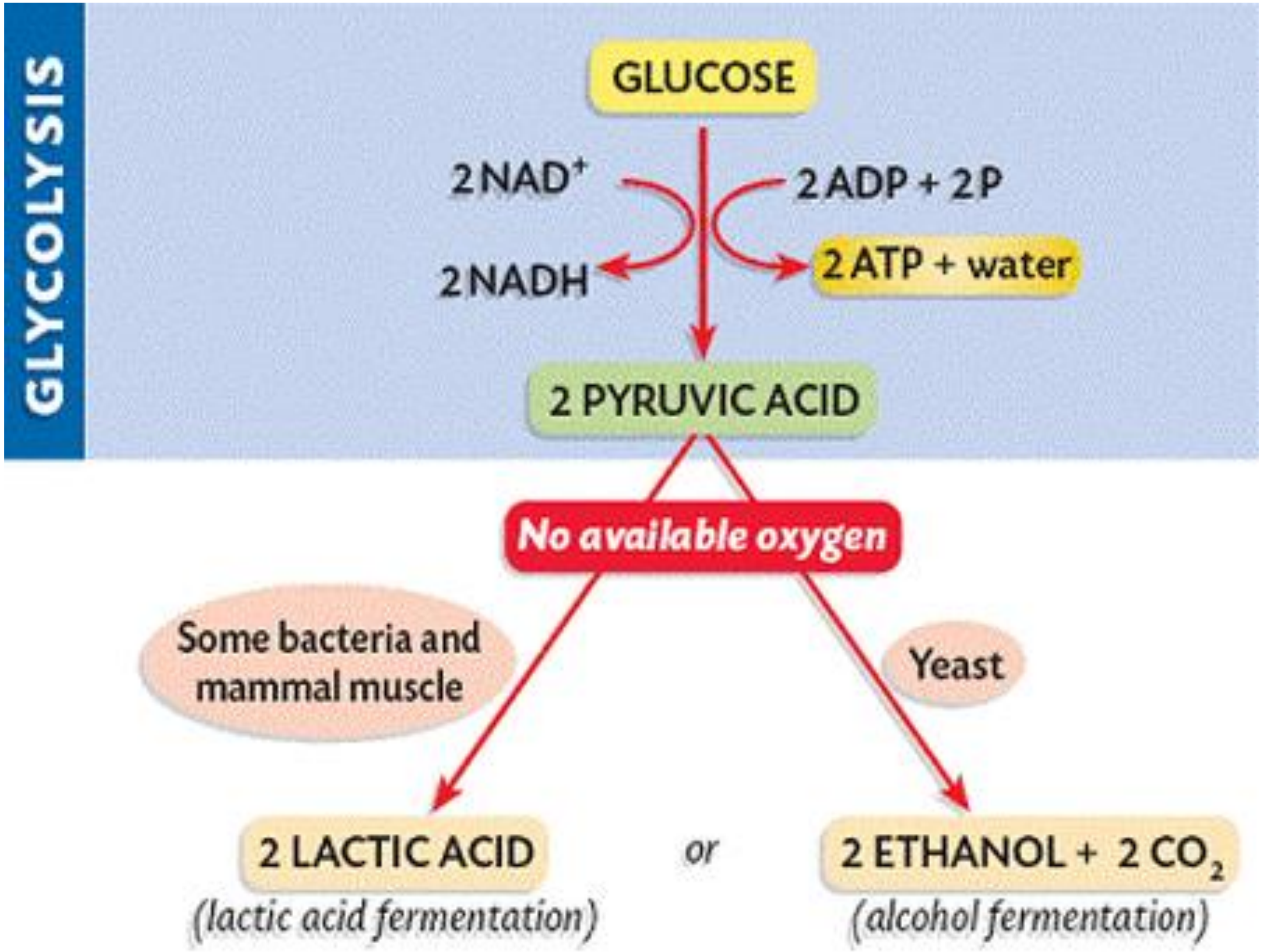
Aerobic Respiration	Anaerobic Respiration
It occurs in the presence of oxygen.	It occurs in the absence of oxygen.
Glucose is completely oxidised.	Glucose is partially oxidised.
Products are CO_2, H_2O and 36 ATPs	Products are ethyl alcohol, lactic acid *(in mammals)*, CO_2, 2 ATPs.
Energy is released in large quantities.	Energy is released much lesser quantity.
Cytoplasm and mitochondria are the sites of breakdown.	Only cytoplasm is the site of breakdown.

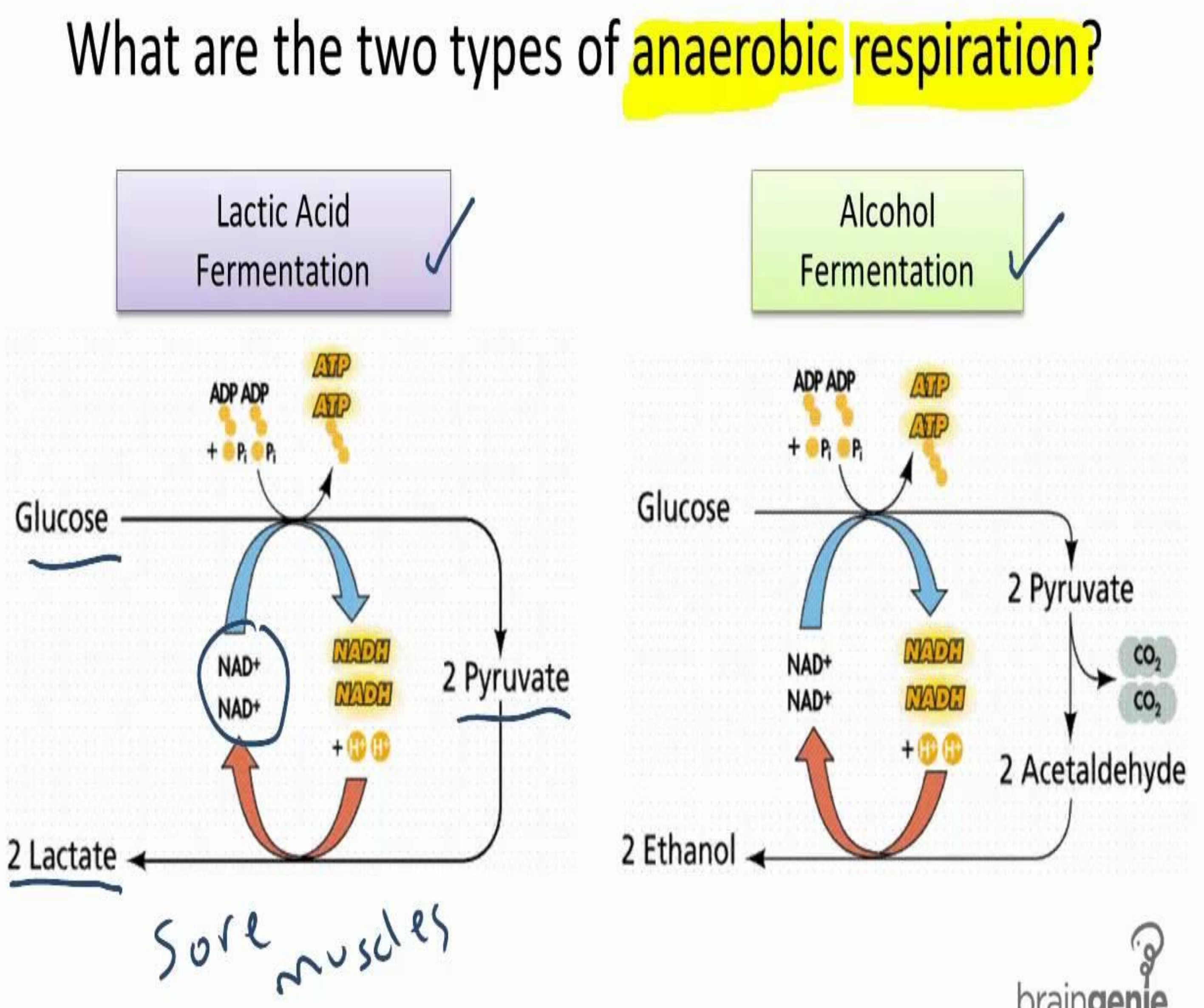
Cellular Respiration-Glycolysis

- Glycolysis is the first step of respiration.
- If the oxygen is ***not available in the cells***, ***breakdown of the glucose*** is always ***anaerobic***. It is common for both aerobic and anaerobic respiration.
- It involves oxidising ***glucose*** *(6-carbon compound)* to two molecules of ***pyruvic acid*** through 10 enzyme catalyzed reactions occuring in ***cytosol*** *(aqueus part of cytoplasm)* called **Glycolysis** *(first step in the breakdown of glucose to extract energy for cellular metabolism that doesn't use oxygen)*.
- At the end of **Glycolysis**, only a small amount of energy is released.


GLUCOSE
CCCCCC
2 ATP
2 NAD+
GLYCOLYSIS
2 PYRUVATE
CCC
4 ATP
2 NADH

Scheme of Cellular *(Anaerobic)* Respiration





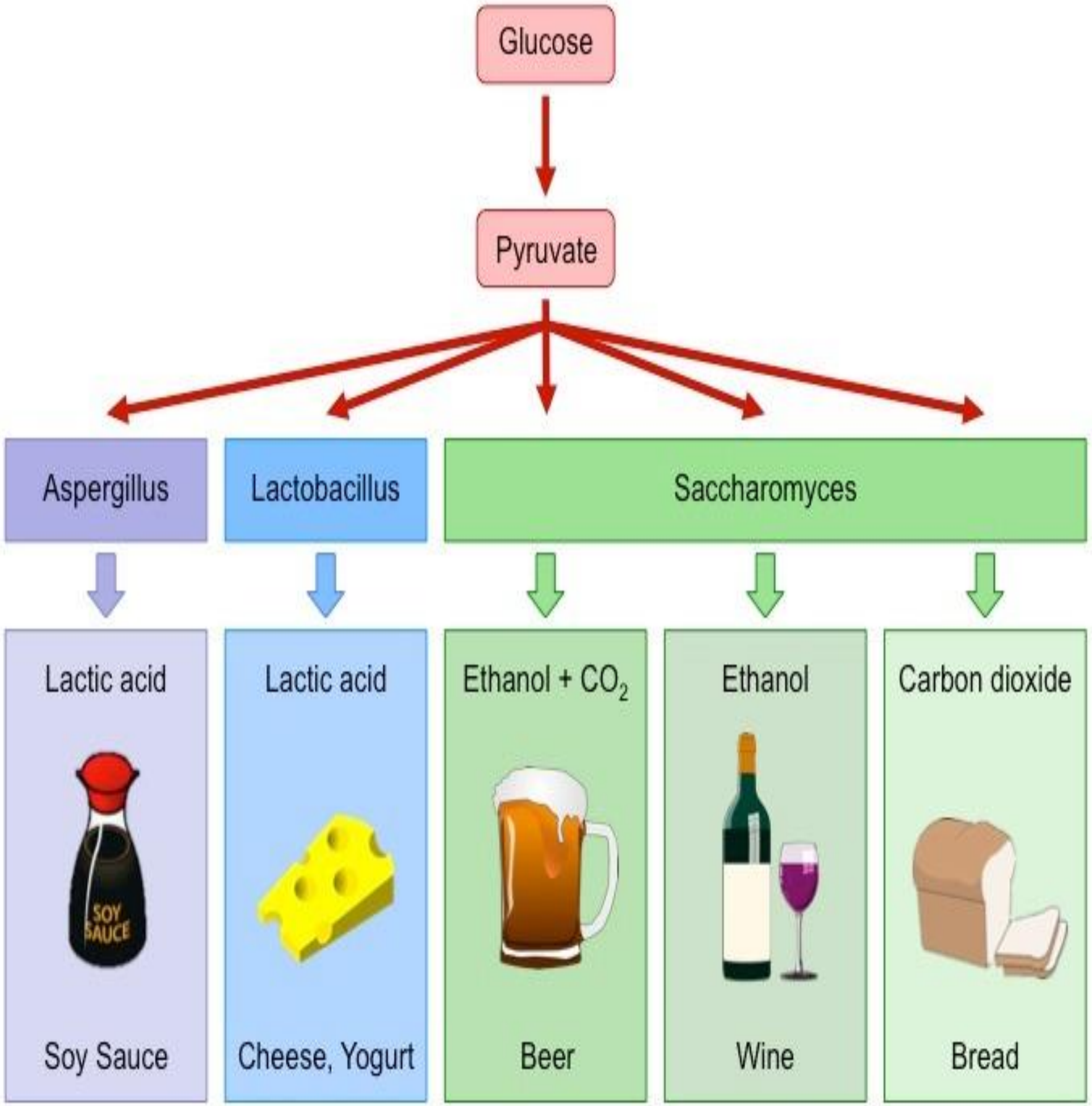
Cellular Respiration

Fermentation

Fermentation involves reduction of pyruvic acid to ***ethyl alcohol*** and CO_2 or to ***lactic acid*** and oxidation of NADH to NAD^+.

Fermentation has a number industrial applications;

1. In bakeries for preparing bread, cakes and biscuits etc.
2. In breweries for preparing wine,beer and other alcoholic drinks.
3. In producing vinegar, and in tanning and curing of leather.



Anaerobic respiration in plants

- Waterlogged roots
- Yeast – brewing and baking
- Lactobacilli – cheese / yoghurt

Germinating seeds respire anaerobically.

When would a plant respire anaerobically?

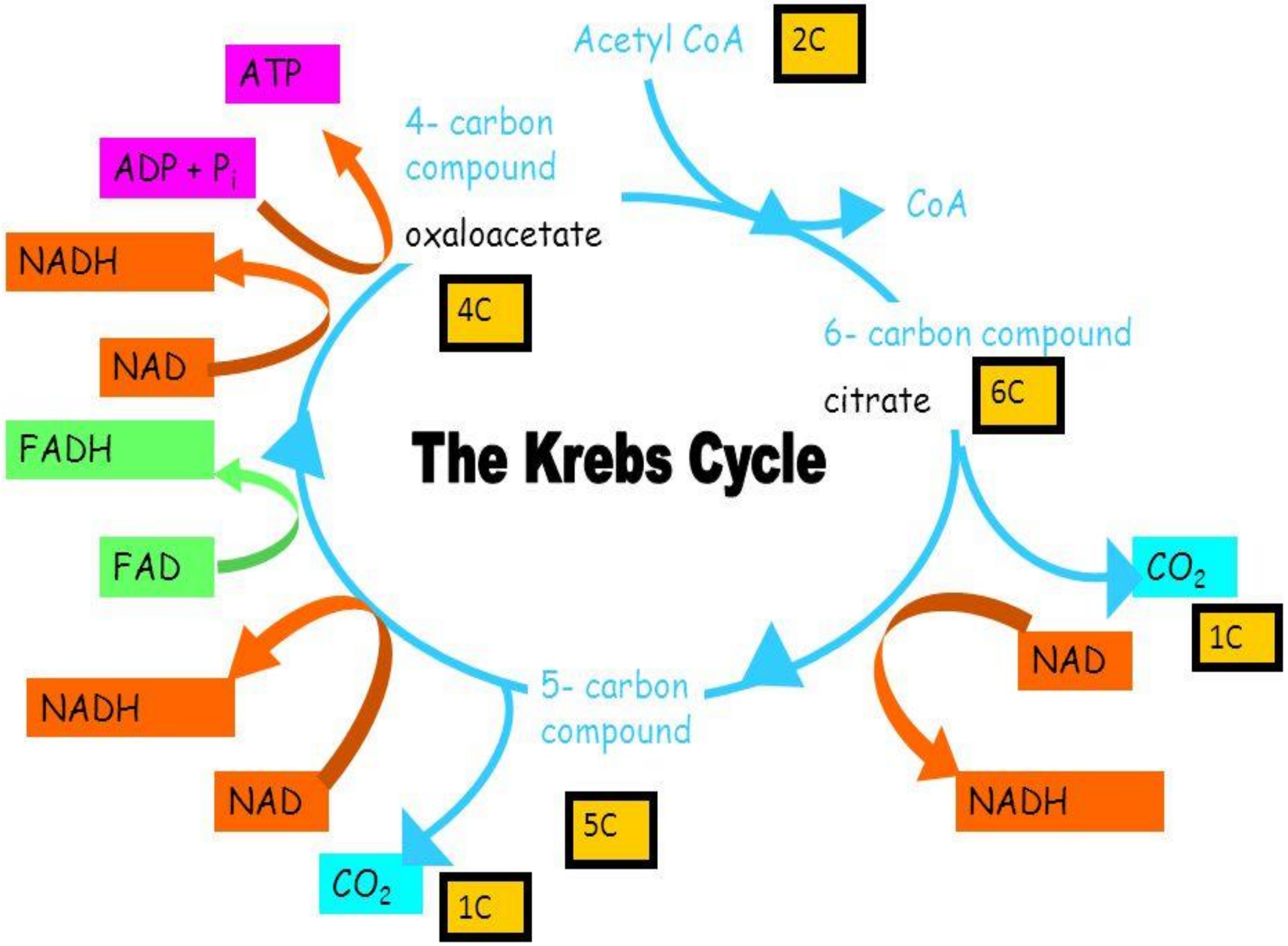
Krebs "Citric Acid" Cycle

Krebs or Citric Acid Cycle is the second step of cellular respiration.

Entering of the ***acetyl CoA (****Acetyl-CoA (acetyl coenzyme A) is a molecule that participates in many biochemical reactions in protein, carbohydrate and lipid metabolism. Its main function is to deliver the acetyl group to the citric acid cycle (Krebs cycle) to be oxidized for energy production)* molecule in Krebs' cycle takes place in the matrix ***(a gel-like material)*** of the mitochondria.

Krebs 'CAC' Cycle is also known as *Tricarboxylic Acid Cycle (TAC).*

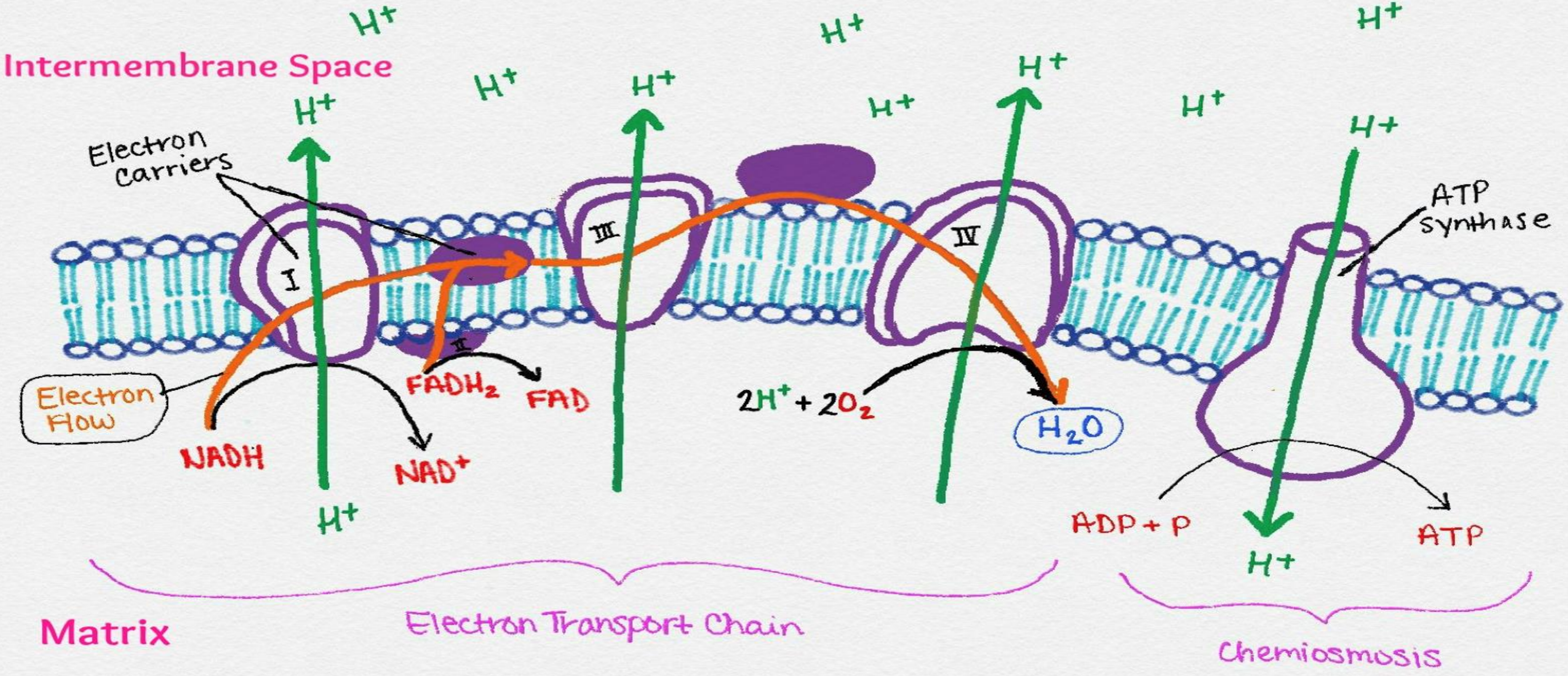
Acetyl group (2-carbon) enters the cycle by combining with ***oxaloacetate (4-carbon)*** to form ***citrate (6-carbon)*** **Which is the first product of the cycle.** This initiate ***Citric Acid Cycle (CAC).***



Respiratory Chain or Electron Transport Chain *(ETC)*

- **ETC is the third (final) step of the cellular respiration.**
- **The hydrogen carriers (NAD$^+$-** *nicotinamide adenine dinucleotide, a coenzyme involved in redox reactions* **and FAD$^+$-***flavin adenine dinucleotide. It is a coenzyme involved in respiration)* **move to the inner membrane of the mitochondria.**
- **Hydrogen carried to the cristae undergoes stepwise** ***(adım adım)*** **oxydation using molecular oxygen and energy is released in series of small steps.**
- **Some of this energy is used to make ATP from ADP and inorganic phosphate (P¡). This is called oxidative phosphorylation.**
- **During these reactions, hydrogen is split into H$^+$ and electrons (e^{-1}) which are accepted by a series of hydrogen and electron carriers ending with oxygen.**
- **This series of carriers constitute the respiratory chain.**
- ***Hydrogen or electrons*** **at a higher energy level are passed from one carrier to the next until they reach oxygen.**
- **Finally, they are reduced to** ***water*** **and some amount of energy released at each transfer is used for** ***ATP*** **synthesis.**

The Electron Transport Chain



The Electron Transport Chain is a series of electron carriers in the inner membrane of the mitochondria. Electrons are passed from NADH to oxygen, moving photons (H+) from the matrix to the intermembrane space. FADH2 also donates electrons to the chain, releasing hydrogen ions into the intermembrane space. Eventually, the high H+ concentration in the intermembrane space causes some of the ions to flow down the concentration gradient and back into the matrix through ATP synthase, producing ATP.

Whitney, E., & Rolfes, S. (2002). Energy Metabolism. In *Understanding Nutrition* (9th ed.). Belmont, California: Wadsworth.

Factors Affecting the Rate of Respiration

- **Respiration Rate (RR) :** $\left(\dfrac{Volume\ of\ CO_2 released}{Volume\ of\ O_2 consumed}\right)$;
- **Factors affecting the 'Respiration Rate';**

✓ ***Internal*** **(Type of Substrate)**

✓ ***External*** **(Oxygen, Water, Temperature, CO_2).**

Internal Factors -Type of Substrates

- Respiratory substrate may be *carbohydrate*, *protein*, or *fats & oils*
- RR values of these substances are as follows.

✓ RR values for *carbohydrates* = 1 as in stem and roots

✓ RR values for *proteins* = < 1 as in protein-rich seeds

✓ RR values for *fats & oils* = > 1 as in oil containing seeds

- RR *is > 1 for fats & oils means that the more energy is released per mol. of fat & oils than per mol.of* glucose *as a result of respiration*.

External Factors

1. **Temperature:**

- Temperature between 30°-35°C is most suitable for respiration. Because the enzymes can work best in this range.
- RR is reduced beyond 50°C and also at very low temperatures (0°-10°C).

2. **Oxygen:**

- RR increases with rise in O_2 concentration. However, beyond a limit, RR falls.

3. **Water:**

- RR is very low if the water content of the protoplasm is low as in dry, matured seeds.
- Dormant seeds show very low RR.

4. **Carbon dioxide:**

- RR decreases if CO_2 is allowed to accumulate.

Photorespiration

- During the dark reaction of photosynthesis, the enzyme RuBisCo *(Ribulose-1,5-bisphosphate carboxylase/oxygenase)* catalyses the carboxylation of RuBP (*Ribulose Bisphosphate as a 5-carbon compound involved in the Calvin cycle, which is a part of the light independent reactions of photosynthesis. Atmospheric CO_2 is combined with RuBP to form a 6 carbon compound, with the help of an enzyme called RuBisCo.* Carboxylation *is a chemical reaction in which a carboxylic acid group is produced by treating a substrate with CO_2.*).
- RuBP+CO_2 = 2 PGA (phosphoglyceraldehyde)(Calvin Cycle).
- The enzyme Rubisco also has very high affinity for O_2 which can catalyze the reaction of O_2 with RuBP (*oxygenation*).
- Respiration that is initiated in chloroplasts and occurs in presence of light and high concentration of O_2 (low CO_2) is called photorespiration.
- There is no ATP production in this process, unlike respiration.

8.
Secondary Metabolites & Plant Defense

What are Secondary Metabolites (SMs)?

- **They are diverse group of plant compounds, commonly referred to as *‘Secondary Metabolites’* which defend plants against a variety of herbivores and pathogenic microbes.**
- **Some secondary metabolites serve other important functions, such as providing *structural support*, as in the case of *lignin*, or acting pigments, as in the case of *anthocyanins*.**
- ***SMs* have no direct function in plant’s growth and development.**

Ecological Functions & Classification of SMs in Plants

- ✓They protects plants against herbivores *(animals eats only plants)* and microbial pathogens.
- ✓They serve as attractants *(odor, color, taste)* for pollinators and seed-dispersing animals.
- ✓They function as agents of *plant-plant competition* or *plant-microbe symbiosis*.

Plant secondary metabolites can be divided into three chemically distinct groups;

1. Terpenes,
2. Phenolics,
3. Nitrogen-Containing Compounds.

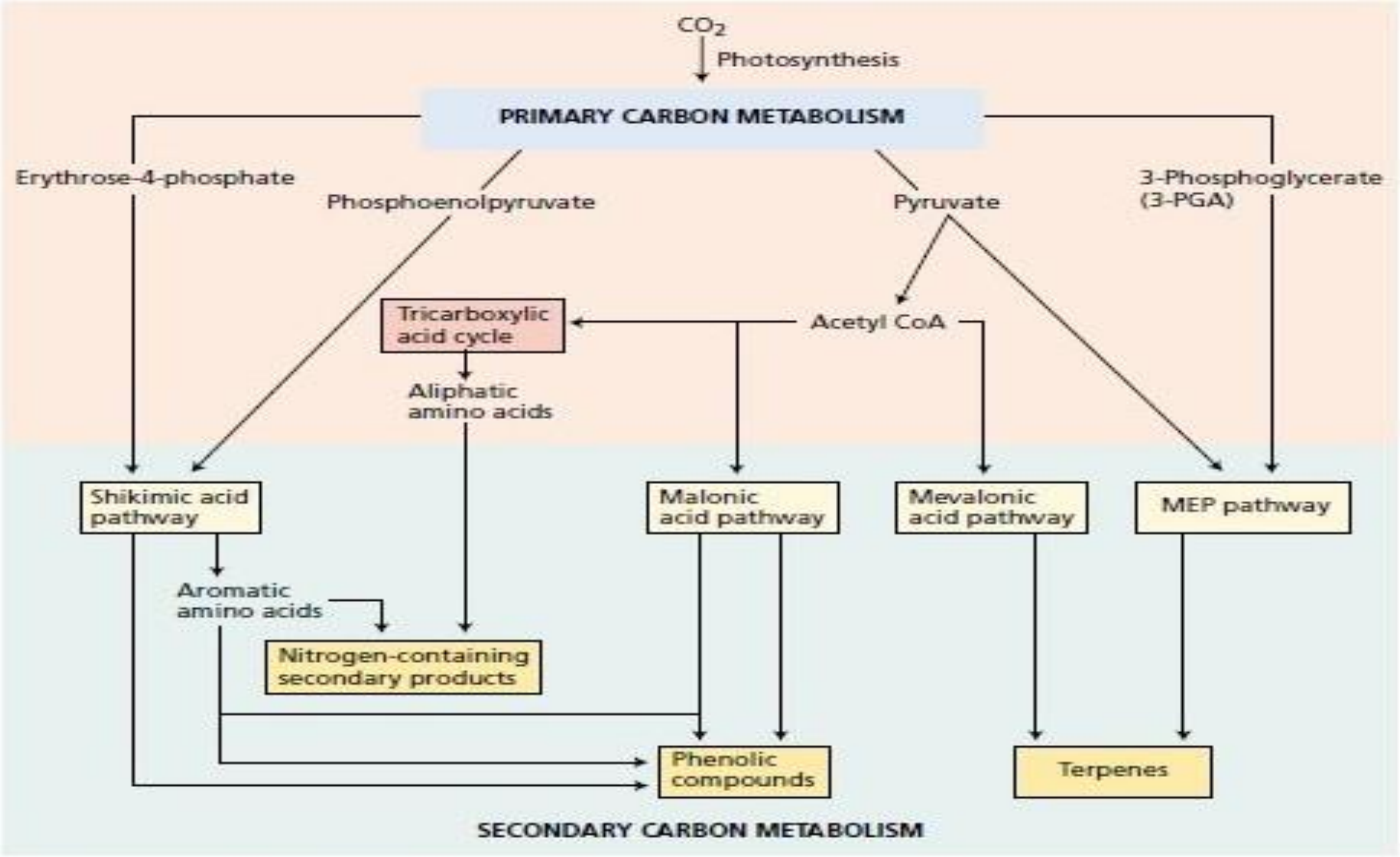


FIGURE 13.4 A simplified view of the major pathways of secondary-metabolite biosynthesis and their interrelationships with primary metabolism.

1. Terpenes

- Terpenes *(or terpenoids)* are the largest class of *SMs*.
- Most of the diverse substances of this class are insoluble in water.
- They are synthesized from *Acetyl-CoA* or its *glycolytic intermediates* (*In glycolysis, glucose is converted into two mol. of pyruvic acid in 10 steps*).
- Terpenes are formed by the *fusion of 5-carbon izoprene units*. Thus, *terpenes* are sometimes referred to as *isoprenoids*.
- Terpenes are classified by the number of *C-5 units* they contain. For example 10-carbon terpenes are called *monoterpenes*, 20-carbon terpenes are called *diterpenes.*
- There are two pathways for Terpene Biosynthesis:

1. Mevalonic acid pathway,
2. MEP *(Methyl-Erythritol Phosphate)* pathway.

Roles of Terpenes on Growth and Development

Certain *terpenes* have well-known functions in plant growth and development, and so they can be considered primary metabolites.

1. *Gibberellins*, an important group of plant hormones, are *Diterpenes (20-C)*.

2. *Brassinosteroids*, another class of plant growth-regulating hormones, originate from *Triterpenes (30-C)*.

3. *Sterols* are *triterpene derivatives* that are essential components of cell membranes.

4. *Carotenoids* *(red, orange, yellow color pigments)* are *Tetraterpenes (40-C)*.

5. *Abscisic acid*, a growth retardant hormone, is a *Sesquiterpene* (*15-C*).

6. *Dolichols* that are *long-chain polyterpene alcohols*, function as carriers of sugars in cell wall and *glycoprotein synthesis*.

Roles of Terpenes on Plant Defense-1

- **Terpenes are toxins and feeding deterrents to many herbivorous insects and mammals. For example, *monoterpene* called *pyrethroids*, found in leaves and flowers of chrysanthemum species, show *insecticidal activity*.**
- **Thus, both *natural and synthetic prethroids* are popular ingredients in *commercial insecticides* due to their low persistence in the environment and their negligible toxicity of mammals.**
- ***Monoterpenes* accumulate as resin ducts *(kanal)* in needles, twigs *(ince dal)*, and trunk of *conifers*. These compounds are *toxic to numerous insects* including bark beetles.**

Roles of Terpenes on Plant Defense-2

- **Many plants contain mixtures of volatile monoterpenes and sesquiterpenes (15-C), called *essential oils*, that lend a characteristic odor to their foliage.**
- ***Peppermint*, *lemon*, *basil* *(fesleğen)* and *sage* *(adaçayı)* are examples of plants that contain essential oils.**
- **Chief monoterpene constituent of lemonoid is *Limonene*, peppermint oil is *Menthol*.**

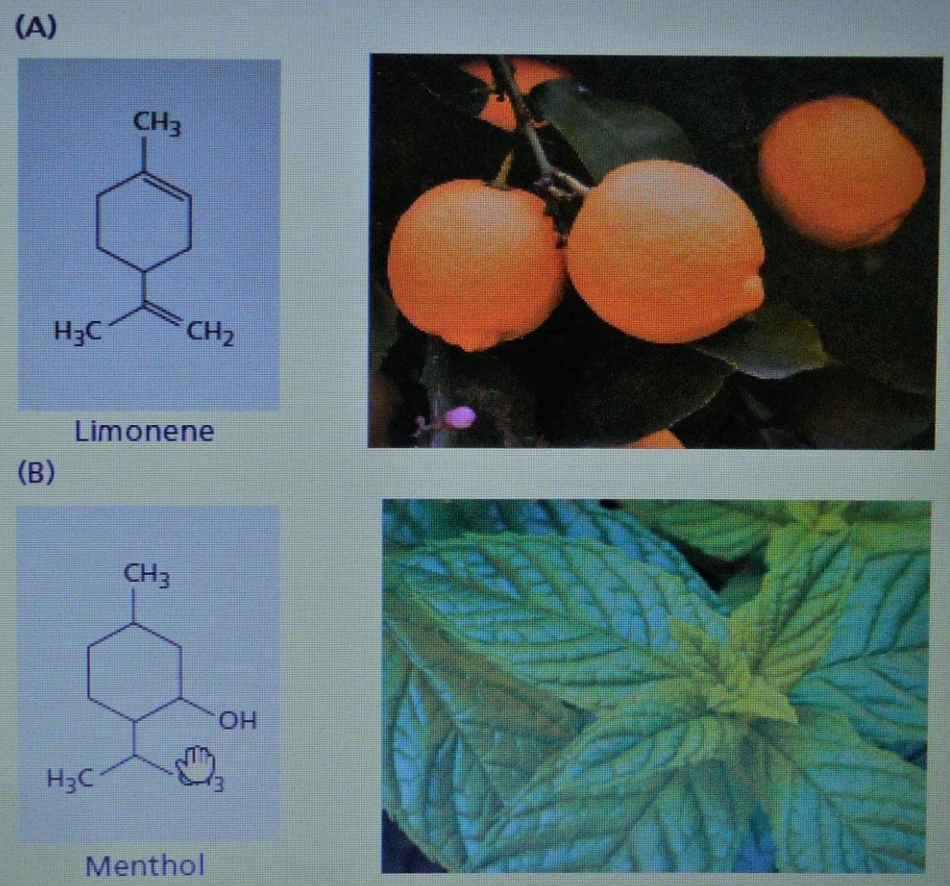
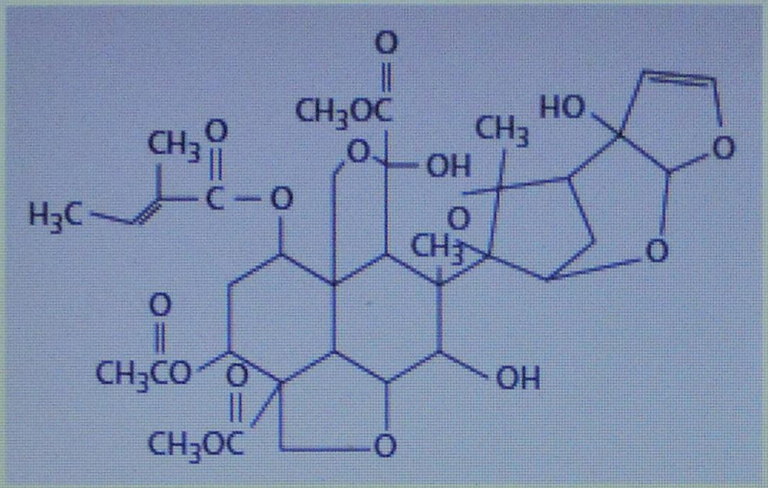


FIGURE A4.3 Structures of limonene (A) and menthol (B). These two well-known monoterpenes serve as defenses against insects and other organisms that feed on the plants that produce them. (A, lemon tree [*Citrus × limon*], photo © Soren Pilman/istockphoto; B, peppermint [genus *Mentha*], photo © Jose Antonio Santiso Fernández/istockphoto.)

Roles of Terpenes on Plant Defense-3

- One of the well-known ***non-volatile*** terpene antiherbivore compounds are ***limonoids***, ***a group of triterpenes*** (30-C) which is responsible for ***bitterness of citrus fruits***.
- Perhaps the most powerful deterrent to insect feeding known as ***azadirachtin***, ***a complex limonoid.***
- ***Phytoecdysones*** are a group of ***plant steroids*** that have the same basic structure as ***insect molting*** ***(kabuk değiştirme)*** ***hormones***. Another defensive function of this compound against ***plant-parasitic nematodes*** has been discovered recently.
- Triterpenes such as ***cardenolides*** and ***saponins***, defend plants against ***vertebrate herbivores***.
- ***Cardenolides*** are ***glycosides*** that ***taste bitter*** and are ***extremely toxic*** to ***higher animals***.
- ***Saponins*** are ***steroid and triterpene glycosides***, so named because of their ***soaplike properties***.

(A) Azadirachtin, a limonoid



(B) α-Ecdysone, an insect molting hormone

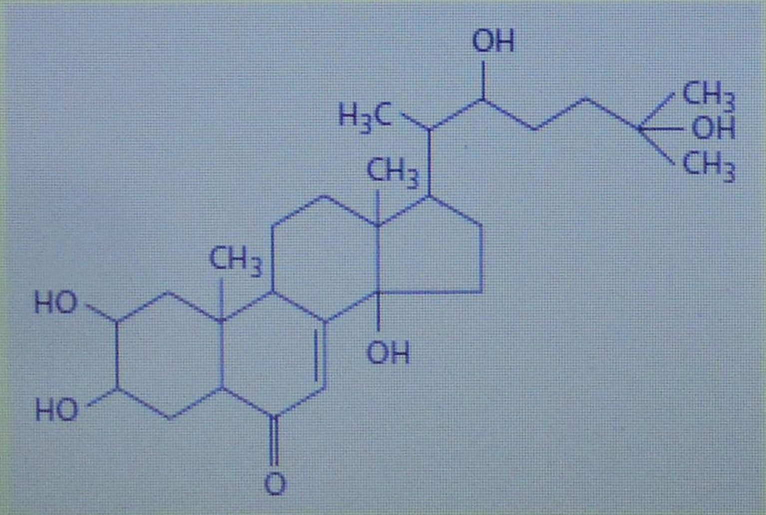


FIGURE A4.5 Structure of two triterpenes, azadirachtin (A) and α-ecdysone (B), that serve as powerful insecticides. Azadirachtin affects more than 200 species of insects and can be considered a natural insecticide. α-Ecdysone, a plant-derived steroidal prohormone of the insect molting hormone 20-hydroxyecdysone, can cause irregular molting in insect herbivores. (A, photo of neem leaves © RN Photos/istockphoto; B, photo of *Polypodium vulgare* leaves, © blickwinkel/Alamy.)

2. Phenolics / Phenolic Compounds

- **Plants produce a large variety of secondary compounds that contain *a phenol group* which is *a hydroxyl functional group* on an aromatic ring.**
- **These substances are called as *phenolic compounds* or *phenolics*.**
- ***Plant phenolics* are a *chemically heterogenous group* of nearly *10.000 individual compounds*.**

Major Functions of Phenolics

Phenolics play a variety of roles in the plant;

1. Serve as *defender against herbivores and pathogens*,
2. Function in *mechanical support*,
3. Attract *pollinators*,
4. Absorb *harmful ultraviolet radiation*,
5. Reduce *the growth of nearby competing plants*.

Biosynthesis of Phenolics

- Plant phenolics are synthesized by two basic pathways: Shikimic acid pathway and Malonic acid pathway (less significance in higher plants).

Shikimic acid pathway:

- This pathway participates in the biosynthesis of most plant phenolics.
- In this pathway, *simple carbohydrate precursors (öncü)* are converted into three aromatic aminoacids as *phenylalanine, tyrosine* and *tryptophan*.
- One of the pathway intermediates is *shikimic acid*.
- Well-known broad-spectrum herbicide *glyphosate (commercially known as Roundup which is a broad-spectrum, non-selective systemic herbicide that WHO has labelled it as probably carcinogenic to humans)* kills plants by blocking a step in this pathway.
- Formation of *many plant phenolics*, including simple *phenylpropanoids, coumarins, benzoic acid derivatives, lignin, anthocyanins, isoflavones, condensed tannins,* and *other flavonoids*, begins with *phenylalanine* which is a vital component of proteins in all living organisms, and in plants is a precursor for thousands of additional metabolites.

Role of Ultraviolet Light on the Activation of Simple Phenolics

- Many **simple phenolics** have important roles in plants as defender against insect ***herbivores*** and ***fungi***.
- A specific example is the ***phototoxicity of coumarins*** called ***furanocoumarins***.
- ***These compounds are not toxic until they are activated by light***.
- ***Sunlight in the ultraviolet A (UV-A) region of the spectrum*** (320-400 nm) causes some ***furanocoumarins*** to become activated to a ***high energy electron state***.
- Activated ***furanocoumarins*** can insert themselves into the ***double helix of DNA*** and **bind the** ***pyrimidine bases to cytosine and thymine***, thus ***blocking transcription and repair***, and ***leading to cell death***.
- ***Phototoxic furanocoumarins*** are especially abundant in ***members of the Umbelliferae***, including ***celery***, ***parsnip*** and ***parsley***.

Phenolics Released into the Soil May Limit the Growth of Other Plants

- ***Plants release a variety of primary and secondary metabolites in the environment.***
- **The release of secondary compounds by one plant that have an effect on neighboring plants is referred as *allelopathy*.**
- **The term *allelopathy* is generally remembered with its harmful effects of plants on their neighbors, although a precise definition also includes *beneficial effects as in weed control.***
- **Simple *phenylpropanoids* and *benzoic acid derivatives* are frequently cited as having allelopathic activity.**
- ***Caffeic acid* and *ferulic acid* found in the soil in appreciable amounts *inhibit the germination and growth of many plants* in lab. experiments.**
- ***Allelopathy* is currently of great interest because of its potential agricultural applications as herbicide.**
- **Yield reductions in some crops caused by weeds or residues from the previous crop may in some cases by a result of *allelopathy*.**

Lignin - *A Highly Complex Phenolic Macromolecule*

- ✓ *Lignin* is the ***second most abundant organic substance*** in plants, ***after*** *cellulose*, which is a highly branched polymer of ***phenylpropanoid groups***.
- ✓ *Lignin* plays both primary and secondary roles in plants, but ***its precise structure is not known*** because it is ***difficult to extract from plants***.
- ✓ *Lignin* is found ***in the cell walls*** of various cell types that make up ***supporting*** and ***conducting*** tissues, notably the ***tracheids and vessel elements of the xylem***.
- ✓ ***Besides providing mechanical support,*** *lignin* ***has significant protective functions in plants***.
- ✓ ***Its physical toughness deters herbivory, and its chemical durability makes it relatively indigestible***.
- ✓ *Lignin* also ***reduces the digestibility of cellulose*** and ***protein*** by bonding them.
- ✓ *Lignification* **blocks the growth of pathogens**.

Flavonoids

- **Flavonoids** *are one of the* ***largest classes of plant phenolics****. The basic carbon skeleton of flavonoid contains 15 carbons arranged in two aromatic rings connected by a 3-carbon bridge.*
- **Four major groups of flavonoids are;**

1. *Anthocyanins*

2. *Flavones*

3. *Flavonols*

4. *Isoflovanoles*

- ***Hydroxyl groups*** **and** ***sugars*** **are usually present in the basic flavonoid carbon skeleton and both** ***increase the water solubility of flavonoids*****.**
- **Different types of flavonoids perform very different functions in the plant, including** ***pigmentation*** **and** ***defense*****.**

Anthocyanins

- The coloured pigments of plants provide visual cues (signal) that help to attract pollinators and seed disperses.
- The most widespread group of pigmented flavonoids is anthocyanins which are responsible for most of the red, pink, purple, and blue colors of flowers and fruits
- Anthocyanins are glycosides, without their sugars, they are called as anthocyanidins.

Protective Role of *Flavones* and *Flavonols* from Damage of Ultraviolet Light

- Two other groups of flavonoids found in flowers are *flavones* and *flavonols.*
- These flavonoids generally absorb light as *shorter wavelengths than to anthocyanins, so that they are not visible to the human eye*.
- But, insects such as ***bees*** can see further into the ultraviolet range of the spectrum and may respond to *flavones* and *flavonols* as visual attractant cues.
- *Flavonols* in a flower often form symmetric patterns of stripes, spots or concentric circles called ***nectar guides*** which are thougth to help insects *to find the location of pollen and nectar*.
- *Flavones* and *flavonols* are also present in the *leaves of all green plants.*
- These two classes of flavonoids protect cells from excessive *UV-B radiation (280-320 nm)*
- *UV-B radiation is known to induce mutations in DNA as well as oxidative stress, which has the potential to damage cellular macromolecules.*

Pharmological Activity of *Isoflavanoids*

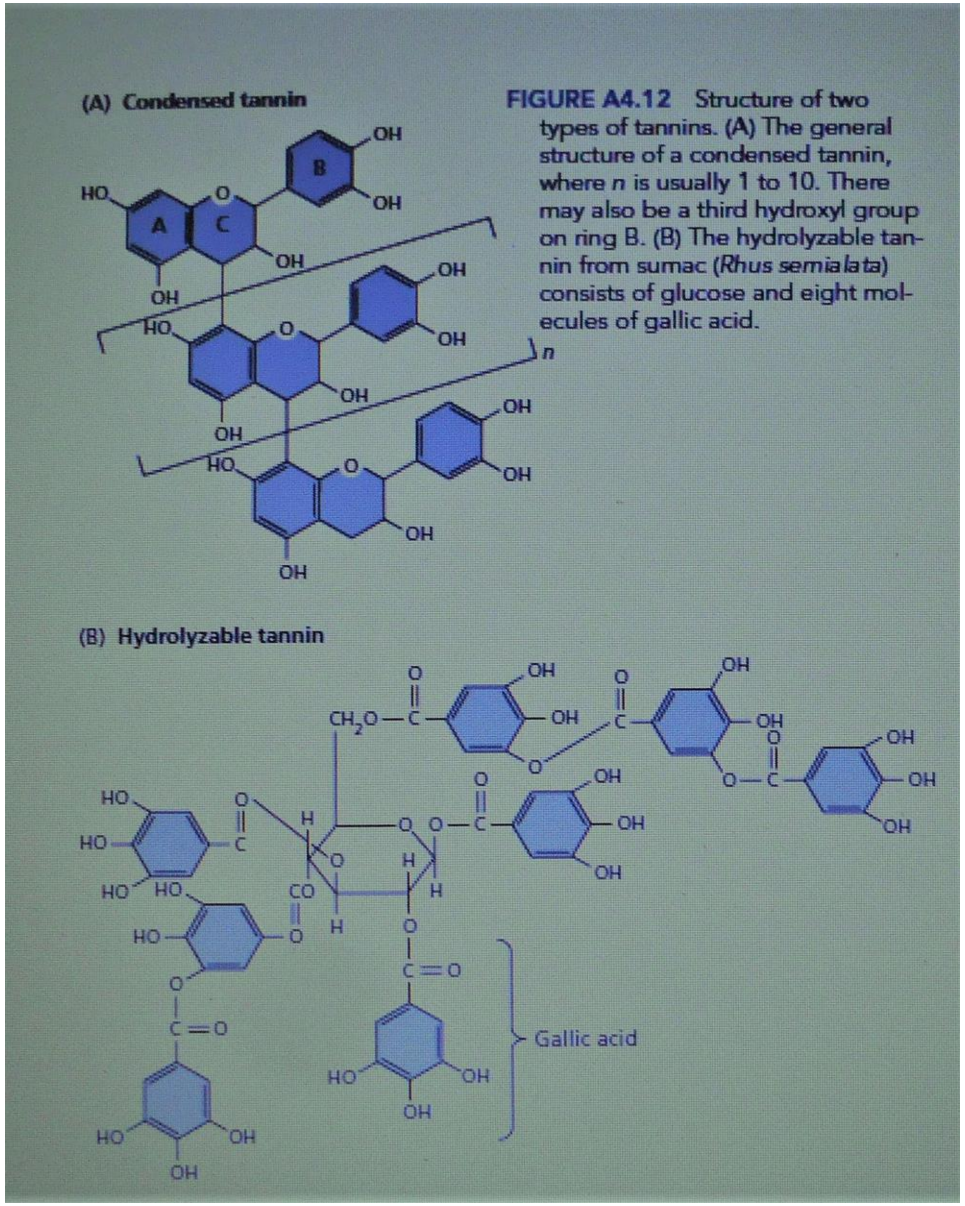
- The *isoflavones (isoflavonoids)* are a group of flavonoids in which the position of one aromatic ring (ring B) is shifted.
- *Isoflavonoids are mostly found in legumes.*
- Some such as *rotenone*, can be used as effectively as ***insecticides, pesticides*** *(e.g. rat poison)* and ***piscicides*** *(fish poison)*.
- *Other isoflavones* have ***anti-estrogenic effects***, for example, sheep grazing on clover rich in isoflavonoids, *suffer from infertility*.
- *Isoflavones* may also be ***responsible for the anticancer benefits of foods prepared from soybeans***.
- In the past few years, *isoflavones* have become best known for their role as *phytoalexins*, antimicrobial compound.

Deterring Effects of *Tannins* Feeding by Herbivores-1

- Tannins are the second largest category of plant phenolic polymers with defensive properties, besides Lignin.
- There are two categories of tannins:

1) *Condensed tannins* are common costituents of woody plants. Because they can often be hydrolyzed into anthocyanidines by treatment with strong acids, so they are sometimes called *pro-anthocyanidines*.

2) *Hydrolyzable tannins* are heterogenous polymers containing phenolic acids, especially *gallic acid*, and *simple sugars*. They are smaller than condense tannins and may be *hydrolyzed more easily*, only dilute acid is needed.



Deterring Effects of *Tannins* Feeding by Herbivores-2

- ***Tannins* *are general toxins*** **that can reduce the growth and survival of many herbivores when added to their diets.**
- ***Tannins*** **also act** ***as feeding repellents*** **to a great variety of animals such as cattle, deer and apes.**
- ***Unripe fruits of parts of plants are rich in tannins which deter feeding*.**
- ***Humans often prefer a certain level of astrigency in tannin-containing fruits*, such as *apples, blackberries, tea* and *grapes*.**
- ***Tannins in red wine*** **have been shown to block the formation of** ***endothelin-1*, *a signaling molecule that causes blood vessels constrict*. *This effect of wine tannins*** **may account for** ***health benefits of red wine*, especially the *reduction in the risk of heart disease*** **associated with** ***moderate red wine consumption*.**
- **In recent years, another phenolic compound,** ***stilbene phenylpropanoid resveratrol*** **has been identified as a health benefit factor** ***in red wine*.**
- **Plant tannins also serve as** ***defenses against microorganisms*, such as fungi and bacteria.**

3. Nitrogen-Containing Compounds
3.1. Alkaloids

- Alkaloids are a large family of *more than 15.000 nitrogen-containing secondary metabolites*.
- They are found in approx. *20% of vascular plant species*.
- Alkaloids are best known for their *striking pharmacological effects* on vertebrate animals.
- As their name would suggest, ***most alkaloids are alkaline***, and are ***positively charged*** and ***generally water soluble***.
- Alkaloids are usually synthesized from one of ***a few common amino acids-in particular,*** *lysine*, *tyrosine* or *tryptophan*.
- Most alkaloids are now believed to function *as defenses against herbivores*, *especially mammals because of their general toxicity and deterrence capability*. *Large number of livestock deaths are caused by the ingestion of alkaloid-containing plants*.
- *Nearly all alkaloids are also toxic to humans* when taken in sufficient quantities, such as *sytrichnine*, and *coniine* are classic alkaloid poisons. However, many are useful parmacologically. *Morphine*, *codeine* and *scopalamine* are currently used in medicine.
- Other alkaloids including *cocaine*, *nicotine*, and *caffeine* have widespread non-medical uses as *stimulants* and *sedatives*.

3. Nitrogen-Containing Compounds

3.2. Cyanogenic Glycosides

- Cyanogenic Glycosides and *glucosinolates* are not *naturally toxic*, but are readily broken down to give off poisons.
- Cyanogenic Glycosides release the *well-known poisonous gas, hydrogen cyanide (HCN).*
- Cyanogenic Glycosides *are not normally broken down in the intact plant because the glycoside and the degradative enzymez are spatially seperated in different cellular compartments or in different tissues.*
- This compartmentalization prevents decomposition of *glycoside*. When the leaves are damaged as during herbivore feeding, cell contents of different tissues mix, and *HCN* forms.
- CGs are widely distributed in the plant kingdom, in many legumes, grasses, and species of rose family.
- CGs have a protective function in certain plants. *HCN* is a fast acting toxin that inhibits metalloproteins such as *iron-containing cytochrome oxidase-* a key enzyme of mitochondrial respiration.
- CGs deters feeding by insects and other herbivores such as snails and slugs.
- *Tubers of Cassava (Monihot esculenta),* a high-starch stable food in many tropical countries, contain high levels of CGs.
- Traditional detoxification methods such as grating (rendeleme), soaking and drying to remove CGs from *Cassava* are not completely effective. So, chronic cyanide poisining leading to partial paralysis of the limbs is still widespread in regions where cassava is major food source.


Cassava (*Manihot esculenta*)

3. Nitrogen-Containing Compounds
3.3. Glucosinolates

- *Glucosinolates* are *second class of plant glycosides*, also known *mustard oil glycosides*, breaks down to release defensive substances.
- They are found principally in *Brassicaceae* and related plant families and break down to produce the compounds responsible for *smell and taste of cabbage, broccoli*, and *radishes*.
- *Glucosinolates* are *stored in the plant seperately from the enzymez* like *cyanogenic glycosides* that hydrolyze them, and *they are brought in contact with these enzymez only when the plant is crushed*.
- Most of the recent research on *glucosinolates* in plant defense has focused on *rape or canola* (*Brassica napus*), a major oilseed crop in North America and Europe.
- Plant breeders have tried to lower the *glucosinolate and erucic acid* levels of rape seeds.


CANOLA OIL
THE GOOD, THE BAD & THE UGLY
healthylivinghowto.com

3. Nitrogen-Containing Compounds

3.4. Non-Protein Amino Acids

- **Plants and animals incorporate the *same 20 amino acids* in their proteins.**
- **Many plants also contain unusual amino acids, called non-protein amino acids that are not incorporated into proteins.**
- **These amino acids are present *in free form and act as defensive substances*.**
- **Many nonprotein amino acids are very similar to common amino acids. For example, *canavanine* is a close analog of *arginine*.**
- **Nonprotein amino acids exert their toxicity in various ways.**
- **Some block the synthesis or uptake of protein amino acids.**
- ***Plants that synthesize non-protein amino acids are not susceptible to toxicity of these compounds*.**

9.
Plant Growth Regulators

What is Plant Growth Regulator (PGR)?

- **Some organic chemicals which have regulatory effects, rather than a nutritional role in plant growth & development, are called *'Plant Growth Regulators'(PGRs)*.**
- **The term *'Plant Growth Regulators' (PGRs)* involves both chemicals *occuring naturally within plant tissues at extremely low concentrations* that are called *'Plant Hormones'*, and *synthetic (man-made) chemicals* with similar physiological activities to plant hormones, called *'Plant Growth Substances'(PGSs)*.**
- ***PGRs* can be classified into two categories as *promoters (biostimulants)* and *inhibitors (bioinhibitors)*.**

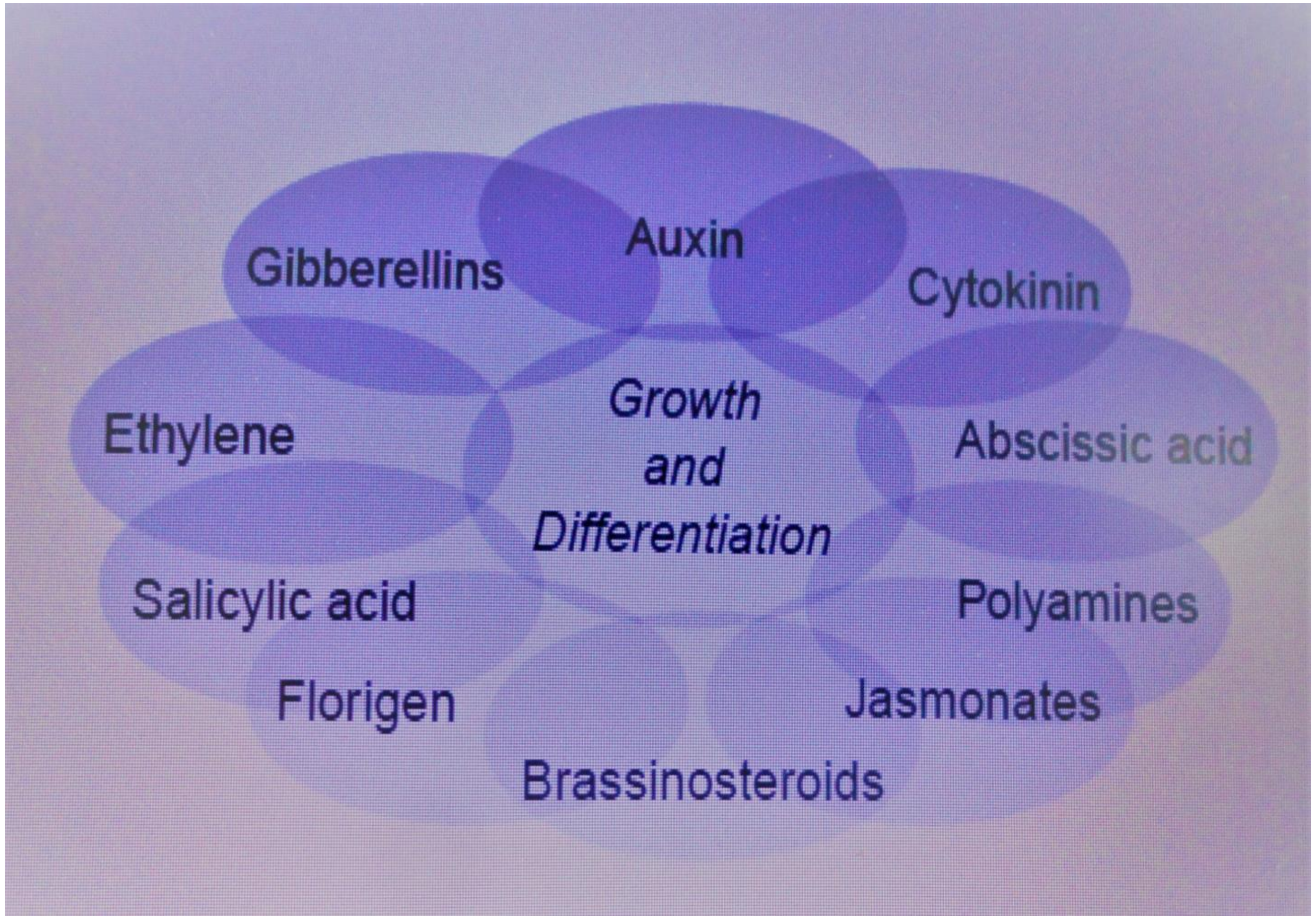
Classification of Plant Hormones

First Five

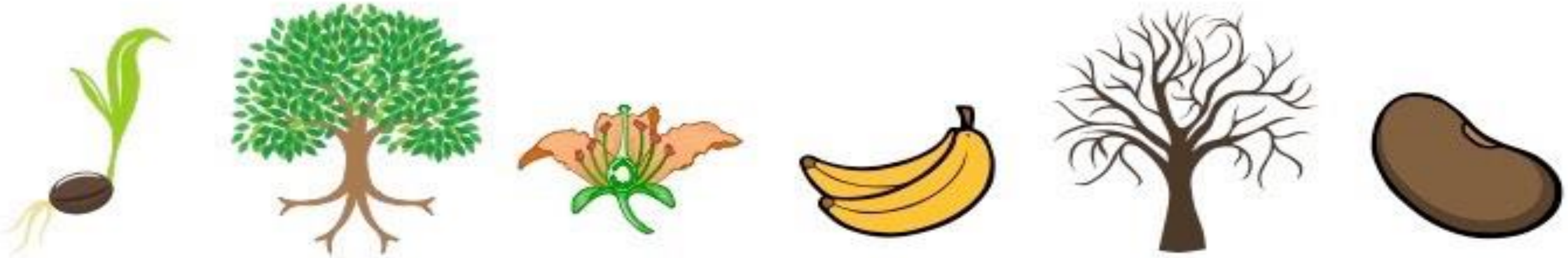
1. Auxin
2. Cytokinins
3. Gibberellins
4. Ethylene
5. Abscisic Acid

Second Five

1. Florigen
2. Brassinosteroids
3. Jasmonates
4. Polyamines
5. Salicylic Acid



Developmental Effects of Major Plant Hormones

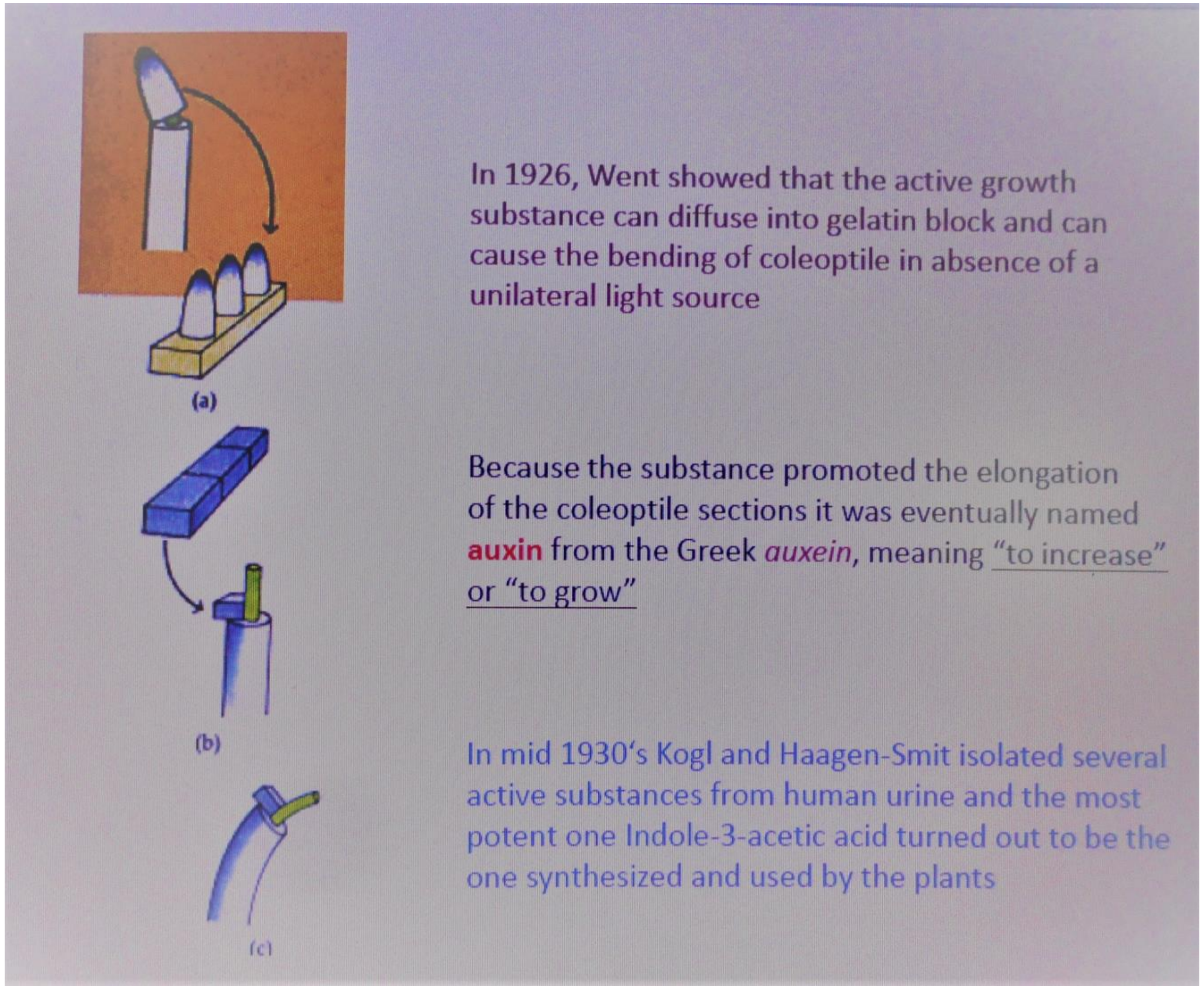


	Germination	Growth to Maturity	Flowering	Fruit Development	Abscission	Seed Dormancy
Gibberellin	✓	✓	✓	✓	✗	✗
Auxin	✗	✓	✓	✓	✗	✗
Cytokinins	✗	✓	✓	✓	✗	✗
Ethylene	✗	✗	✓	✓	✓	✗
Abscisic Acid	✗	✗	✗	✗	✓	✓

Auxins

Description & Discovery

- An auxin is a plant hormone or growth regulator that promotes *cell elongation* in tissue segments when applied at low concentrations.
- The general term *auxins* is used to refer to the group of substances which have auxin-like properties when applied to growing plants.



Classification

- **Naturally Occuring Auxin**
- ***Indole- 3-Acetic Acid (IAA) ($C_{10}H_9NO_2$)***
- **Synthetic Auxins**

Indole-3-Butyric Acid (IBA) ($C_{12}H_{13}NO_2$)

Naphtalene Acetic Acid (NAA) ($C_{12}H_{10}O_2$)

2,4-Dichlorophenoxy Acetic Acid (2,4-D) ($C_8H_6Cl_2O_3$)

Production

Auxin synthesis occurs in young meristematic tissues;

1. **Apical meristems of shoot and root,**
2. **Developing embryos,**
3. **Young fruit,**
4. **Young, rapidly growing leaves.**

Transport

- **Auxin transport is generally described as *basipetal* that occurs from either shoot or root apices towards the juncture of the root and the stem.**
- **Auxin transport in cells and tissues is *strongly polar*** ***(Polar auxin transport is the regulated transport of the plant hormone auxin in plants. It is an active process, the hormone is transported in cell-to-cell manner)*** **which is temperature sensitive and requires metabolic energy.**

Developmental Effects

1. Induction of Cell and Stem Elongation:

- Auxin induces cell elongation.
- While auxin stimulates stem elongation, it inhibits the elongation of root cells.

2. Tropic Responses:

Auxin is responsible for two very important plant tropic responses;

a) Phototropism-inclining towards light

b) Gravitropism-inclining towards gravity

3. Promotion of Root Initiation:

Auxin stimulates root initiation on stem cuttings.

4. Lateral Shoot Inhibition *(Apical Dominance)*:

- Auxin inhibits lateral shoot formation in many species by inhibiting lateral bud growth which is known as *apical dominance*.

Examples of Horticultural Utilization of Auxins

1. Use of 2,4-D as Herbicide

One of the most prevalent uses of synthetic auxins is the use of 2,4-D, as a selective broadleaf herbicide.

2. Root Promotion

Root formation from stem cuttings is enhanced using auxins.

3. Fruit Thinning

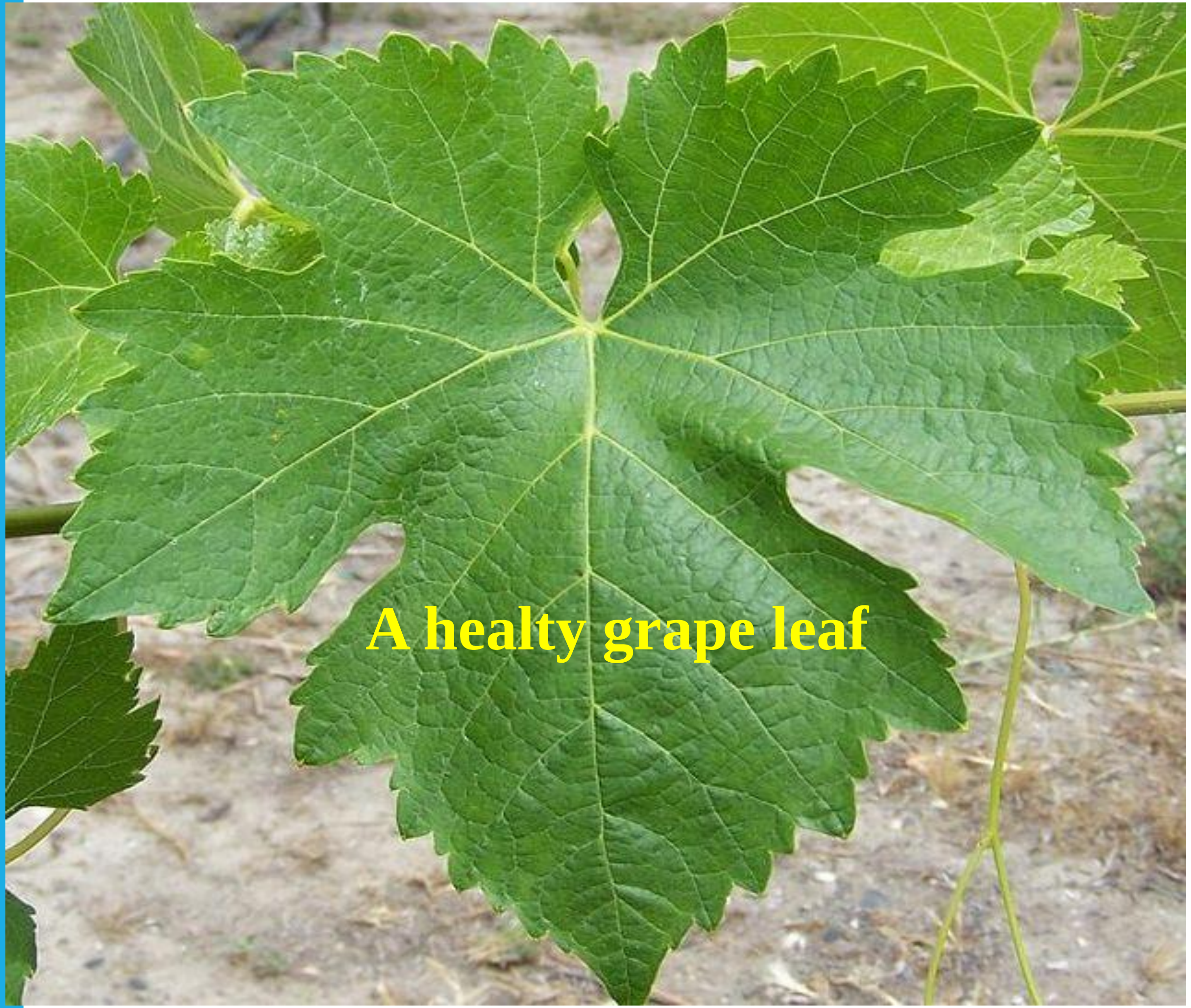
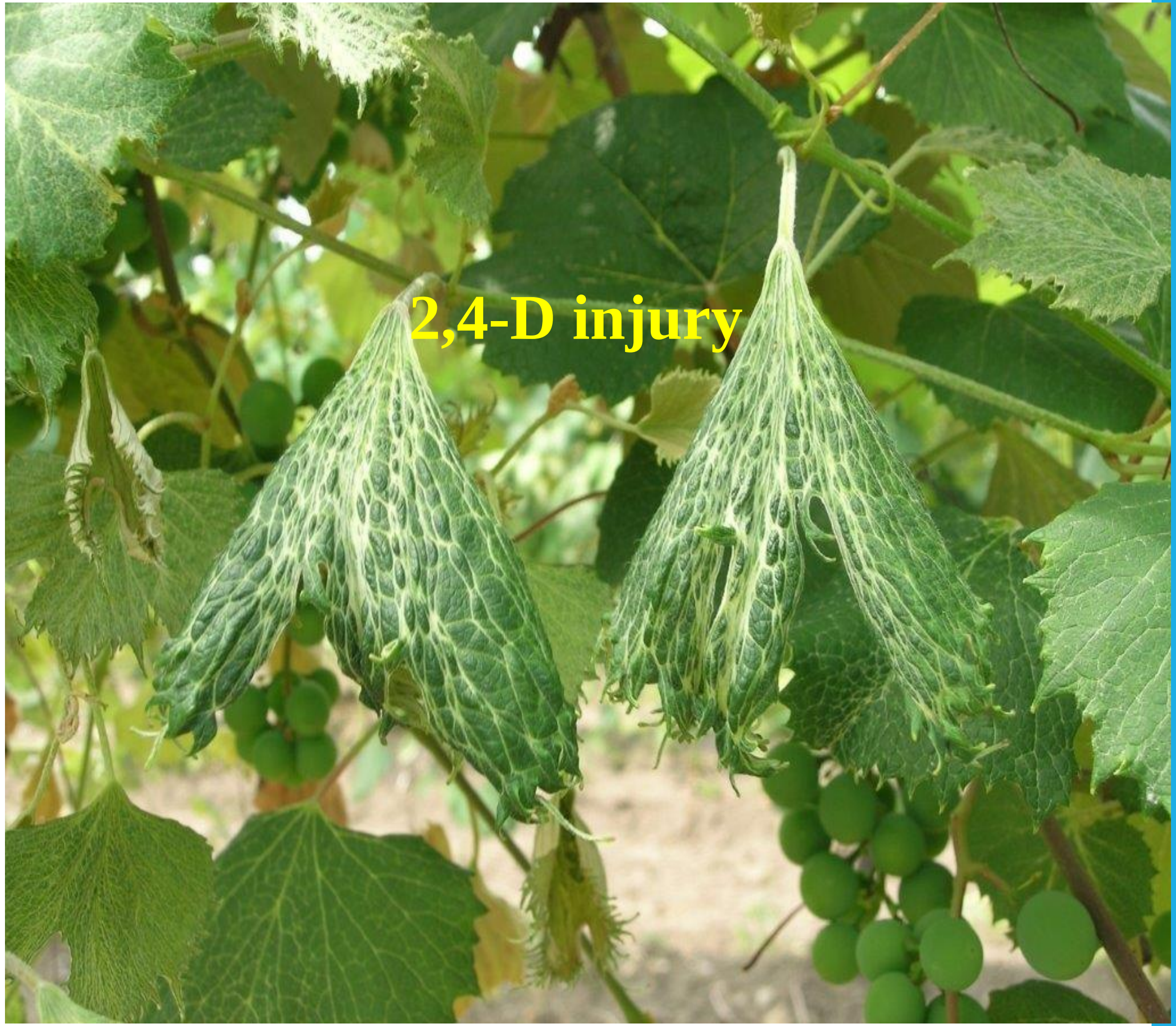
Foliar application of NAA at *10 ppm* is often used for thinning apples.

4. Floral Induction

Foliar application of NAA induces ethylene production which induces floral induction in pineapple.

5. Stimulation of Fruit-Set

Fruit set of *tomato, eggplant, pepper and cucumber* grown in unheated greenhouses in the absence of adequate pollination and fertilization can be enhanced with auxin application.


A healty grape leaf

2,4-D injury

Cytokinins

Description & Nomenclature

- Cytokinins are plant hormones which promote ***cytokinesis (cell division)*** in tissue culture ***(in presence of auxin)***.
- The first plant-based cytokinin was ***Trans-Zeatin*** *6 - (4-Hydroxy-3-methylbut-2-benzylamino) Purine* ($C_{10}H_{13}N_5O$)
- The naturally occuring cytokinins are mostly based on ***Zeatin***.
- The two major synthetic cytokinins are;

✓ ***6-Benzyladenine (BA), also called 6-Benzylaminopurine (BAP)***

✓ ***(6-Furfurylaminopurine) (Kinetin)***

Production & Transport

- Cytokinins are produced primarily in ***root tips*** **and** ***developing seeds***. However, any tissue with a high rate of cell division may produce cytokinins.
- Cytokinins are transported generally ***in the xylem***.
- ***Phloem sap*** also contains cytokinins, but at much lower levels than xylem sap.

Developmental Effects

1. Induction of Cell Division

- **Cytokinins stimulate cell division in callus culture, but growth is limited if auxins are absent.**
- **If the *balance of auxin to cytokinin* is tissue culture is shifted towards cytokinin, *shoot formation* is favoured, if it is shifted towards auxin, *root formation* is favoured.**

2. Overcoming Apical Dominance

- **Cytokinins stimulate the release of lateral buds from apical dominance imposed by auxin from the apical bud.**

Horticultural Utilization

- **Commercial formulations of BA are available from a number of manufacturers, and are often a mixture with gibberellins;**

1. Fruit Thinning

Fruit size and weight can be enhanced via fruit thinning with the application of BA in apple and pear at the period from full-bloom to the fruits reached *10-12 mm in size*.

2. Lateral Branching

In nursery production of apple, pear and cherry, lateral branching can be induced with BA that accelerates the formation of a well-branched tree.

3. Delay of Senescence

Application of a mixture of BA and GA to lilly bulbs, delays senescence of lower leaves and open flowers.

4. Induction of Growth in *Poinsettia*

If a similar BA/GA combination apply to Poinsettia *(Euphorbia pulcherrima)*, (also called Gazi Atatürk Flower which name is given by Prof.Dr. Kirk Landın who is the breeder of the flower at Wanderbit Univ. in Chicago), before short-day induction of flowering, overall vegetative growth is induced.

5. Increase of Berry Quality

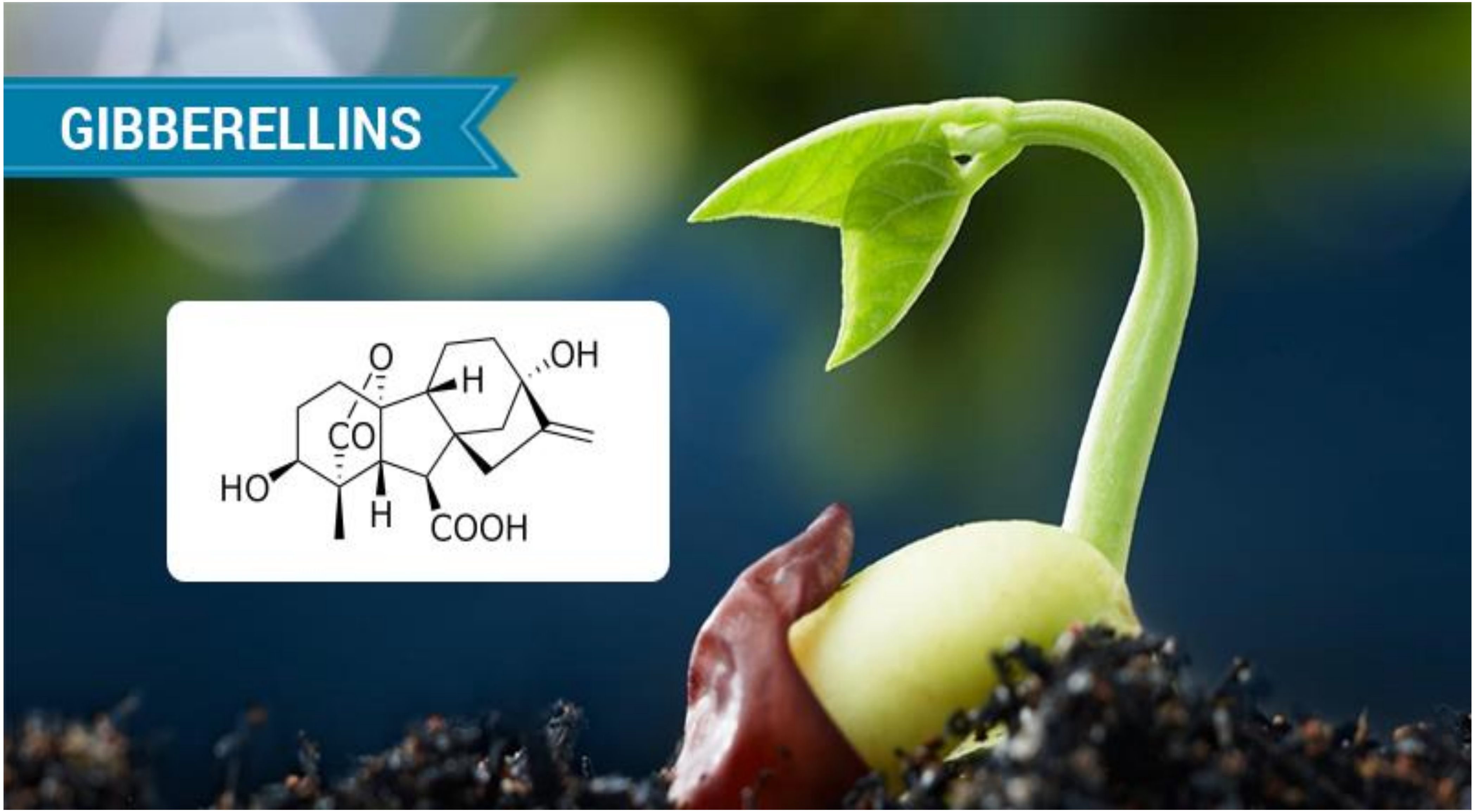
A synthetic cytokinin forchlorfenuron (4-CPPU) increases berry size and uniformity in table grapes and kiwifruit leading the increased yield.

Poinsettia (Gazi Atatürk Çiçeği)

Gibberellins

Description

- **Gibberellins are growth regulating substances while promote *stem, root and fruit growth*.**
- **They are structurely *diterpenes (20-C)*.**
- **They are over *110 different moleculer forms* of gibberellin, and they are identified as *gibberellic acid* (*GA_1, GA_2, GA_3.........GA_{110}*).**
- **Although they are *similar in structure*, they are all *very different in their biological activity*.**
- ***Only about 30% of the known gibberellins* are *physiologically active*.**
- ***GA_1* is *most biologically active*, and GA_3 ($C_{19}H_{22}O_6$) *is the easiest and least expensive GA* to extract from fungal cultures for commercial use.**


GIBBERELLINS
O
H
OH
CO
HO
H
COOH

Discovery & Production

Discovery

- The first gibberellin GA_3 was isolated from cultures of *Gibberella fujikuro* fungus which is responsible for *foolish seedling disease of rice* and given the name gibberellin.
- Since its discovery, over 110 forms of GA have been isolated from plant tissues.

Production

- Growing meristematic tissue including *root and shoot apical cells, young leaves, young fruits, and developing seeds* (especially the endosperm) produce GAs.
- GA_3 is the only gibberellin obtainable in commercial quantities.
- A more expensive mixture of GA_4 and GA_7 is now available for specific uses.

Transport

- ***GA*** **transport occurs primarily in *phloem*, but may also occur in *xylem* and from cell to cell.**
- **Shoot apex and root tips has always a high level of *GA*.**
- **It appears that *GAs* are transported from shoots to roots via *phloem*.**

Developmental Effects

- **1. Stem Elongation**

✓ ***GA*** **induces extensive stem growth in many *rosette* plants and dwarf mutants.**

- **2. Flowering , Pollination & Fruit-Set**

✓ ***GA*** **generally *stimulates pollen germination* and subsequent *pollen tube growth down* the style leading to fertilization.**

✓ ***GA*** **enhances *fruit-set* above the normal such as *tomato* *(Solanum lycopersicum)*, *grape* *(Vitis spp.)*, *stone fruits* *(Prunus spp.)*, *apples* *(Malus spp.)* and *pears* *(Pyrus spp.)*.**

✓ **Parthenocarpy** *(seedless fruit formation without fertilization)* **in *apples*, *grapes*, *pumpkin*, and *eggplant* may also be *stimulated with GA treatment*.**

✓ **3. Seed Germination**

✓ **Certain seeds have a specific long-day photoperiodic requirement for germination.**

✓ ***GA*** **treatment can substitute for the long-day requirement.**

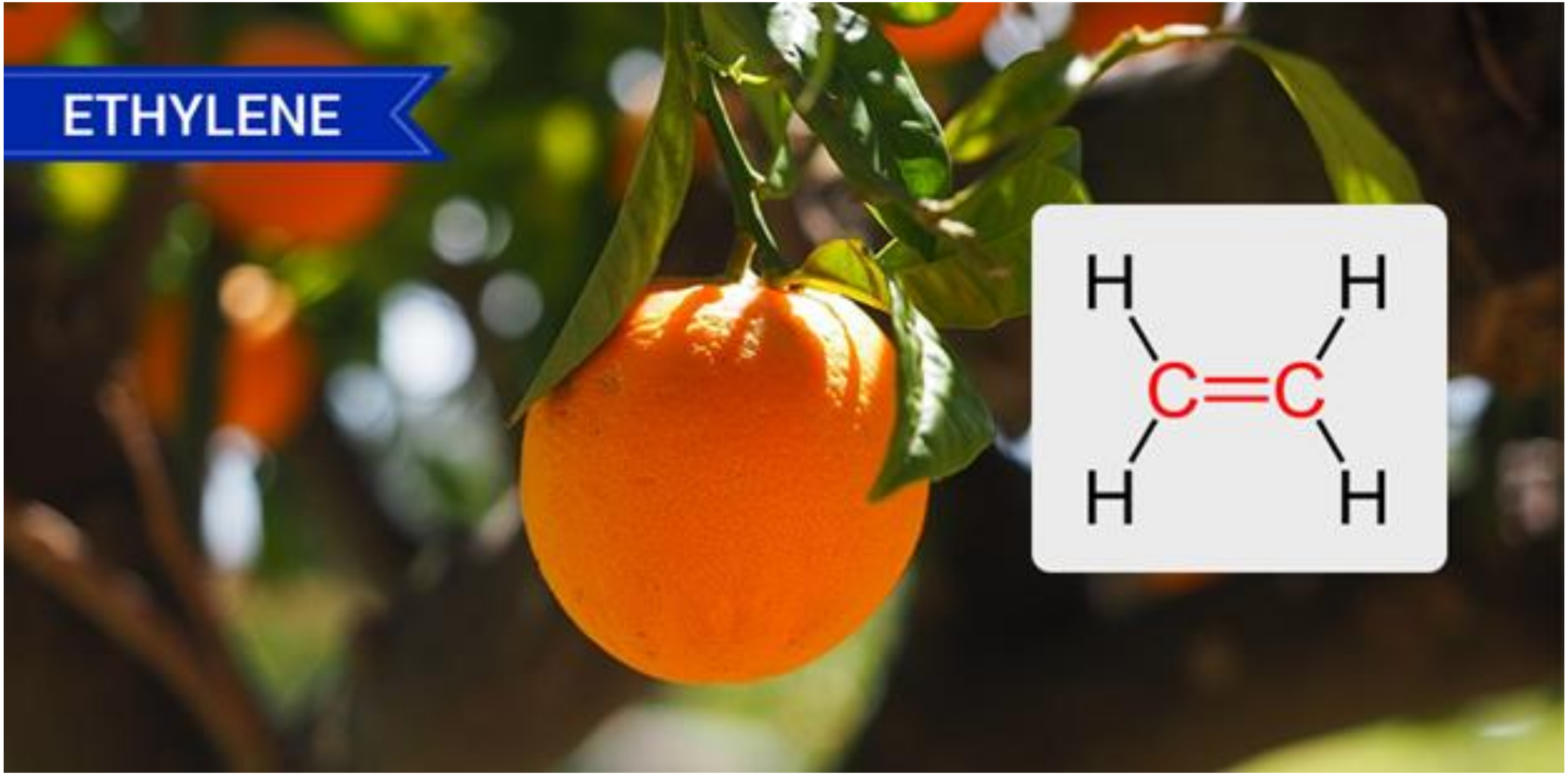
Horticultural Utilization

1. ***GA_3* sprays elongates the stalks of *celery* and *rhubarb*.**

2. ***GA_3* sprays at full-bloom and/or in a week after berry-set increase the size of clusters and berries of stenospermocarphic seedless grape varieties such as *Sultani*, *Perlette*, *Flame*.**

3. **There are a number of chemicals which inhibit the *GA* synthesis that are used extensively in ornamental horticulture including *Phospan D*, *CCC (cycocel)*, *Amo 1618*, *Ancymidol*, *Paclobutrazol*, *and Alar (B-nine)* to control the growth rate.**

Ethylene


ETHYLENE
H H
C=C
H H

Description-Production-Transport

Description:

- **Ethylene (C_2H_4) is the single substance which exists in nature as a gas.**
- **It is also only hydrocarbon with a pronounced effect on plant growth & development.**

Production:

- **Ethylene is produced in all plant tissues, often as a response to stress such as drought, flooding, mechanical pressure, injury or infection.**
- **Ethylene production is often stimulated by auxin.**
- **Meristematic regions and senescing tissues, especially fruits are rich sources of ethylene gas.**

Transport:

- **Ethylene travels through the plant via diffusion from cell to cell.**
- **Since it is produced in all tissues, it's transport is not normally necessary for an effect to be realized.**

Development of Ethephon

- **Since the development of Ethephon *(2-chloroethylphosphonic acid)*, Ethylene application is greatly simplified.**
- **Because Ethephon is applied as an aqueous spray and is absorbed into plant tissues.**
- **It decomposes there to release ethylene gas, chloride and phosphate ions.**

Developmental Effects

1. Fruit Ripening, Senescence & Abscission:

- Since ethylene promotes fruit ripening, senescence, and abscission, so known as *ripening* and *aging* hormone.

2. Ethylene Triple Response:

- Pea *(Pisum sativum)* seedlings treated with ethylene show a triple response to the gas proportional to the level of exposure; a) greatly shortened internodes, b) increased stem diameter, c) a lack of normal gravitropic response.

3. Thigmomorphogenesis:

- Responses of plants to touch known as *thigmomorphogenesis*, are usually attributable to ethylene action.

Continued…

- **4. Delay of Flowering:**
  - **Ethephon application to peach (Prunus persica) or cherry (Prunus avium) in the fall at approx. 50% of leaf fall, flowering is delayed in the following spring by as much as 14 days that also increases the cold tolerance of flowers buds by reducing the size and water content and increasing the sugar content of the pistil.**

5. Epinasty:

- **Excessive watering of houseplants is a common malady leads to ethylene production by the plants that induce epinasty, a downward bending or drooping of leaves.**
- **Caretakers often see this drooping as a sign of water stress and proceed to water the plant even more.**

- **6. Fruit Ripening:**
  - **Ethylene enhances ripening of climacteric fruits (tends to ripen after harvest) that are harvested mature but not ripe, such as banana, apple, pear, kiwifruit, avocado, persimmon.**

Abscisic Acid

Facts About Abscisic Acid

- **1. Description:**

✓ **Abscisic acid (ABA) ($C_{15}H_{20}O_4$)** *is often described* ***as an inhibitor*** *which is unfortunate as ABA promotes several physiological components of plant growth and development.*

2. Discovery:

✓ **ABA** *was recognised in 1967 as a new plant hormone with this name* **ABA.** *Naturally, it is a* ***sesquiterpene*** ***(15-C).***

3. Nomenclature:

✓ **ABA** ***is a single substance,*** *rather than a group of related substances as in auxins, GAs, and cytokinins.*

4. Production:

✓ *ABA is primarily synthesized in* ***mature leaves and roots*** *in response to water stress, or in all other plant tissues.*

✓ *It is mostly synthesized from* ***carotenoids*** *(tetraterpenoid plant pigments responsible for bright red, yellow and orange hues in many fruits and vegetables).*

5. Transport:

✓ *Long-distance transport is* ***mostly in phloem****, and to a lesser degree in the xylem.*

Developmental Effects

1. Plant Stress and Cross-Protection:

- ✓ ABA *increases during times of plant stress, providing protection from the stress via various mechanisms. Thereby, ABA acts a promoter, promoting plant survival.*
- ✓ **During drought stress, ABA levels in leaves rise dramatically, causing closure of stomata and the production of proteins that are protective membranes and other cellular structures during dehydration.**
- ✓ *The general response of increased synthesis of specific proteins during many different types of stresses such as salt, heat and pathogen attack, led to define ABA as a stress hormone in plants. This is known as cross-protection.*

2. Water Stress Responses:

- ✓ *Water stress induces a rapid increase in* ABA *synthesis, but increase in tissue* ABA *content is transient, with removal of stress,* ABA *synthesis decreases even if the stress is removed.*
- ✓ *So,* ABA *must be a signal for cellular stress-coping mechanism.*

3. Seed Maturation and Dormancy

- ✓ **Second major function of ABA is its involvement in seed maturation and dormancy.**

Horticultural Utilization

- In spite of some promising attempts recently, there are still no practical use of ABA in Horticulture.
- Because it is very expensive to synthesize.
- Additionally, it degrades rapidly in the light.

- Increases in cold hardiness have been associated with ABA and ABA analog application, but consistent positive results are still lacking.

Other *(Second Five)* Plant Hormones

1. Florigen:

Many plant scientists have also sought a single substance, florigen, that is responsible for the transition from the vegetative to the sexually reproductive state in plants.

2. Brassinosteroids (BRs):

They are naturally occuring steroids (*triterpenes with 30-C molecules*) that promote stem elongation, stimulate tracheid formation in differentiating xylem tissue, and pollen tube growth.

3. Jasmonates:

Jasmonates as Jasmonic Acid and Methyl Jasmonate have been identified as the major compounds responsible for inducing plant defense responses to insect and pathogen attack, also increase the production of secondary metabolites that play a role in plant defenses.

4. Polyamines:

They are strongly basic protein-based substances of low molecular weight that exist either free or bound in all plant cells that enhance cell division, and prevent mitotic senescence.

5. Salicylic acid (*SA*) ($C_7H_6O_3$):

A phenolic plant hormone with roles in photosynthesis, transpiration, ion uptake and transport. Most widely known roles of SA for *signaling plant defense against pathogens*, and *thermogenicity* *(ability in raising their temperature above environment)* in plants and *flowering* in certain species.

10.
Growth & Development

What is Growth?

- **Growth is an irreversible increase in the number and/or size of cells in a living organism.**
- **For a while, growth may rely on cell division, while later in development it may primarily rely on cell enlargement.**
- **Growth is irreversible. Once the number of cells in an organism increases, their number normally does not decrease.**
- **Senescence envisioned as the opposite of growth, a decrease in size due to a decrease in cell size** ***(as a result of water loss and utilization of cell reserves),*** **number** ***(due to cell death),*** **or both.**

How to Measure Growth?

- Growth is often measured at different levels.
- At cellular level, growth can be measured as an increase in cell number, cell diameter, cell volume.
- On a whole plant or tissue level, shoot length, stem diameter, fruit volume, fruit weight can be measured.
- Once we have a series of measurements over time, we can create a graph of the growth over time of this organism.
- This graphical representation of growth is called growth curve.

Types of Growth

- **Primary Growth:**
  Increase in the length of the plant body by the mitotic division of meristematic cells present at the root and shoot apex.
- **Secondary Growth:**
  Increase in the diameter of the plant body by secondary meristem.
- **Unlimited or Indeterminate Growth:**
  Continuous growth of the root and the shoot system of plants from germination stage to the death or throughout the life span of the plant.
- **Limited or Determinate Growth:**
  Cessation of growth of the leaves, fruits and flowers after attaining certain size.
- **Vegetative Growth/Phase:**
  The earlier growth of plant producing leaves, stem and branches without flowers.
- **Reproductive Growth:**
  Production of flowers which is the reproductive part of the plant after the vegetative growth.

Growth Rate & Exponential Growth

- It should be kept in mind, growth is not simply a straight line.
- Growth Rate is growing over time (per hour, day, week, month, season 'year' etc.)
- Exponential Growth is characterized by an increasing rate of over time.
- One of the major characteristics of the Exponential Growth curve is that growth increases at a faster and faster rate as time passes.
- If we calculate the increase in growth as a percentage, this is called Classic Exponential Growth.
- Description of growth measurement with a mathematical equation is called modeling.

Sigmoidal Growth Curve

Sigmoidal Growth Curve consists of three main stages;

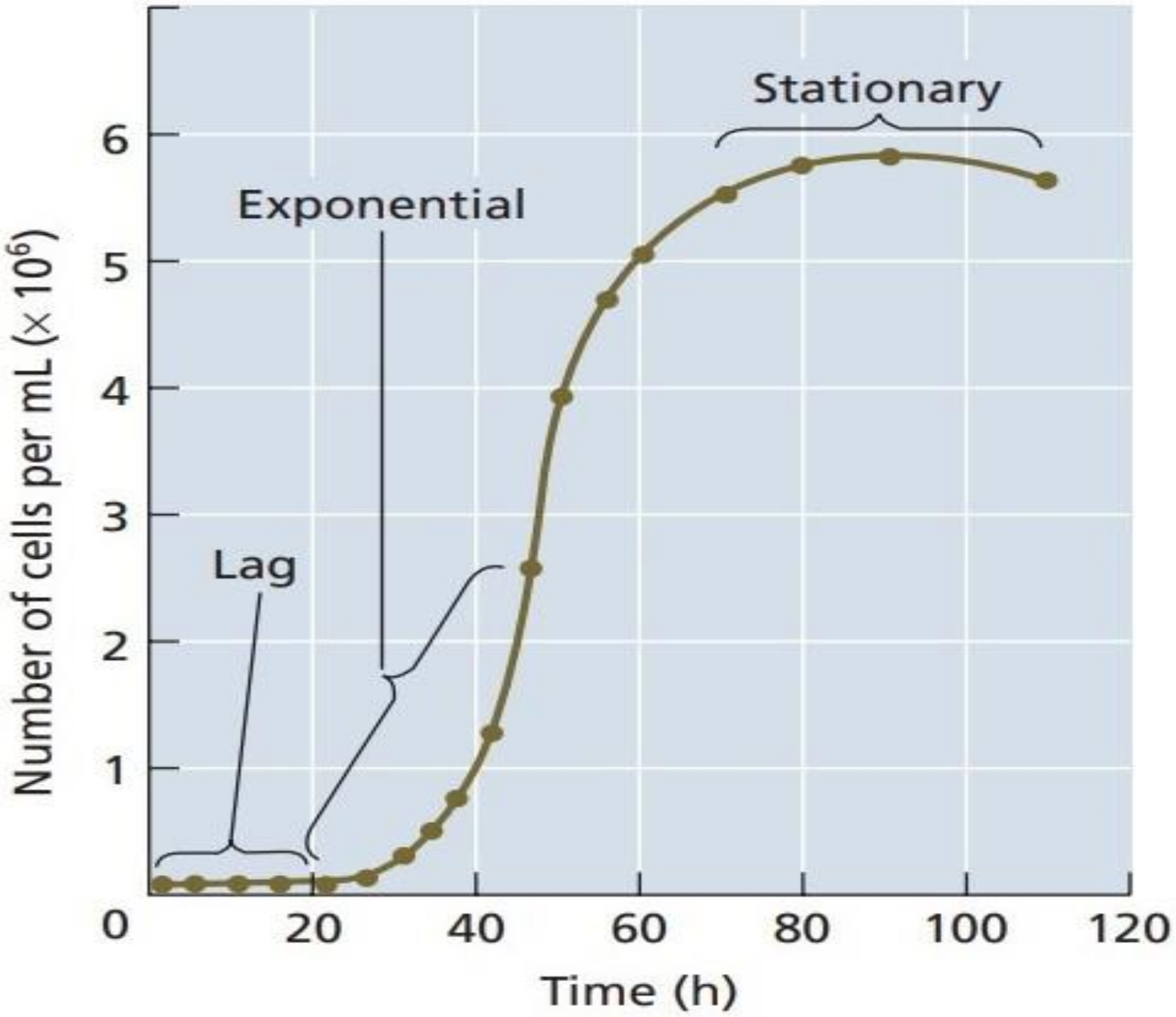
1. Lag Phase: This first phase is characterized by an initial slow gradual increase in growth parameters.

2. Log phase: There is a rapid increase in parameter also called as *Exponential Growth Phase.*

3. Stationary phase: There is a gradual decline in the rate of increase of parameter.

Usually the increase ceases and the curve levels out.

Fruit growth often follows the *Sigmoidal Growth Curve*.



Double Sigmoid Growth Curve

- While an apple fruit follows a sigmoid curve, a grape berry and a peach fruit follow a Double Sigmoid Growth Curve.
- A Double Sigmoid Curve can be thought of as two sigmoid growth curves.
- First Sigmoid Curve represents growth of the fruit mesocarp (flesh), primarily by cell division and is often called 'Phase I'.
- Second Sigmoid Curve represents the period called final swell which is due to mesocarp cell enlargement, called 'Phase III'.
- 'Phase II' is the period of endocarp or pith hardening, called Lag phase.

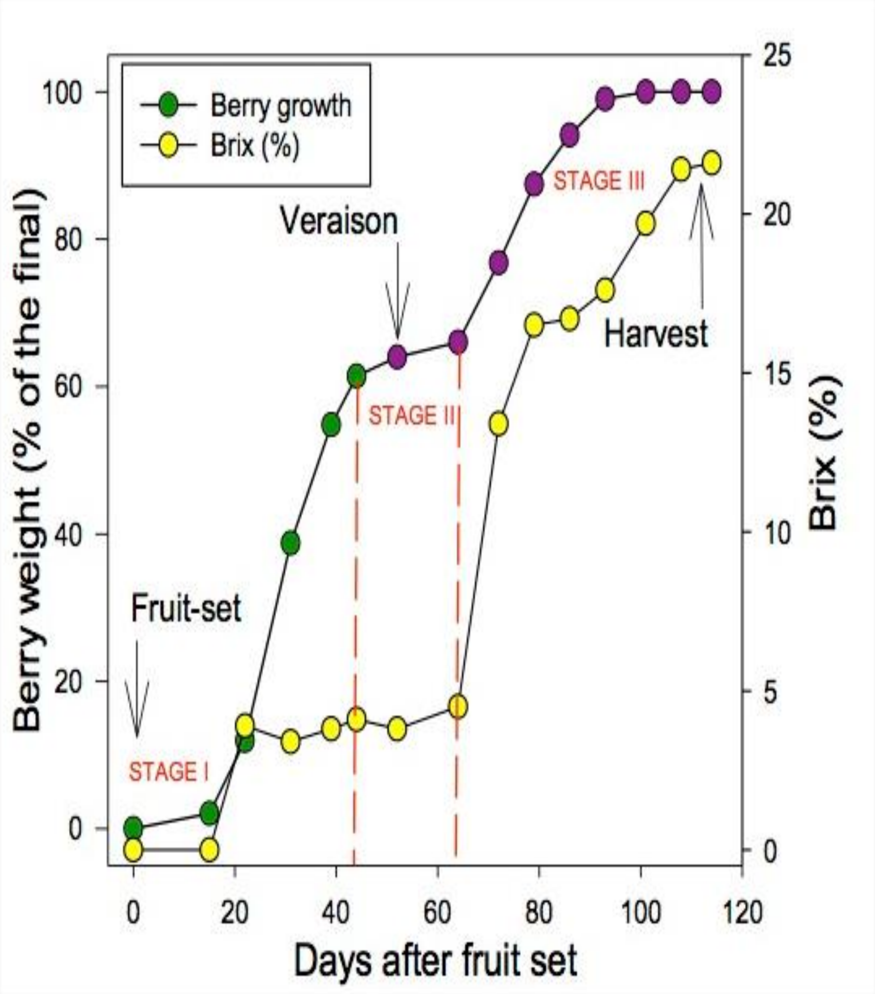


Figure 1. Berry growth (percent of final weight) and sugar accumulation (Brix) in Cabernet franc from fruit set to harvest. Note the three distinctive stages (I, II, and III) of the double sigmoid pattern and the rapid accumulation of sugar at the end of Stage II.

Development & Differentiation

- **Development:**
  Forward growth of organs and whole plant, all towards achieving the plant's ultimate functionality.
- **Differentiation:**
  Specialization process in the cells of the root and the shoot apical meristems and the cambium mature to perform specific functions.
- **De-differentiation:**
  Return to cells to a general or primitive state. It can occur at the cellular level. Cells once held a differentiated function may be de-differentiate to form a mass of non-differentiated tissue called callus.

- ✓ **While development and differentiation are irreversible, de-differentiation is reversible.**
- ✓ **Development is a part of differentiation.**
- ✓ **Since all cells of a given organism have the same genetics, differentiation within an organism is largely directed by environment.**
- ✓ **Development follows differentiation.**

Development of a Plant From an Embryo Through Maturity

1. If an Angiosperm plant is formed via sexually, reproduction starts out as a single-celled zygote formed from the union of an egg cell and a sperm cell.

2. This single cell reproduces via mitosis to form a multi-cellular embryo.

3. The embryo continues to increase in size via cell division and enlargement.

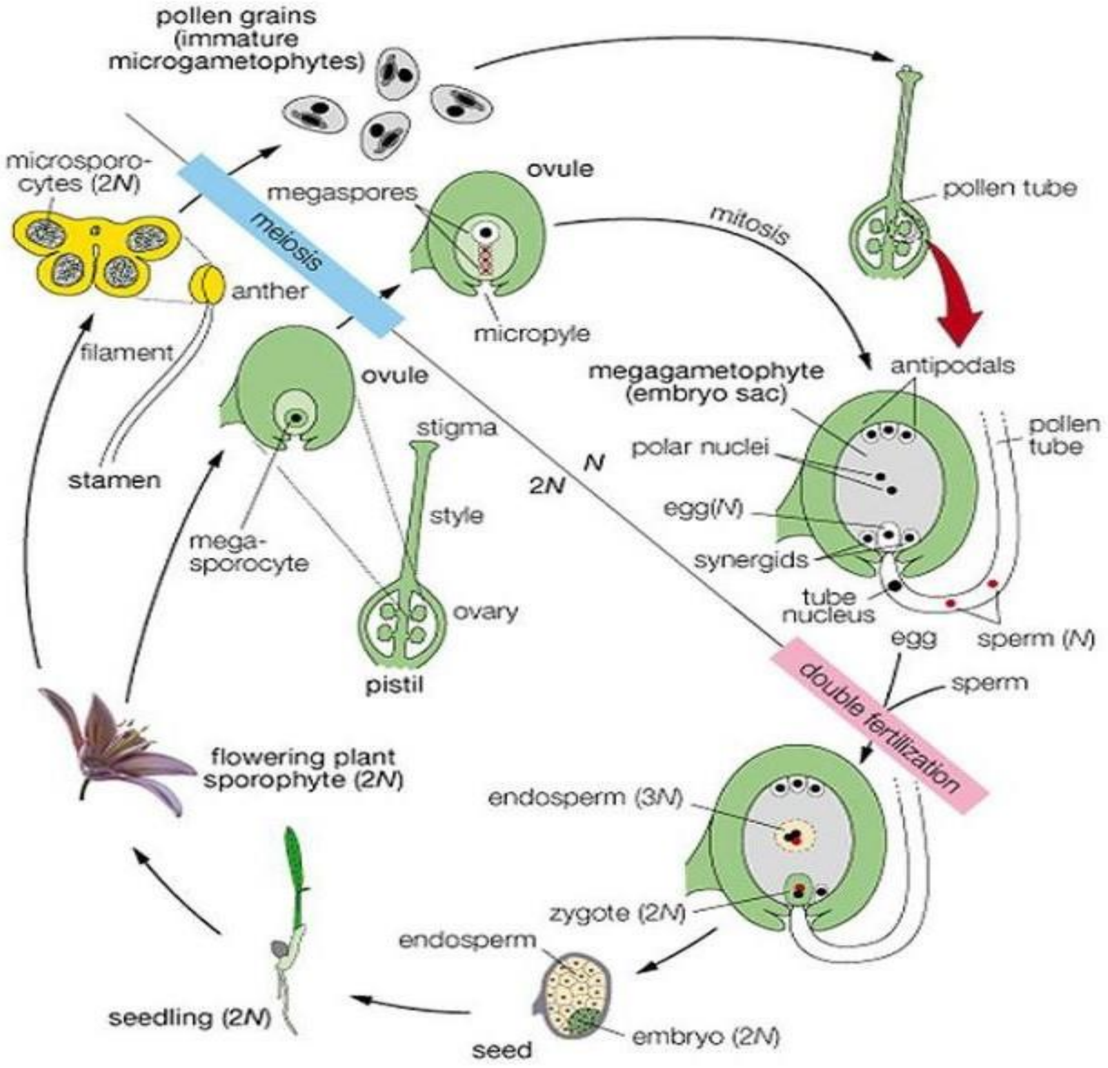
4. Root tissues begin to become distinguishable from shoot tissues.

5. Leaves begin to be distinguished from stems, and the development of the new plant *(seedling)* proceeds.

6. There may be a lag phase in growth as a seed lays dormant, waiting for conditions to be acceptable for further movement towards final form and function *(dormancy)*.

7. Conversely, embryo may not stop in its movement, and may quickly develop via germination into a young seedling.

8. Seedling then proceeds towards its final destination.



Factors Affecting Growth & Development

(1. Genetics)

- Genetics hold the potential for plant growth.
- Genetics is a simply elegant code for one of the most sophisticated *(karmaşık)* process on earth; life.
- Essentially, four nucleotides (*the basic building block of nucleic acids, RNA and DNA),* *adenine, guanine, cytosine, thymine* pair up (*adenine with thymine,* and *guanine with cytosine*) to form sequences of base pairs *(baz çifti)* which ultimately code for the 20 amino acids commonly found in proteins.
- Proteins formed from combinations of these amino acids form enzymes which control the all life processes that are run by the enzymes and all enzymes are proteins.

Factors Affecting Growth & Development
(2. Environment)

- **Environmental factors control the expression of genetic potential.**
- **There are specific proteins in plants in response to environmental stimuli.**
- **One of the most highly studied signal-catching proteins in plants is Phytochrome, and the signal that it catches is light.**
- **Phytochrome changes its shape when exposed to light of differing wavelenghts particularly red (660 nm) and far-red (730 nm) light.**
- **The Phytochrome molecule's shape or form, most often called *Pr* or *Pfr*** *(biologically-inactive form of phytochrome (Pr) is converted to the biologically-active form Pfr under illumination with **red light**),* **then influences what sort of physiological response occurs.**
- **Original light signal perceived by the plant is passed along within the plant via secondary messages in a process called transduction** ***(transfer of signal).***

Plant Movements as a Response to Environmental Stimuli

Plants may exhibit a series of **induced movements** in response to external stimuli.

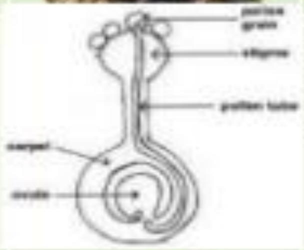
Three classes of **induced movement** are tropic, nastic, and tactic.

1. **Tropic Movement:** A positive or negative response of a plant to a stimulus that are growth movements toward or away from a unidirectional environmental stimulus such as light, chemicals, water, temperature, touch etc.
2. **Nastic Movement:** A quick movement by plants in reaction to external stimulus such as light, temperature, chemicals, touch etc.,that are reversible and repeatable. The movement can be due to changes in turgor or changes in growth.
3. **Tactic Movement:** A locomotory movement of complete cells or organelles (e.g. chloroplasts) in response to external stimuli such as light, chemicals, or temperature.

Tropic and Nastic Plant Movements

	Tropic Movement	Nastic Movement
DEFINITION	Tropic movement is a response to a stimulus that comes from one direction	Nastic movement is a non-directional response for a stimulus
DIRECTION OF THE RESPONSE	Directional	Non-directional
DIRECTION OF THE STIMULUS	Depends on the direction of the stimulus	Does not depend on the direction of the stimulus
REASON FOR ACTION	Cell division	Turgor pressure
TYPES	Phototropism, geotropism, thigmotropism, chemotropism, hydrotropism, etc.	Epinasty, hyponasty, photonasty, nyctinasty, chemonasty, hydronasty, thermonasty, geonasty and thigmonasty, etc.
EXAMPLES	Plant shoots bend towards the light, roots grow towards the gravity, etc.	Movement of Venus flytrap, folding of mimosa leaves as a response to touch
SPEED OF MOVEMENT	Slow	Immediate

Types of Tropic Movements

Tropism	Definition	Stimulus	Example	Picture	Advantage
Phototropism	Growth in response to light	Light	Sunflower moving to face the sun		Increased light so increased photosynthesis
Chemotropism	Growth in response to chemicals	Chemicals	Pollen tube growing towards ovaries		Pollen can fertilize egg in safe protected place for reproduction
Gravitropism	Growth response to gravity	Gravity	Roots growing down into the ground, shoots growing up against gravity		Roots gain anchorage, growth towards water, Shoots grow towards light for p/s
Thigmotropism	Growth response to touch	Hard surface	Grape vine curling around a stake		Growth up towards the light for photosynthesis
Hydrotropism	Growth response to water	Water	Willow roots growing into river banks		Get water for photosynthesis, transpiration and turgity
Heliotropism	Tracking the path of the sun	Light source	Sunflower moving to face the sun		Increased light so increased photosynthesis

Nastic Movements


Thigmonasty-Response to contact


Photonasty-Response to light


Thermonasty-Response to temperature


Nyctinasty-Movements at night

Chemonasty-Response to nutrients


Hydronasty-Response to water

11.
Physiology of Growth in Specific Organs
(Roots-Stems-Leaves)

Roots
(Geotropism or Gravitropism)

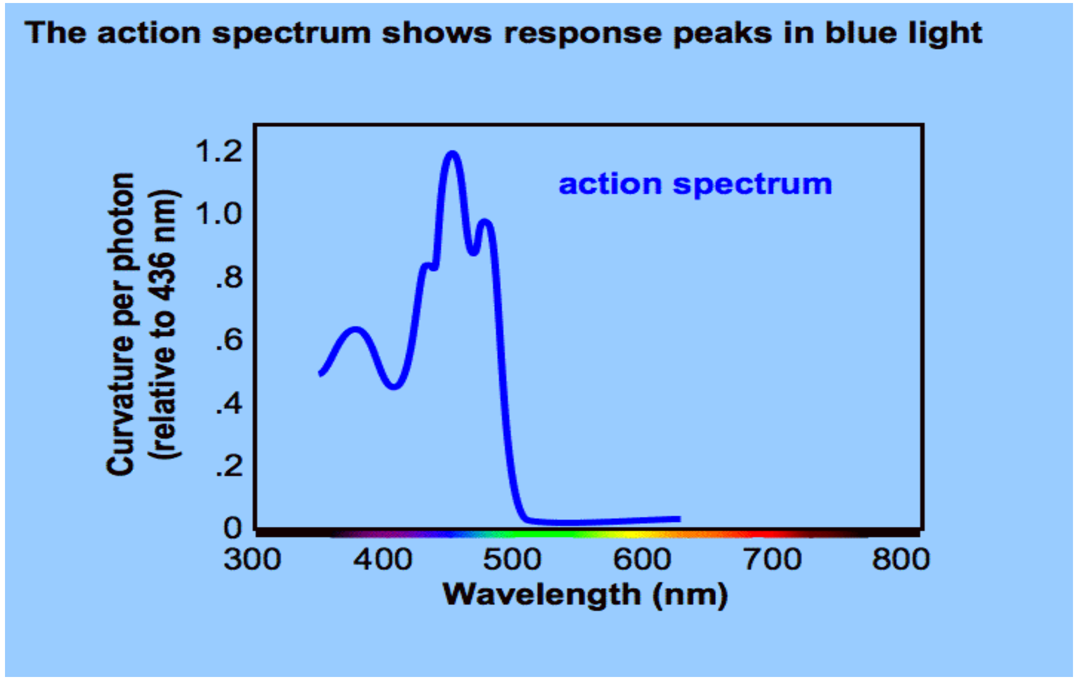
- Roots grow down because of gravitropism.
- This is a tactic plant movement *(response related to the direction of stimulus)* in response to the pull of gravity.
- Roots move towards the gravity stimulus.
- This gravitropic response of roots is considered a positive tactic response.
- If a seedling is placed on its side, the roots will begin to grow downwards *(positive gravitropism)* and the shoot will begin to grow upwards *(negative gravitropism)*, both gravitropic responses occuring at the same time in the same plant.
- The upright growth of the shoot could be partially attributed to light, but this response to light is really secondary, since shoots will always grow upright even in the dark.

Positive gravitropism

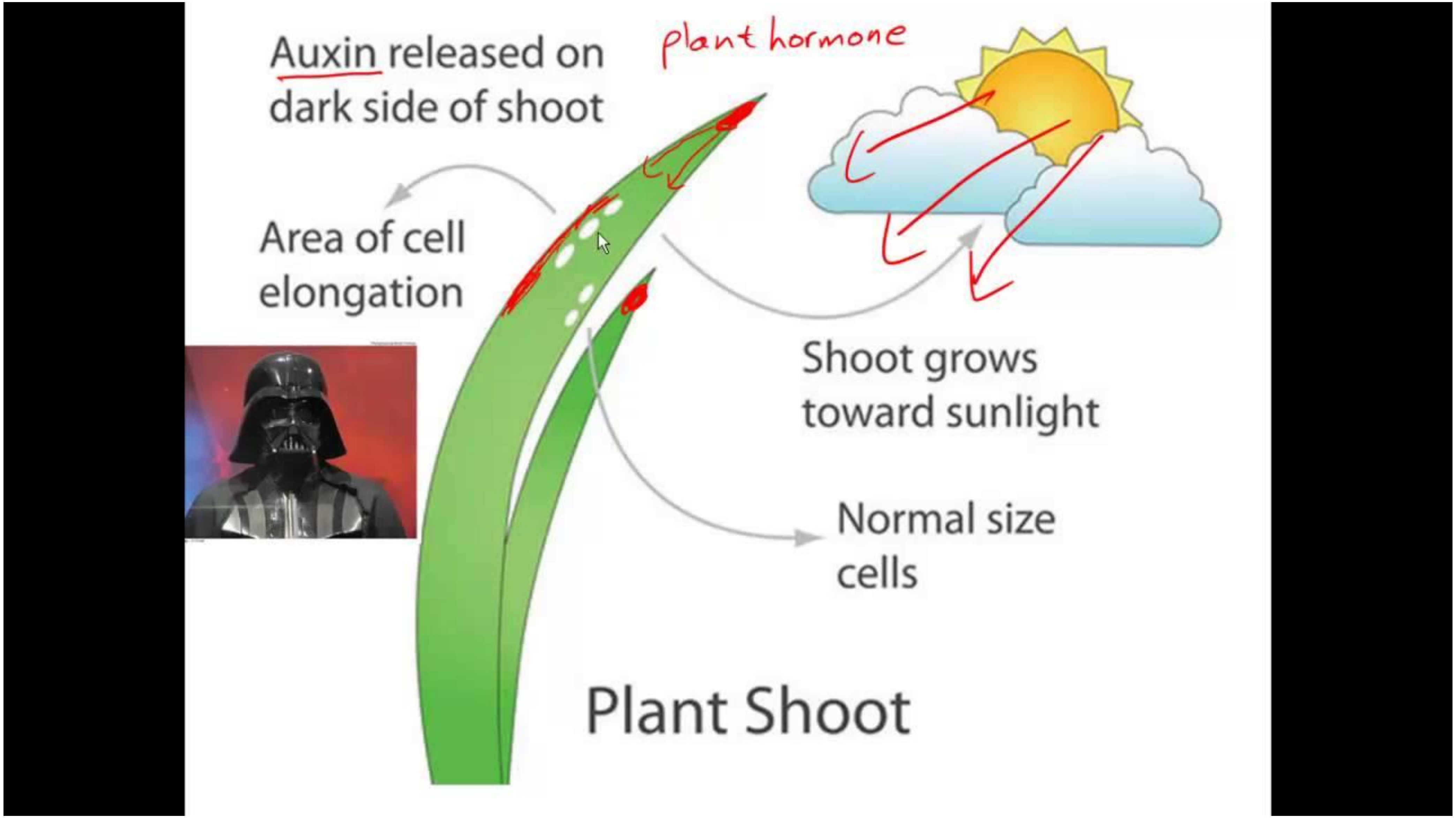
Negative gravitropism

Stems
(Phototropism: Reaching for the Sun)

- Phototropism is bending of plants towards the light.
- As in other tropic responses, phototropic response can be *positive* *(toward a light source)* or *negative* *(away from the stimulus).*
- Phototropism is a growth response to a light gradient.
- Phototropism is a blue-light response.
- Phototropic action spectra show two peaks in blue region of the spectrum near 450 nm and 475 nm. In addition, there is a broad action peak in the UV-A region near 370 nm.
- Phototropism orients a plant for optimal photosynthesis.
- The singular impact of phototropism orients plant growth and leaf angle toward incident light to maximize light interception for photosynthesis.
- Plants also use blue light to control stomatal opening and facilitate gas exchange as well as to relocate chloroplasts within the cell.
- Phototropism in green plants has not been yet well understood.


The action spectrum shows response peaks in blue light
action spectrum
Curvature per photon
(relative to 436 nm)
1.2
1.0
.8
.6
.4
.2
0
300
400
500
600
700
800
Wavelength (nm)

The Role of Auxin in Phototropism



Thigmo Responses

- **Plant response to *any form of touch* stimulus is called *Thigmo Response*.**
- ***Thigmotropic responses* occur directionally, based on the direction of the stimulus (e.g. the movement of a tendril winding around a trellis).**
- ***Thigmonastic (seismonastic) responses* occur independently of the direction of the stimulus such as the closing of *Mimosa pudica* leaves.**

Tendril Movement as a Thigmotropic Movement

- Some plant species have specialized organs called tendrils specifically adept *(skillful)* at coiling around solid objects which facilitates better exposure to sunlight for photosynthesis.
- These thin, long, often threadlike organs have a high degree of sensitivity to touch and friction on solid bodies which allows them to wind tightly around stakes, string, or even shoots.

Origin of Tendrils

1. **Stems:** Some tendrils are modified shoots such as in **grapes** (*Vitis spp.*), **passionflower** (*Passiflora spp.*), **porcelain berry vine** (*Ampelopsis glandulosa*), and **evergreen grape vine** (*Rhoicissus capensis*).

2. **Leaves:** These tendrils originate from a node as a specialized leaf where the blade never forms, such as ***garden peas*** (*Pisum sativum*), many members of the family ***Cucurbitaceae***.

3. **Leaf tips:** This type of tendrils originate from the tips of developing leaves, such as **South American flowering vine** (*Mutisia spp.*), **Asian pitcher** (sürahi) plants (*Nepenthes*).

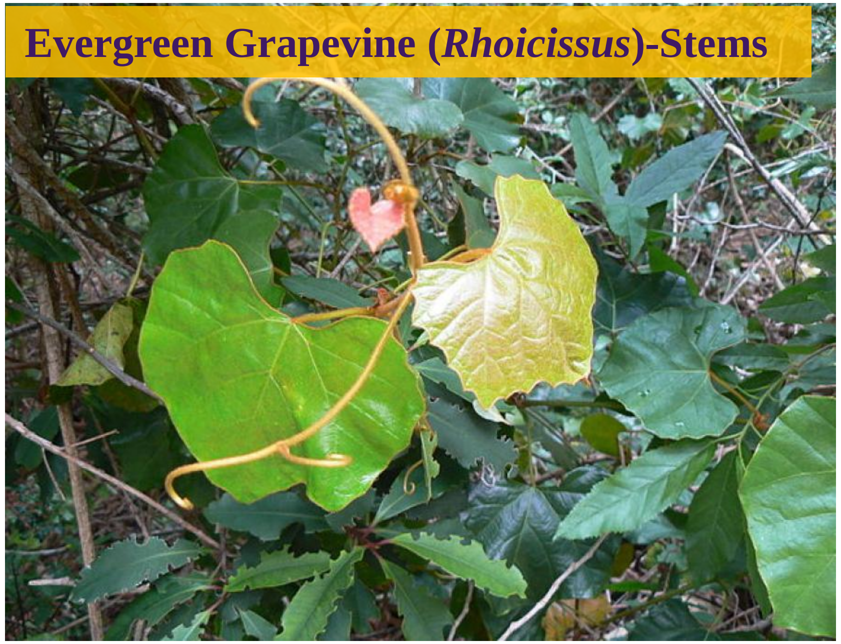
4. **Leaflets:** Tendrils can also form from a leaflet of a compound leaf (*Vicia*, *Lathyrus* 'vetch-fiğ', *Pisum*)

5. **Stipules:** Smilax (*saparna,melocan*) has tendrils form from stipulus that are small appendages at the base of a leaf.

6. **Leaf stalks (petioles):** *Clematis* (*akasma*) forms tendrils from petioles.

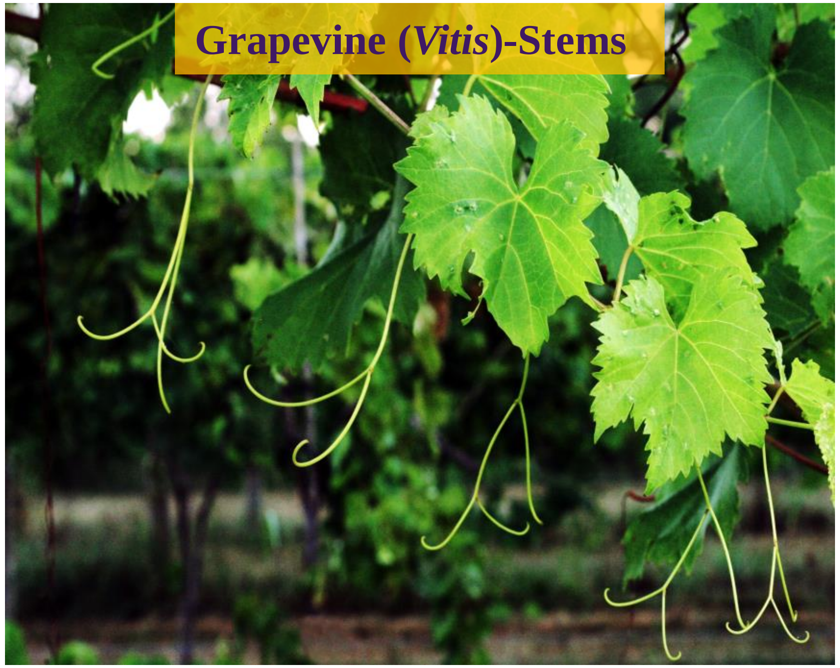
7. **Flowers:** Pedicel or peduncle tendrils develop from the axis of an inflorescence, such as **chewstick** (*Gauania lupuloides*).

8. **Roots:** Tendrils of the tropical orchids that we use as flavoring (*Vanilla spp.*) originate from roots.


Evergreen Grapevine (*Rhoicissus*)-Stems


Porcelain Berry Vine (*Ampelopsis*)-Stems

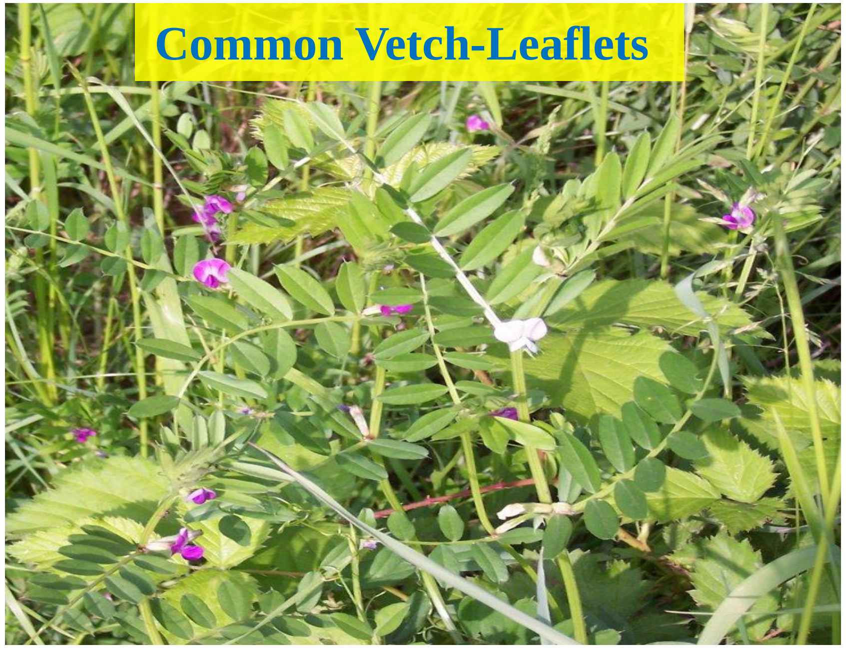

Passionflower-Stems


Grapevine (*Vitis*)-Stems


Garden Pea-Leaves


Wild Cucumber-Leaves


Broad Bean-Leaflets
Fava Beans (Vicia faba)
Steve Christman ©2014 Floridata.com


Common Vetch-Leaflets


Smilax-Stipules
gettyimages
Ed Reschke


Clematis-Leaf Stalks


Chewstick-Flowers


Vanilla-Roots

Other Mechanisms of Climbing

1. Adhesive pads: Boston ivy (*Parthenocissus tricuspidata*) and Virginia creeper (*Parthenocissus quinquefolia*) climb via stem tendrils that are touch-sensitive adhesive pads.

2. Shoot twining: Shoot twinning consists of the encircling growth of a shoot around an object as the shoot elongates such as morning glory (*Ipomea spp.*), green beans (*Phaseolus vulgaris*), clematis (*Clematis spp.*) and honeysuckle (*Lonicera spp*).

3. Clinging stem roots: Hydrangea (*Hydrangea petiolaris*), most ivies such as English ivy (*Hedera helix*) and Irish ivy (*Hedera hibernica*), and also some *Euonymus spp*. climb by utilizing groups of short, stout (tombul) roots that have the ability to cling to nearly any surface they come into contact with. The roots secrete acids which can damage paint and mortar (sıva).

4. So-called climbers: Some plants appear to be climbing as if they were vines but have no mechanism to climb on their own, including *Bougainvillea* and climbing roses (*Rosa spp.*) simply have very long, flexible stems.


Virginia Creeper-Adhesive Pads

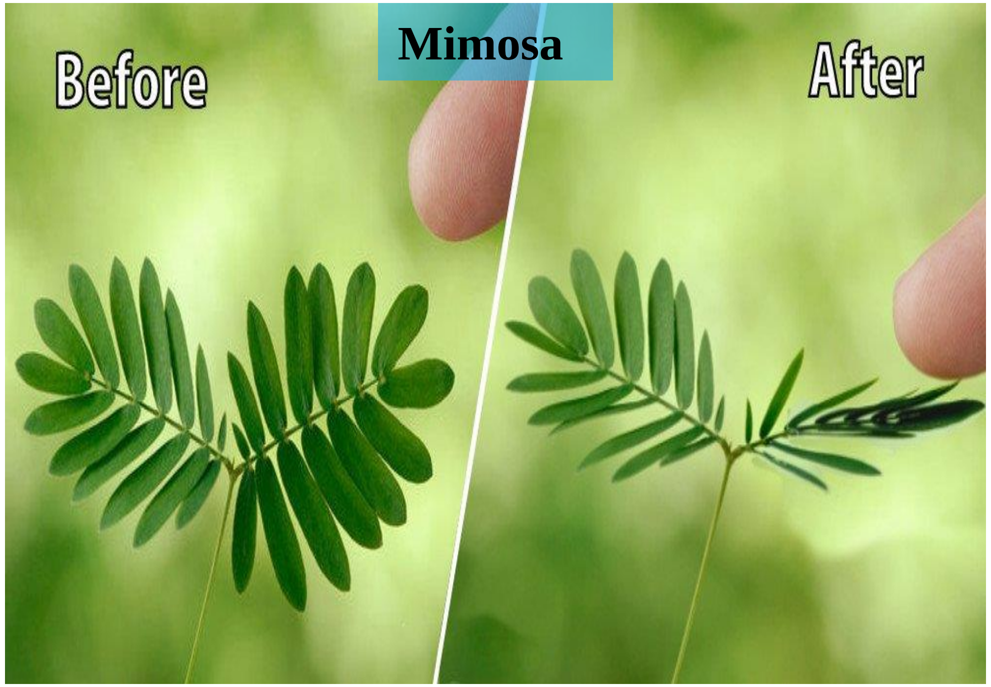

Honeysuckle-Shoot Twining

English Ivy-Clinging Stem Roots


Bougainvillea-Flexible stems

Leaves-Thigmonastic Responses

- **Physiological responses to touch by leaves is called *seismonasty*.**
- **One of the best example is leaflet folding in Oxalis (*Oxalis spp.*) as *photonasty*; Mimosa (*Mimosa spp.*), Venus flytrap (*Dionaea muscipola*) as *thigmonasty* and many legumes.**
- **This folding is mechanically controlled by specialized organs called *pulvini* at the base of leaflets.**
- **The folding leaf movement is the result in *loss of turgor* from extensor *(açıcı)* cells.**



Thigmonastic Responses in *Carnivorous* Plants
(1. Venus Flytrap-*Dionaea muscipula*)

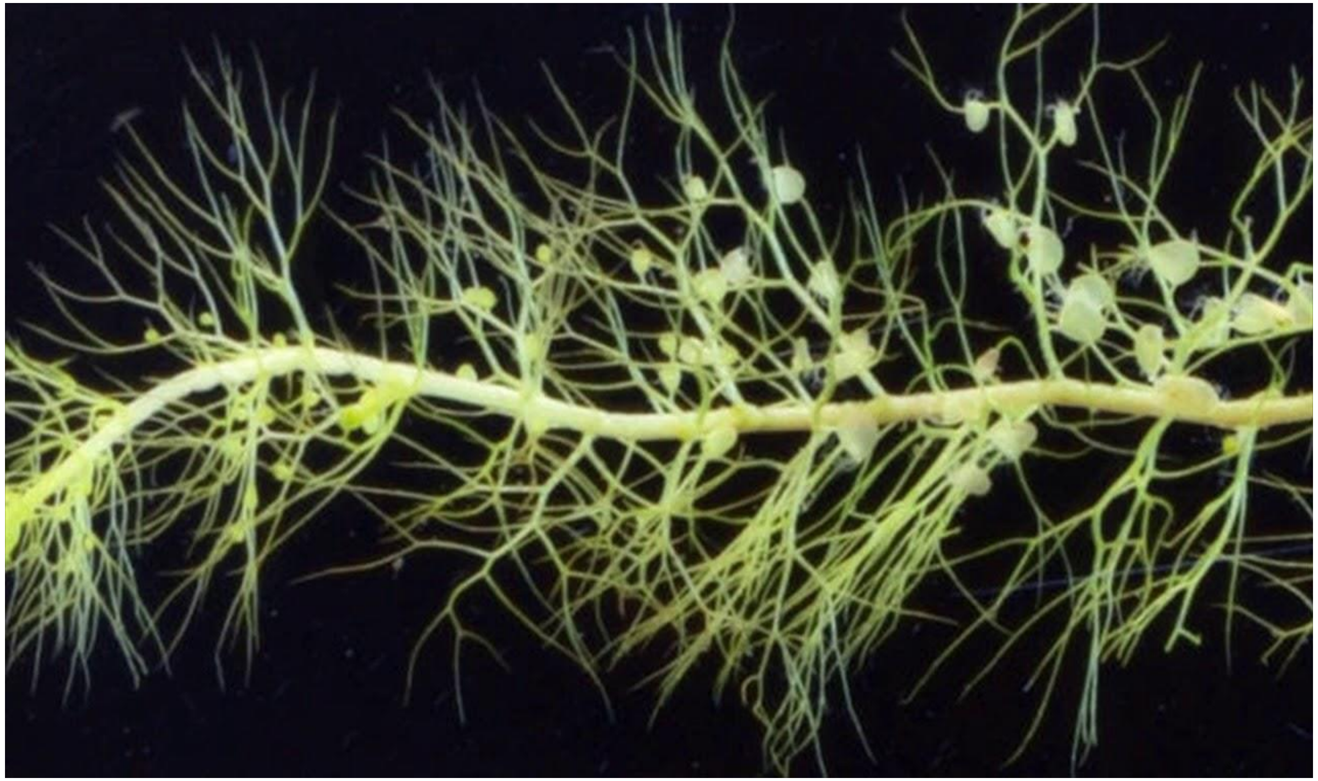
- This species is probably the most widely known *carnivorous plant*.
- Specialized bi-lobed leaves with three trigger hairs on the inside surface of each lobe wait for stimulation by an unsuspecting insect.
- Upon several stimulations of one hair or concurrent (*synchronous*) stimulations of two or more hairs at a time, lobes quickly close, entrapping the victim.

Continued… (2. Sundew-*Drosera spp.)*

- There are many different species within the genus *Drosera* called Sundew plants.
- All sundews are characterized by having tentacle *(dokunaç)*-covered leaves which excude sticky musilage.
- Insects landing on the leaves become entrapped in glucy musilage.
- Tentacle movement is both *thigmonastic* and *thigmotrophic*.
- The sensitivity of tentacles is incredible in that they can detect prey weighing less than 1 µg.

Continued… (3. Bladderwort-*Urticularia spp.*)

- Bladderwort *(su miğferi)* is a rootless plant that grows in aquatic and moist terrestrial environments.
- They have numerous bladders *(hava kesesi)* approx. 3 mm in length attached to its fine leaves.
- Each bladder is a hollow sac, two-cell thick with a valve which remains closed until stimulated by an unsuspecting insect.



General Growth Responses-Thigmomorphogenesis

1. Gradual changes in growth of plants due to stimuli such as touch or wind is known as Thigmomorphogenesis.

2. These growth changes occur slowly over time.

3. Shoot thigmomorphogenesis is often characterized by decreased elongation growth with a concomitant *(birlikte)* increase in radial expansion.

4. Other growth responses are; a. Time of Flowering, b. Dormancy Induction and Release, c. Senescence, d. Stress Sesistance.

5. The signal for these growth changes probably involves the plant hormones as well as intracellular calcium levels.

6. Rapid increases intracellular calcium occur in response to touch or wind stimuli.

7. Reactive Oxygen Species (ROS) are also thought to play a role in morphogenic signaling and probably interact with calcium in morphogenic regulation.

8. Ethylene has long been implicated in Thigmomorphogenic Responses.

- Exogenous application of Ethylene can induce Thigmomorphogenic Growth Responses.

9. A group of genes called Touch Inducible Genes (TCH genes) were discovered in *Arabidopsis*.

- Later on, many more examples of genes induced by touch have been revealed.

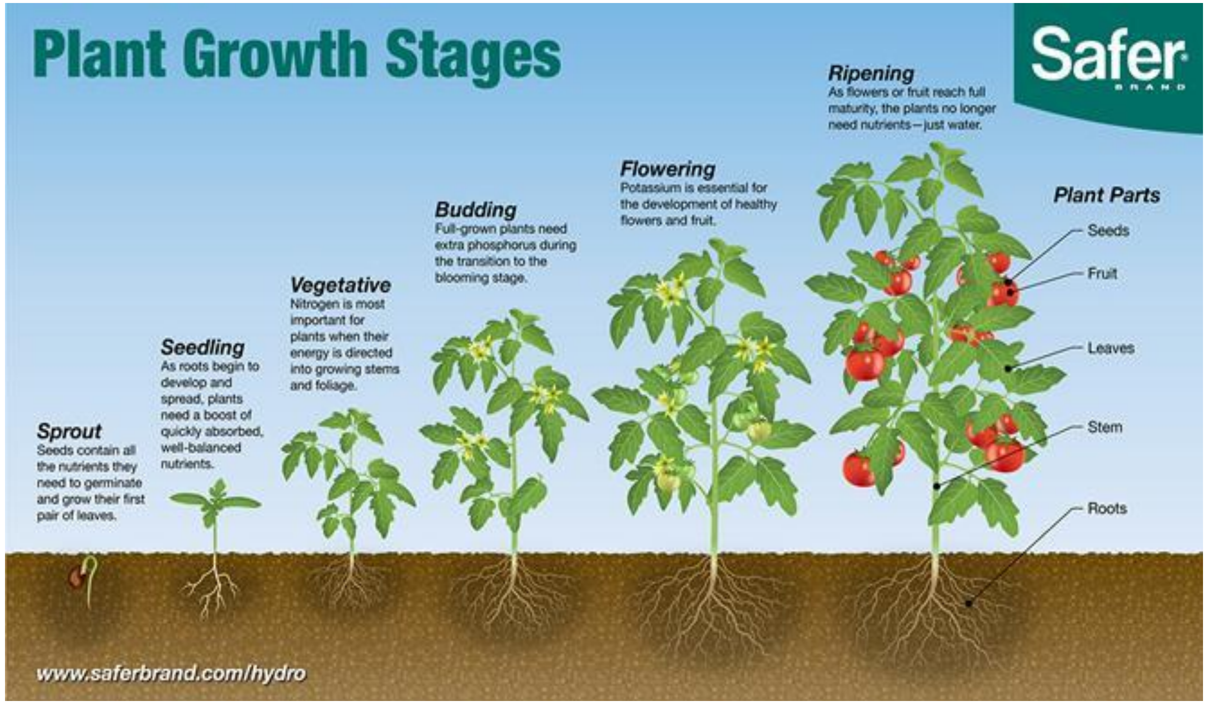
12.
Physiology of Growth in Specific Organs
(Flowers-Fruits-Seeds)

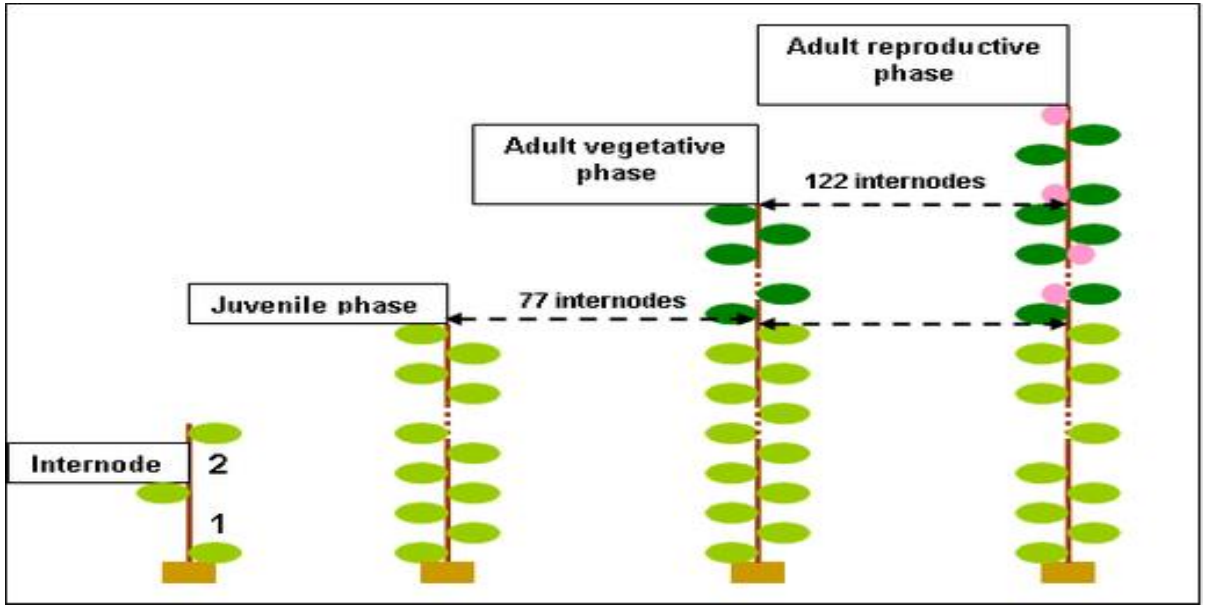
Flowers

- Flowers and bees are extremely important to life on earth.
- Much of our food is derived from flowers then they convert into fruits and seeds as extremely valuable nutrients.
- Bees play a vital role for our life.
- Flowers also provide immeasurable aesthetic value making our lives richer and more colorful.
- Flower growth and development from bud to seed, is a carefully orchestrated physiological phenomen.

Juvenility

- All species need a genetically programmed minimal stage of vegetative development before they begin the flowering process, called juvenility which varies considerably among species.
- When a plant is capable of flowering in the presence favorable environmental conditions, this plant is considered as competent or ripe to flower.
- This minimal stage needed for beginning of flowering can be measured in time or plant stage.
- The usual measure of a plant's stage of development is the number of nodes or leaves it has produced.





Juvenility in Perennial Plants

- Juvenility stage is often measured as the stage of a plant must be before it will flower.
- Some perennial species will flower in their first year of growth, *such as some conifers* while others require from several years to many decades of vegetative growth before their first flowering.

Age of Flower Development in Some Woody Plants.

Species	Length of juvenile period
Rose (*Rosa* spp.)	20–30 days
Grape (*Vitis*)	1 year
Apple (*Malus* spp.)	4–8 years
Ivy (*Hedera helix*)	5–10 years
Sequoia (*Sequoia sempervirens*)	5–10 years
Pear (*Pyrus* spp.)	6–10 years
Pine (*Pinus monticola*)	7–20 years
Larch (*Larix decidua*)	10–15 years
Maple (*Acer pseudoplatanus*)	15–20 years
Douglas-Fir (*Pseudotsuga menziesii*)	20 years
Redwood (*Sequoiadendron giganteum*)	20 years
Norway spruce (*Picea abies*)	20–25 years
Hemlock (*Tsuga heterophylla*)	20–30 years
Oak (*Quercus robur*)	25–30 years
Fir (*Abies amabilis*)	30 years
Beech (*Fagus sylvatica*)	30–40 years

Juvenility in Biennial Plants

- Biennial plants require two growing seasons to flower.
- The first growing season is for vegetative growth, the second is for flowering.
- These two growing seasons are usually seperated by a season of endo-dormancy which must be removed by exposure to cold temperatures (0-5°C).
- In many biennials, flower bud induction and initiation occur in the first season, while differentiation and development occur during the dormant and second growing season.
- In other biennials, all stages of flowering occur in the second growing season that will only takes place after cold-temperature exposure to release dormancy.


Common Mullein

Forget-Me-Not

Foxglove

Holyhock

Pansy

Sweet William


Kohlrabi

Cabbage

Carrot

Celery

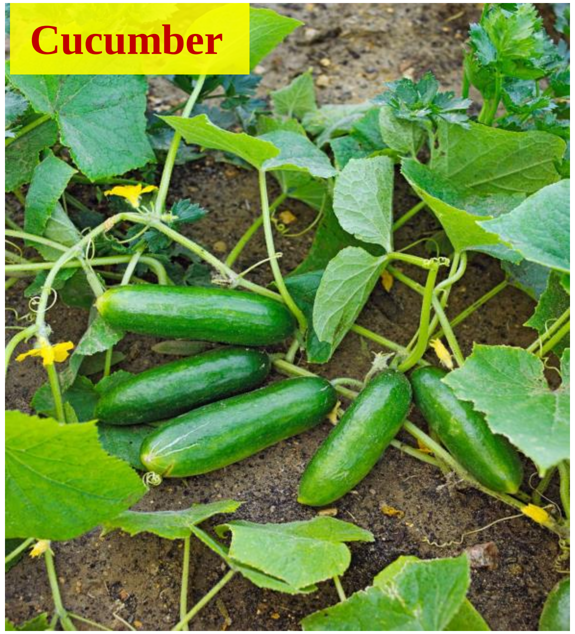
Onion

Parsley

Juvenility in Annuals

- **Most annuals reach a ripeness to flower after a predetermined number of nodes (or leaves) have been produced.**
- **Some species produce a certain number of flowers then die, while others continue to flower until adverse environmental conditions prevent flowering.**
- **These differences are important in determining the potential yield of different cultivars for cut flowers, fruits or seeds.**
- **Mostly there is a fine balance between vegetative growth and crop load it can support.**
- **Cultivars which produce fewer flowers per plant often produce large fruits due to lack of competition for photosynthates e.g. *watermelon* and *squash*.**
- **Conversely, cultivars tend to produce copious number of flowers per plant, flowers or young fruits are often removed, called thinning to encourage the production of larger fruits e.g. *apples*, *peaches* and *table grapes*.**

Annualy Flowering Vegetables



Annual Flowers of Ornamentals

The Flowering Process

- This process is extremely complex, strongly controlled by *genetics* and *environment*.
- *Light* and *Temperature* are the two most important environmental factors controlling flowering.
- Flowering Process most often occurs into four major steps;

  (1) Induction,

  (2) Initiation,

  (3) Differentiation,

  (4) Development
- Each step has its own set of responses to light and temperature.

Flowering process

Induction

Initiation

Differentiation

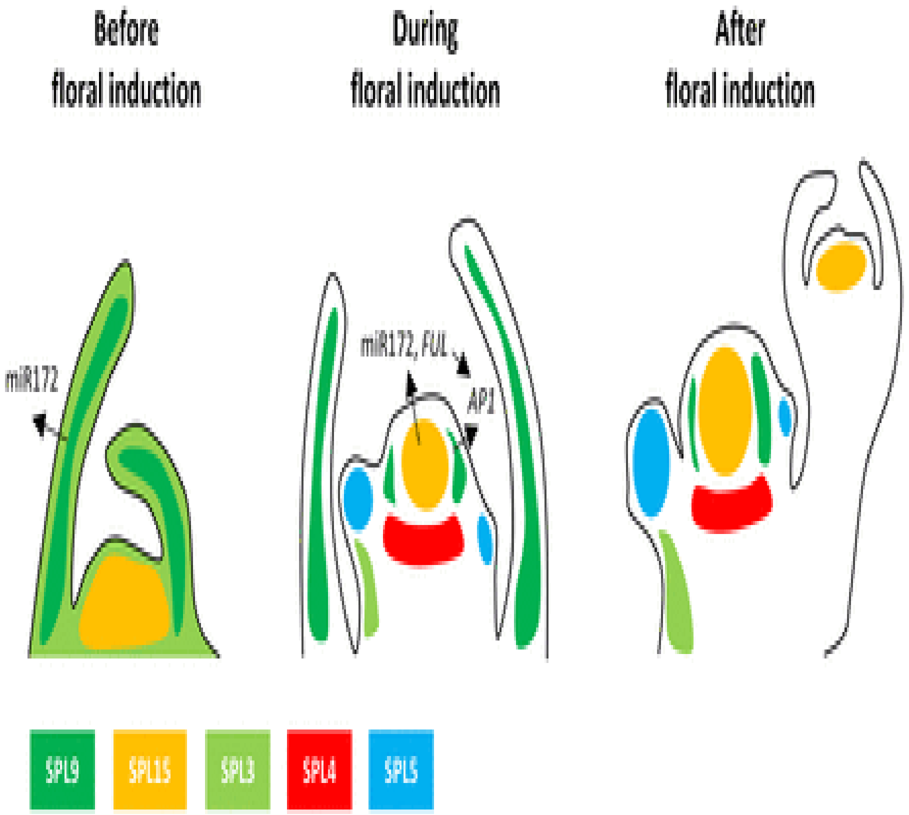
Development

(1) Induction

- Induction is a process which normally occurs in the leaf as a plant perceives (feel) the signal to pass from a vegetative stage to a flowering stage.
- This change ultimately occurs at the meristem, but signal as light or temperature is detected by leaves.
- The number of the leaves produced over time is monitored and average leaf production rate is estimated.
- Once the signal to switch from vegetative to floral growth has been detected, the signal must be tranferred to the site of flower production, a meristem.
- The signal is transferred via the flowering hormone, called florigen.
- Once the signal is received by the meristem, the next stage of flowering, called initiation, begins.

(2) Initiation

- Flower initiation is associated with the observable morphological changes which occur at a meristem as the meristem transitions from leaf to floral production.
- Actually the change is merely a change in the direction of development as flowers are simply modified leaves.
- Initiation can be detected by observing changes in morphology of the meristem at the macroscobic level.
- During the transition, vegetative meristem that is rather pointed and narrow, becomes rather flat and broad.
- This difference can be observed easily in most species.



Spatially distinct roles of *SPL* genes *(Squamosa-Promoter Binding Like (SPL) gene family)* in the Arabidopsis SAM. Left, Two closely related genes, *SPL9* and *SPL15*, are expressed before floral induction in leaves and the SAM, respectively. *SPL9* is expressed in leaves, where, in adult plants after reduction in miR156, it participates in the accumulation of miR172 to promote the transition to adult leaf morphology. Middle, During floral induction under short days, the accumulation of miR172 and mRNA of the floral activator *FUL* at the SAM requires the function of *SPL15*. During and after floral induction, *SPL9* mRNA appears on the flanks of the meristem and the protein activates the floral identity gene *AP1* in cooperation with DELLA and LFY. *SPL3*, *SPL4*, and *SPL5* mRNAs are expressed at the shoot apex. Right, After floral induction, *SPL15* is expressed in the floral meristem and the inflorescence meristem. *SPL3*, *SPL4*, and *SPL5* are expressed in specific patterns at the apex.

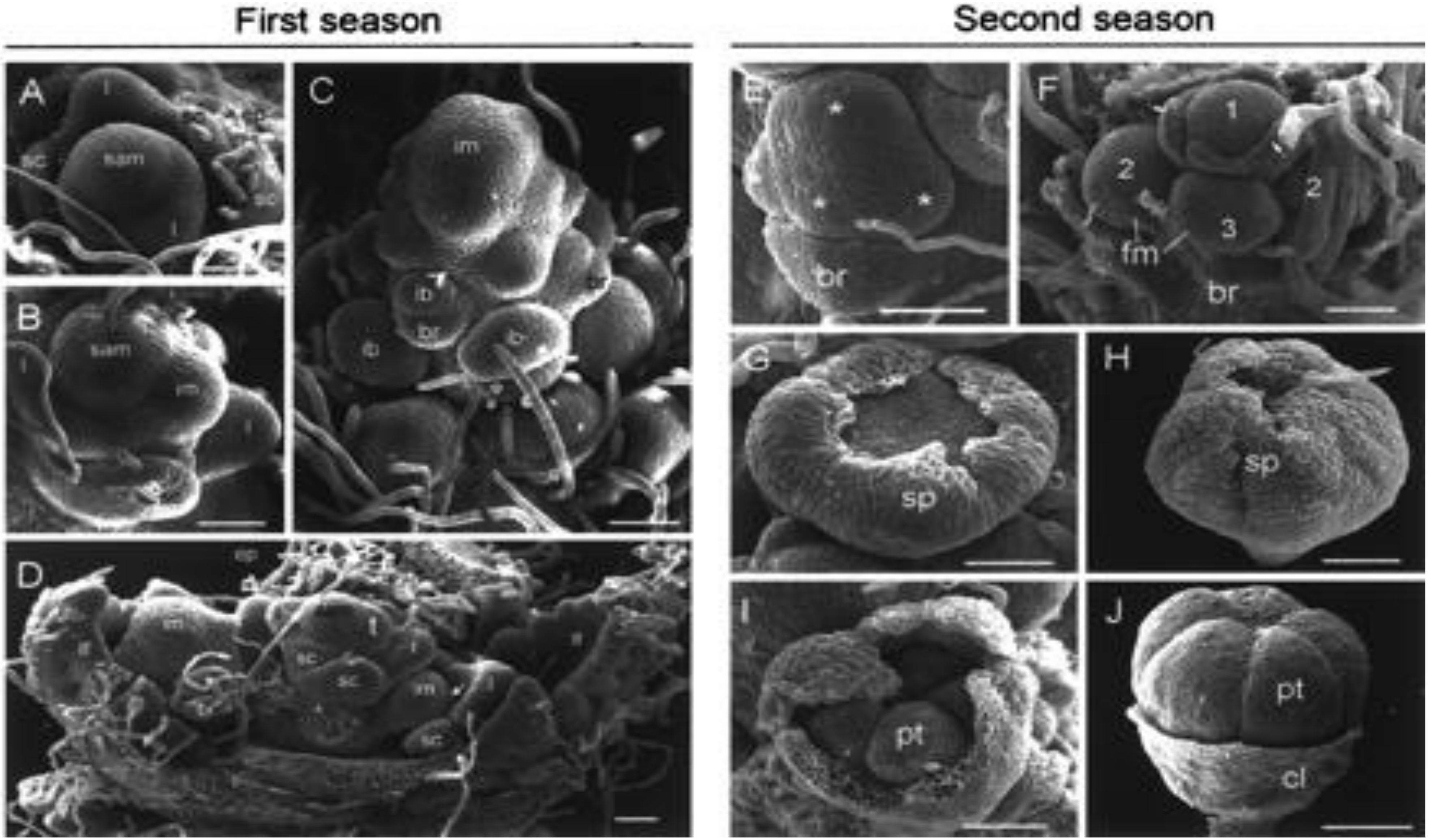
(3) Differentiation

- **There is a fine line between initiation and differentiation.**
- **Differentiation is the process in which the various flower parts are formed after initiation.**
- **Differentiation can be monitored via dissection of plant apices under a dissecting scope at magnification from x10 to x20.**
- **In many biennials and perennials, differentiation takes place over an extended period.**
- **But, it occurs quickly in annuals.**

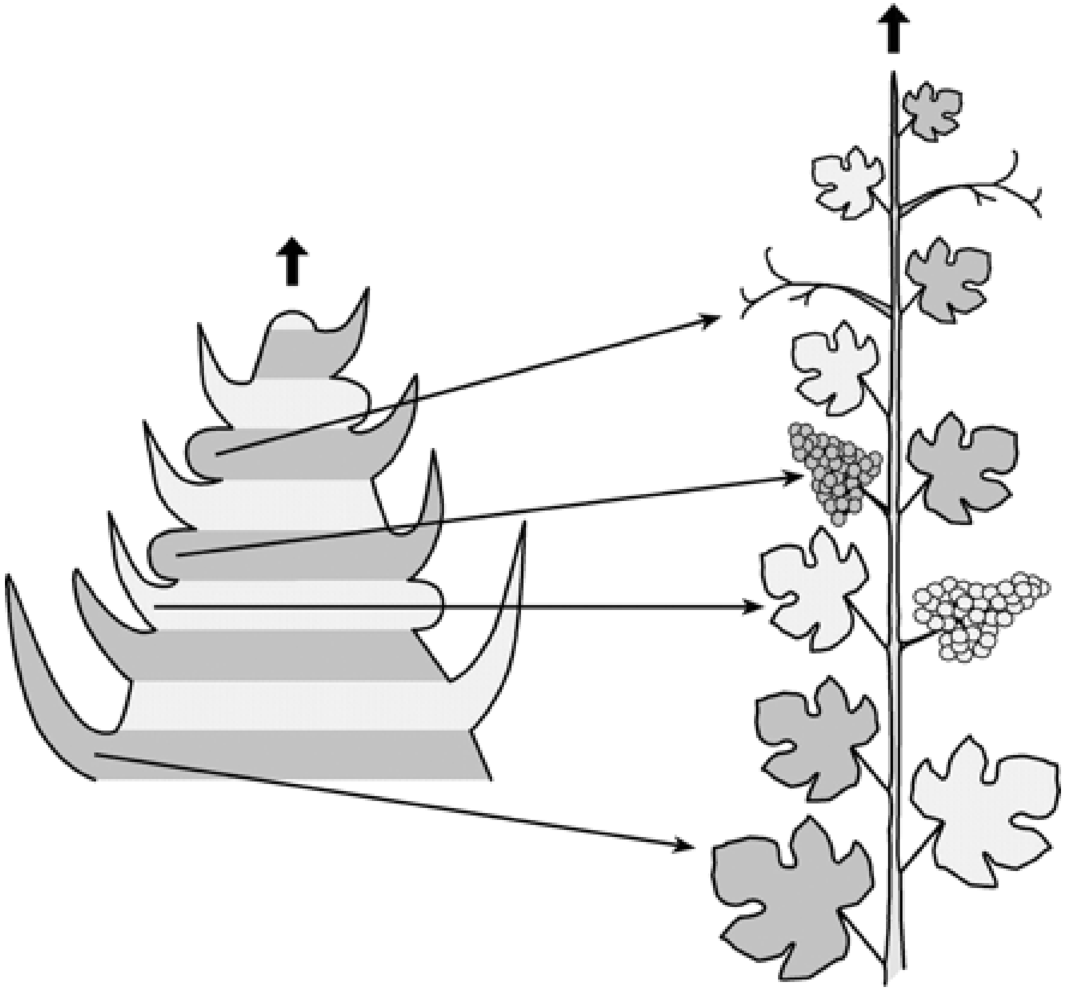
(4) Development

- Development refers to the macroscobic production of flowers that are visible without magnification.
- It is monitored by visual counts of numbers of flowers per plant, inflorescence etc.
- Monitoring floral development closely allows us to examine the factors that influence the fruting potential of many plants.
- Many other steps are involved in the production of fruits and seeds after production of flowers.

Floral Development Stages of Grapevine by SEM



Bud Derivatives in Grapevine



- ***Left***, Schematic representation of a latent bud during the ***first season*** showing the phyllotaxis of meristems and primordia at this stage. ***Right,*** derivatives formed from those meristems and primordia during the ***second season***. Lateral meristems giving rise to inflorescences or tendrils are indistinguishable in morphology and position at the time they are formed.

Reproductive Mechanisms - Alteration of Generations

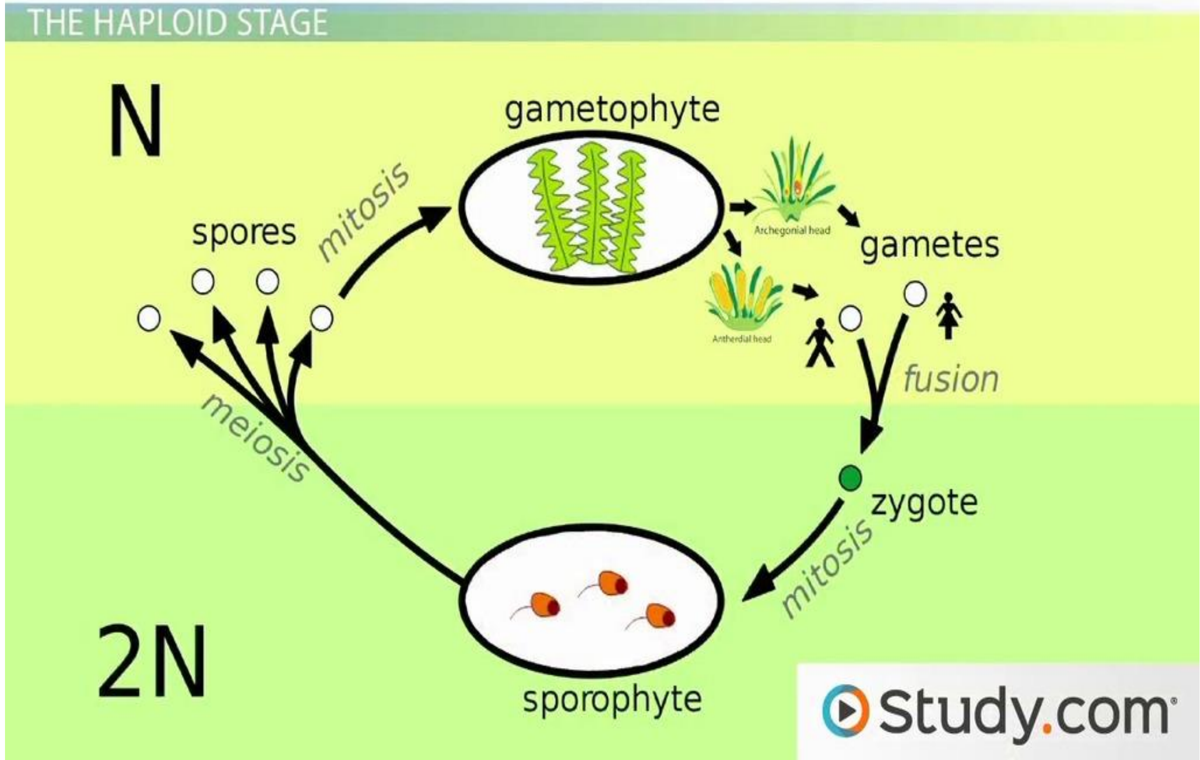
Sporophyte Generations:

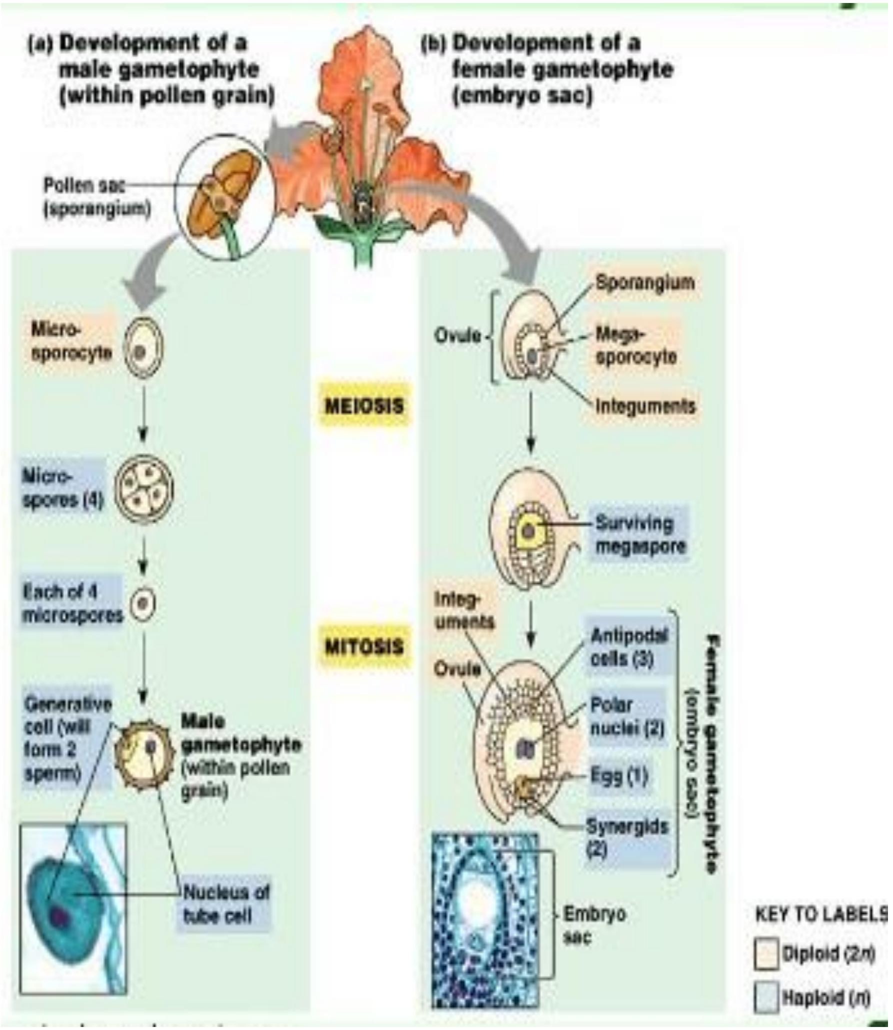
- This generations refers to a normal diploid plant, meaning it has two sets of chromosomes.
- The smallest sporophyte plant is single-celled diploid zygote that results from the fertilization of an egg with one of the sperm cells from a pollen grain.

Gametophyte Generations:

- They are multicellular haploid organisms residing in the flowers of sporophyte plants.
- *The male gametophyte* is called pollen grain which is derived from a microspore mother cell which is found in the anther. The pollen grain is a three-celled haploid male gametophyte plant made of two sperm cells living inside a tube cell.
- *The female gametophyte* is a seven-celled haploid plant which develops from a megaspore. This diploid megaspore mother cell located in the ovule forms four haploid megaspores by meiosis. The third haploid megaspore forms eight haploid cells by four-times mitosis.
- One of these cells is egg cell which is fertilized with a smaller generative (germ) cell to produce a single-celled diploid zygote, eventually grows into an embryo. The sporophyte plant develops from this embryo in the seed.

Alteration of Generations





Plant Types with Regard to Residing the Reproductive Organs

- **Although many species (85%) of plants have flowers that are <u>perfect</u> *(i.e. include both male and female gametophytes residing in the same flower),* there are many species which have different behaviour to sexual reproduction.**
- **If both male and female organs are produced on the same plant but they reside in seperate flowers, the species called as <u>monoecious</u>.**
- **About 7% of plant species are <u>monoecious</u> such as *walnut, hazelnut, some figs, squash, corn, cucumber, melon, birch, oak, pine, spruce*.**
- **If male and female gametophytes reside on seperate plants, that species are <u>dioecious</u> such as *pistachio, mulberry, dates, kiwifruit, some persimmons, asparagus, spinach, holly, sago, ginkgo*.**
- **About 6% of plant species are <u>dioecious</u>. In dioecious species, male and female plants must be close enough together to transfer the pollens from male plant to the female plants.**

Time of Bloom in Fruit Species

- Time of bloom of two different plants within the same species can be synchronous or asynchronous.
- Some cultivars, especially in fruit crops are self-incompatible with respect to pollination such as *apples, pears, plums, sweet cherries, almonds, and avocado* that they need a pollinator from a different cultivar of the same species.
- Others such as almost all *grapevines, citruses, apricots, peaches & nectarines, sour cherries, pomegranate, raspberries, and blackberries* are self-compatible.
- Synchronous bloom among cultivars is important for effective pollination.
- Asynchronous time of bloom is an effective mechanism for preventing the cross-pollination that encourage the heterozygousity.
- Once flowering occurs, two more steps, pollination and fertilization will occur.

Chilling & Heat Unit Requirements for Fruit Species

- Every species has an integrally programmed time to bloom under the ultimate genetic control.
- Many decidious fruit species require exposure to a period of relatively cold temperatures **(0-5°C)** during dormant season, called ***'Chilling Requirement'*** calculated as hours below +7.2°C for temperate fruits , determines the efficiency of the cold period in any location to regular flowering.
- There are several models for determining chilling hours, but the simplest is: one chilling unit (CU) is equal to one hour's exposure to the chilling temperature; these units are added up and totaled for a whole season.
- Once the chilling requirement has been fulfilled, plants begin growth when exposed to warm temperatures, measured as ***'Heat Units'*** calculated as degree-days above a threshold temperature (+7.2°C for temperate fruits, +10°C for grapevines), also determines the efficiency of any location for full maturity of the varieties.

Very low-chill fruit types:

figs	<100
berries	<300
grapes	<150
jujube	150
mulberry	< 200
persimmon	< 200
pomegranate	<200
quince	100

Apples

Anders	<500
Fuji	<400
Gala	500
Granny Smith	400
Gravenstein	700
Honey Crisp	800
Pink Lady	4 – 500

Blueberries

Northern highbush	800+
Southern highbush	most <400
O'Neal	3-400
Misty	300
Jubilee	400
Sharpblue	150
Sunshine Blue	150
Southmoon	500

Apricots

Blenheim/Royal	400 – 500
Harcot	700

Cherries, sweet

Lapins	650
Stella	700
others	800+

Cherries, pie

Morello	400
Montmorency	900

Nectarines

Arctic Fantasy	400
Flavortop	6 - 700
Goldmine	400
Independence	900

Peaches

Babcock	250
Donut	450
Elbertas	800
June Gold	450
Loring	800
O'Henry	7 – 800
Red Baron	250
Redhaven	900
Rio Oso Gem	900
Summerset	750

Pears

Asian pears	400 – 450
Bartlett	800
Beurre d'Anjou	700
Comice	5 – 600
Fan-Stil*	500
Kieffer*	400
Moonglow*	500
Pineapple*	200
Seckel	300

* good fireblight resistance

Plums

Japanese plums	<500
except: Elephant Heart	650
European/prune plums	7 – 800
Green Gage	3 – 400

Interspecific hybrids:

pluots	4 - 500
except: Flavor Supreme	7 – 800
apriums	<500
Necta-Plum	2 - 300
Peacotum	500

Nuts

Almonds:	500 or less
Pecans	3 - 500
Walnuts	most 700

references: L. E. Cooke Co.
pecans: Journal of the American Hort Society
berries: http://aggie-horticulture.tamu.edu/fruit-nut/files/2010/10/blackberries.pdf
pluots, interspecific hybrids, and walnuts: Dave Wilson Nursery

Genetic Control of Bloom
(Low-Chill Cultivars)

- Every species has an integrally programmed time to bloom under the ultimate genetic control.
- Many decidious fruit species require exposure to a period of relatively cold temperatures (0-5°C) during dormant season, called **'Chilling Requirement'.**
- Once the chilling requirement has been fulfilled, plants begin growth when exposed to warm temperatures, measured as **'Heat Units'.**
- Some cultivars of **peach & nectarine** (*Prunus persica*), **apple** (*Malus domestica*), **pear** (*Pyrus communis*), **apricot** (*Prunus armeniaca*), **cherry** (*Prunus avium*), **plum & prune** (*Prunus domestica*), **fig** (*Ficus carica*), **kiwifruit** (*Actinidia chinenesis*), **persimmon** (*Diospyros kaki*), **pomegranate** (*Pumice granatum*), **quince** (*Cydonia vulgaris*), and **walnut** (*Juglans regia*) have a greatly low chilling requirement less than 300 hrs when compared with other cultivars within the same species, called '**Low-Chill Cultivars**'.
- These cultivars are often used for commercial production in regions which normally do not receive enough cold weather *(warm climates)* to fulfill the normal chilling requirement.
- But, they should not be grown in areas *(cool climates)* where significant chilling accumulation occurs, since their chilling requirement would be fulfilled early in the dormant season. So, any exposure to warmer weather will cause an early growth (flowering) even in winter which would be injured by the late frosts.
- The low-chill character is genetically controlled and has been quantified for many commercial cultivars.

Genetic Control of Bloom-*High-Chill or Late Blooming Cultivars*

There is a large high-chill group of *apple, apricot, cherry, peach & nectarine, pear, plum & prune, and walnut cultivars* which tend to bloom much later than the average cultivar due to a greater ***'Heat-Unit Requirement (HUR'.***

The greater ***HUR*** may be due to;

1. An absolute increase in the amount of heat needed for development,

2. It could be a result of decreased sensitivity to lower temperatures.

Environmental Control of Bloom

1. All species have an inherent genetic control of the time of bloom which may be modified by the environment.
2. Species generally have a genetically controlled chilling and heat-unit requirements which is constant and quantifiable.
3. Time of bloom can be modified by altering the chilling/heat accumulated.
4. Accelerated bloom is usually not desirable trait for most field-grown horticultural crops, but may be desirable for out-of-season production in greenhouses or high tunnels.
5. Most attempts/efforts are being spent to delay bloom time for avoiding late (spring) frost injury to especially fruit blossoms.
6. In certain regions of the world, frost or freezing injury may result in 100% crop loss.

Pollination & Fertilization

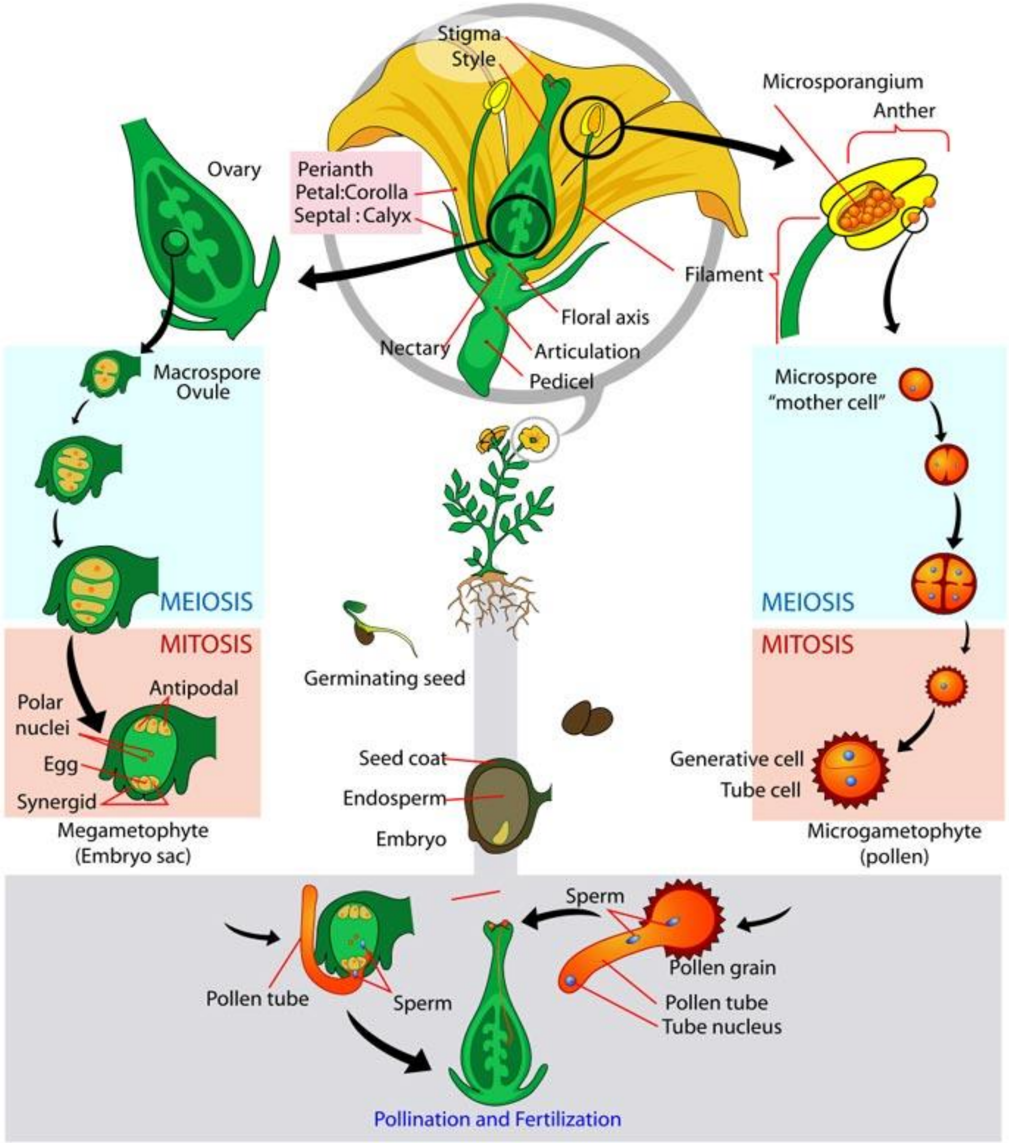
- Sexual reproduction is a highly specialized process closely regulated anatomically and physiologically.
- Our similar genomes *(an organism's complete set of DNA, including all of its genes)* can cooperate to form a new individual via sexual reproduction.
- Successful **pollination** requires several steps;

1. Pollen must land on the stigma of a pistil by wind (10%) or insects (90%).

2. Once the pollen lands on the stigma, it must germinate, grow into the stigma then down through the style into the locule of the ovary towards the awaiting egg cell.

3. Pollen tube growth through the style is accomplished with the weakening of stylar tissue by enzymez produced by both the pollen tube and the style.

4. Once the pollen tube reaches the egg cell, the egg cell and one of the sperm cell from the pollen unite to form zygote, called **fertilization** which eventually develops into the embryo.

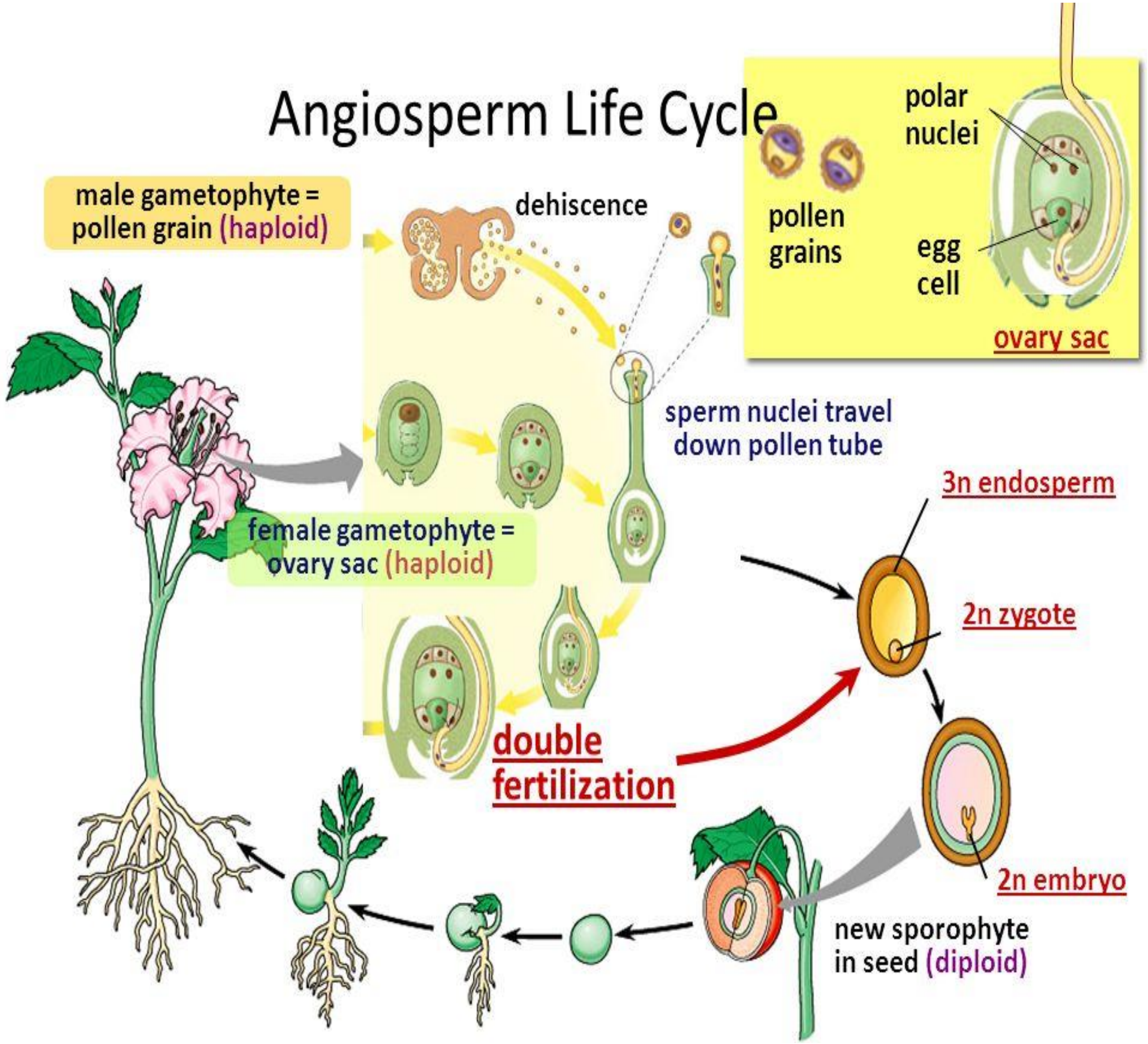


Double Fertilization

- Fertilization in most plants has two component, called as; <u>Double Fertilization</u>.

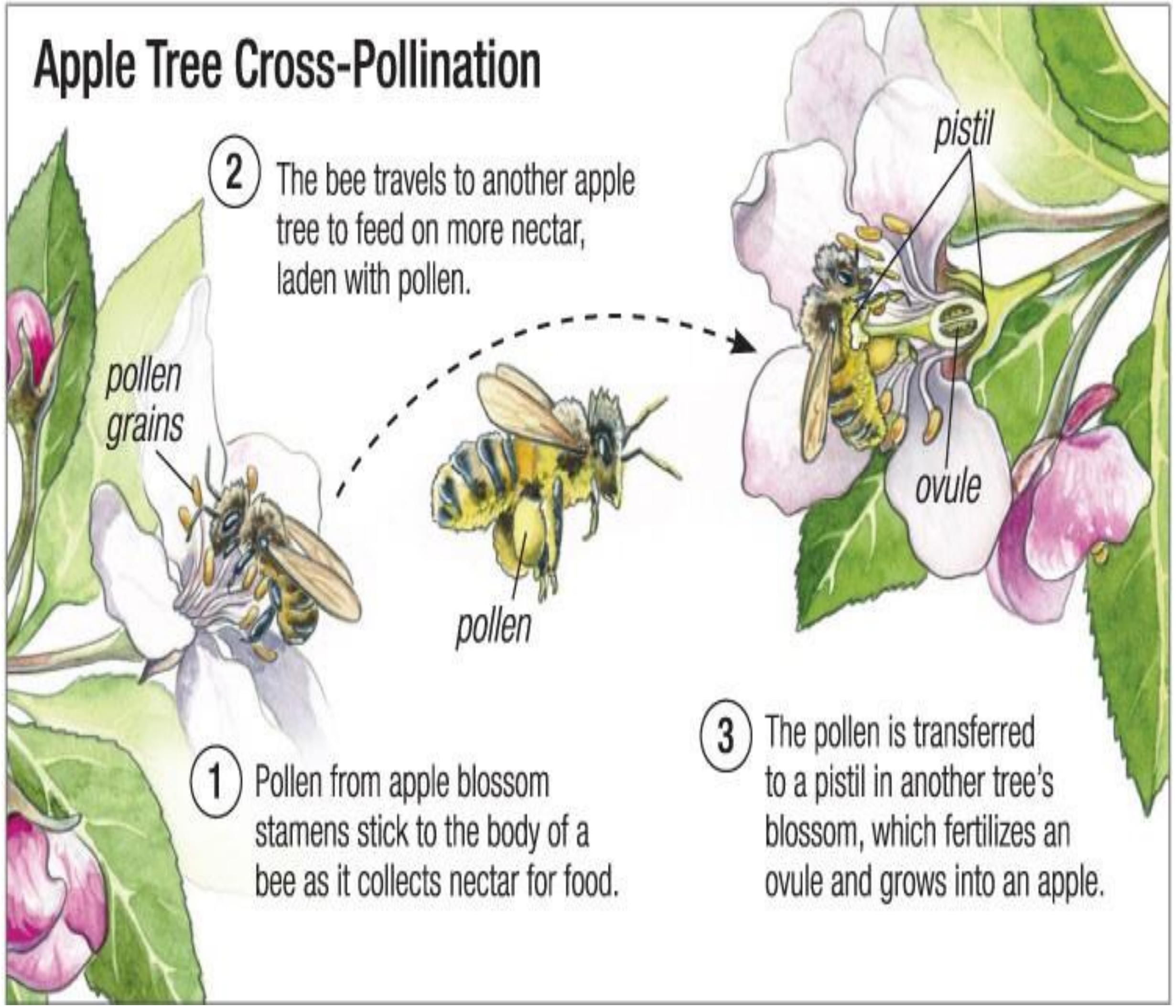
1st Phase: One of the sperm cells unites with the egg cell to form a single-celled zygote which undergoes mitosis and transforms into a multi-celled embryo.

2nd Phase: The second sperm cell fuses with the polar nuclei (diploid) to form the triploid (3n) endosperm which is parenchymatic tissue with the primary function of food storage.



Cross-Pollination

- Nearly **90%** of flowering plants require a **pollinator**.
- The plant which provides pollen is called **pollinizer**.
- Most of the 200.000 or so **pollinators** are **insects**.
- Pollination by **insects** is called **entomophily** and is accomplished by organisms such as; 1. Bees, wasps and ants (*Hymenoptera*), 2. Beetles (*Coleoptera*), 3. Moths and butterflies (*Lepidoptera*), and 4. Flies (*Diptera*).
- Most plants pollinated by insects have colorful, strongly scented flowers.
- Pollination with **vertebrates** is called **zoophily**, accomplished by birds and bats.
- Plants that are pollinated by bats or moths have white petals with strongly scented flowers, while plants pollinated by birds usually have **red petals** and not much of a scent.



Taxonomic Limits of Pollination & Fertilization

- **Pollination and subsequent Fertilization between Genera is relatively rare due to the pollens from different genera is not compatible because of differences in chromosome number, with some notable exceptions, such as many common orchids, and leyland cypress.**
- **Within a Genus, interspecific pollination and fertilization can occur resulting in interspecific hybrids. French-American hybrid grapes (*Vitis spp.*) are well-known examples. Other examples are grapefruit (*Citrus x Paradisi*), tangelo (*Citrus x Tangelo*) and peppermint (*Mentha x Piperita*).**
- **Within a Species, crosses between cultivars may or may not occur readily due to one or several types of incompatibility.**

Self-Incompatibility

- **Nearly *60%* of angiosperm species have some form of self-incompatibility in which the pollen of a plant will not develop a pollen tube on the stigma of the same plant, called as *'Self-Incompatibility'*.**
- **The *'Self-Incompatibility'* ensures *'Cross-Pollination'* and is a barrier to <u>inbreeding</u> and the <u>homozygosis</u> that it causes.**

<u>Gametophytic Self-Incompatibility:</u>

- **It is regulated by a single gene (SI) with multiple alleles (SI1,SI2,SI3...SIn) is the common type.**

<u>Sporophytic Self-Incompatibility:</u>

- **It occurs when some molecular component in the pollen is refused by the stigma which prevents effective germination of the pollen tube.**

<u>Mechanism of Incompatibility:</u>

- **The incompatibility reaction occurs whenever the pollen *(haploid with one allele)* and the stigma *(diploid with two alleles)* have the same alleles.**
- **<u>So, effective pollination and fertilization may only occur if the alleles of pollen and stigma are different.</u>**

Types of Pollination

1. Self-Pollination:

- It occurs when the pollen of a plant lands on its own stigma and germinates into a pollen tube.

2. Cross-Pollination:

- It occurs when the pollen from one plant *(cultivar)* lands and germinates on the stigma of another plant *(cultivar)*.

3. Controlled Crosses:

- This type of pollination occurs when the pollen of a specific cultivar is used to pollinate the stigma of a second specific cultivar to *produce seed of a hybrid cultivar* which needs many years of work called *cross-breeding* by one or more plant breeders.

Sterility

- **Sterility is a reproductive system in plants which fail to produce functional gametes.**
- **'Male Sterility' is much more prevalent and more widely known than 'Female Sterility'.**
- **Because male sporophyte *(diploid:2n)* and gametophyte *(haploid:n)* are less protected from the environment compared with their female counterparts.**
- **It is also easy to assay male sterility with staining tehniques.**
- **Conversely, detection of female sterility requires crossing.**

Mechanism and Types of Male Sterility

- **Male sterility arises from spontaneous mutations in nuclear or cytoplasmic genes and appears in a number of different ways.**
- **It can appear as;**

1. An absence or malformation of the stamen

2. Lack of male flowers

3. A failure of flowers to produce anthers

- **It can be classified as;**

1. Phenotypic Male Sterility ***(structural, sporogenous, functional)***

2. Genotypic Male Sterility ***(genic, cytoplasmic, genic-cytoplasmic)***

Dichogamy

- **Dichogamy** is the difference in time of maturation of male and female flower parts in which self-pollination is prevented.
- **Protandry** refers to the earlier maturation of anthers than the pistils. In species that exhibit protandry, pollens are released from anthers before the stigma in the same flower is receptive such as in corn (*Zea mays*), carrot (*Daucus carota*) and walnut (*Juglans regia*).
- **Protogyny** occurs when the stigma becomes receptive before the anthers in the same flower shed their pollen such as many species of the family *Rosaceae* and *Cruciferae*.

Fruit Set

- The first stage of fruit growth and development is called Fruit Set.
- Fruit Set describes a visible developmental stage of the remnants of the flower that will convert into a harvestable fruit.
- Fruit Set is the most often quantified as a percentage of flowers present at bloom to ones developing into harvestable fruit.
- Most fruit and vegetable crops require both Pollination and Fertilization for fruit set and growth.

Seedless Fruit Formation/Parthenocarpy

- Seedless fruit formation is known as Parthenocarpy.
- There are three forms of parthenocarpy;

1) Vegetative Parthenocarpy
2) Stimulative Parthenocarpy
3) Stenospermocarpy

1. Vegetative Parthenocarpy

- **Fruit set without pollination/fertilization is called Vegetative Parthenocarpy.**

✓ **Seedlless Cucumber (*Cucumis sativus*),**

✓ **Pineapple (*Ananas comosus*),**

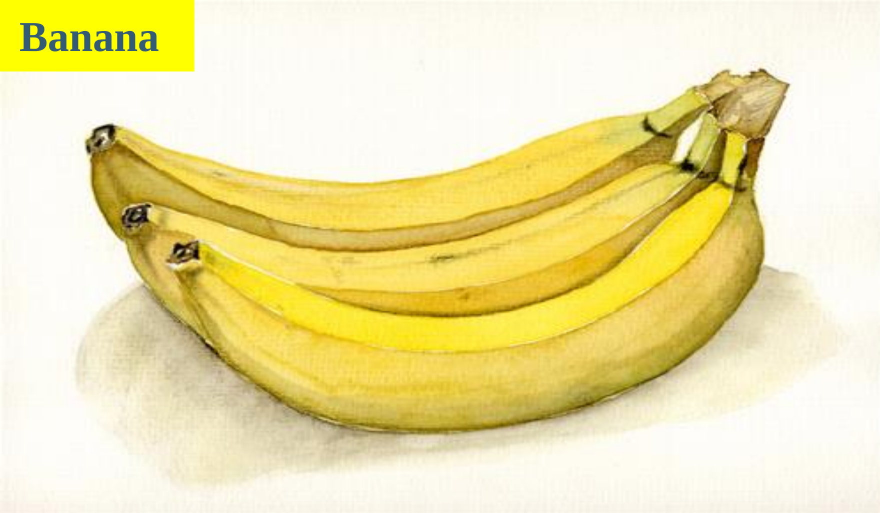
✓ **Satsuma Mandarin (*Citrullus reticulata*),**

✓ **Washington Navel Orange (*Citrus sinensis*),**

✓ **Some Sycomore Figs (*Ficus sycamorus*)**

✓ **Dessert Banana (*Musa acuminate*)**

are the notable examples.



Banana

Pineapple

Fig

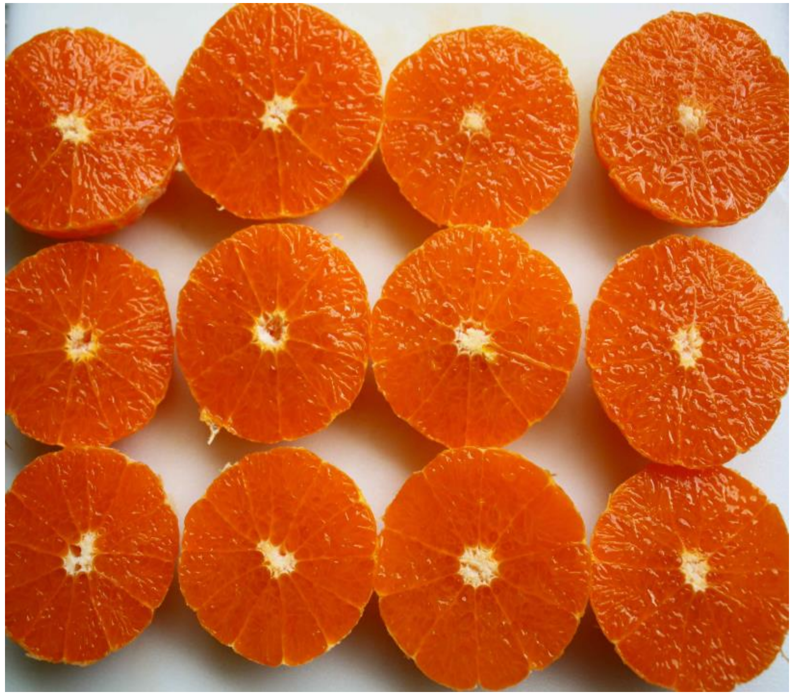
Papaya

Mandarin

Orange

2. Stimulative Parthenocarpy

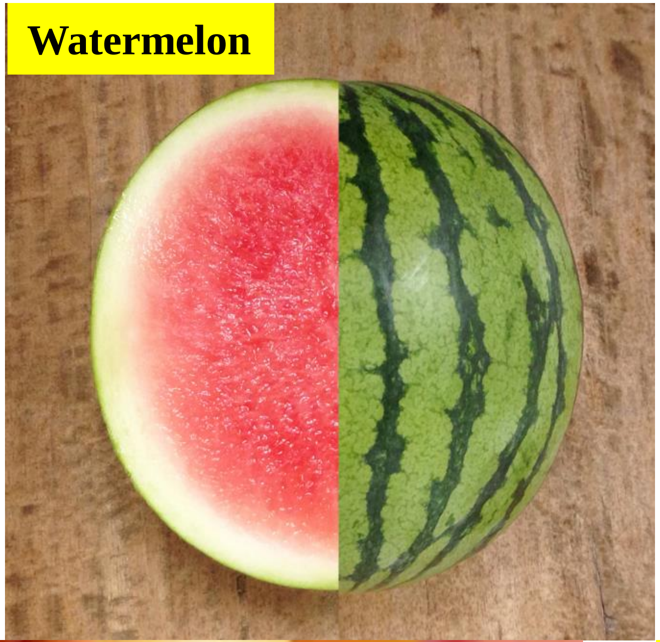
- Fruit set with pollination but without fertilization is called Stimulative Parthenocarpy.
- Black Corinth grape cv. (*Vitis vinifera*), Seedless Clementines (*Citrus reticulata*) and Eggplant (*Solanum melongena*) are the notable examples.



3. Stenospermocarpy

- **Stenospermocarpy** is a type of parthenocarpy where fertilization occurs and the seed begins to develop but eventually aborts, leaving behind a noticeable *'seed trace'*.
- Seed traces are generally soft enough that they do not have the crunch of fully developed seed.
- This occurs in most seedless grapes, watermelon and other fruits such as avocado and litchee.
- Stenospermocarpic seedlessness in all grapes are all due to a naturally occurring harmful *'point mutation'* in the section on the grape chromosome responsible for seed development.
- Many use the word mutation or mutant in a negative context, but this mutation is a desirable character occurred naturally.
- Most commercial seedless grapes are sprayed with gibberellic acid (GA_3) to increase the size of the fruit and also to make the fruit clusters less tightly packed. But, there are some new cultivars, such as Autumn King, Superior Seedless and Melissa have naturally larger fruit so does not require gibberellin sprays.
- Grape breeders have developed some new seedless grape cultivars by using the embryo rescue technique.
- Embryo rescue allows the crossing of two seedless grape cultivars.

Examples of Stenospermocarpy

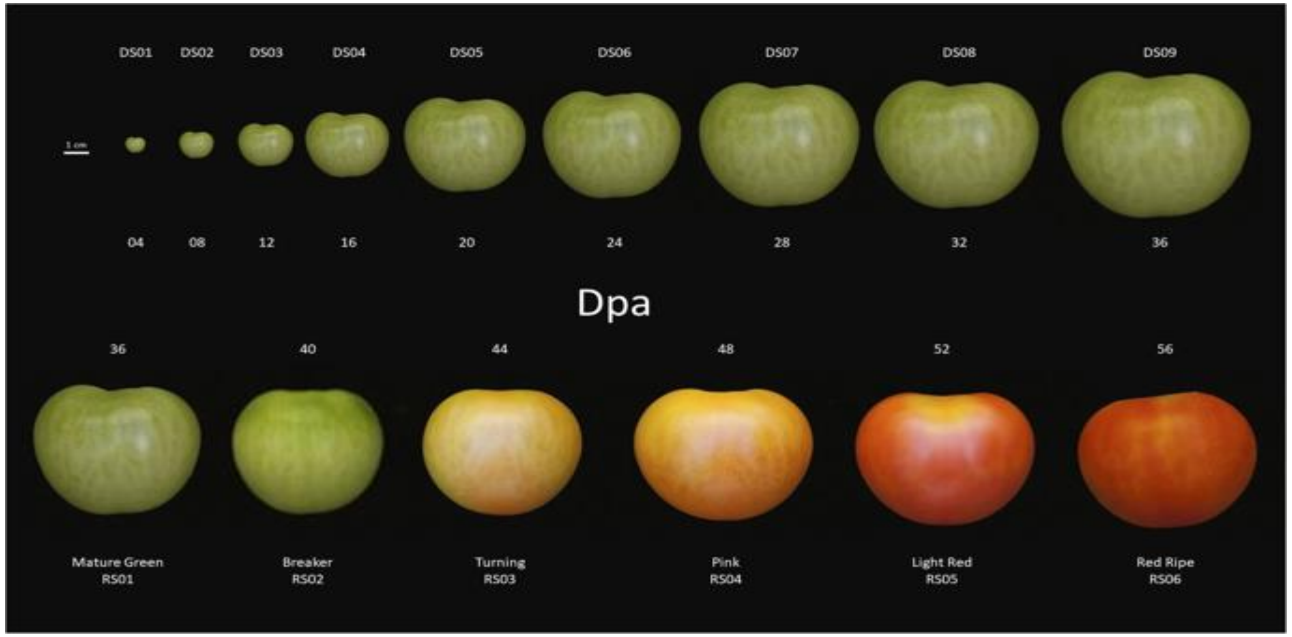


Fruit Drop/Fruit Thinning

- **Once a fruit growth begins, sufficient photosynthates must be translocated to the developing fruit.**
- **If there are many fruits developing on a plant, the available photosynthates will often be translocated to the larger, stronger fruits, resulting in the abortion of the embryo and abscission of the weaker fruits from the plant.**
- **In fruit tree production particularly in apple, pear, quince and peaches &nectarines, this is called 'June Drop'.**
- **One of the tasks of a fruit grower is to prevent excessive fruit set for a full crop by a balanced fruit thinning.**
- **Chemical thinning also helps to reduce the crop load which in turn promotes increased fruit size.**
- **It is a fact that excessive crop leads to biannual bearing.**
- **PGRs used for this purpose are *Ammonium-Thiosulphate (ATS) as blossom thinner; Naphthaleneacetatamide (NAAmide), Naphthalene Acetic Acid, (NAA) Carbaryl, 6-Benzyladenine (BA/BAP) as post-bloom thinner.***

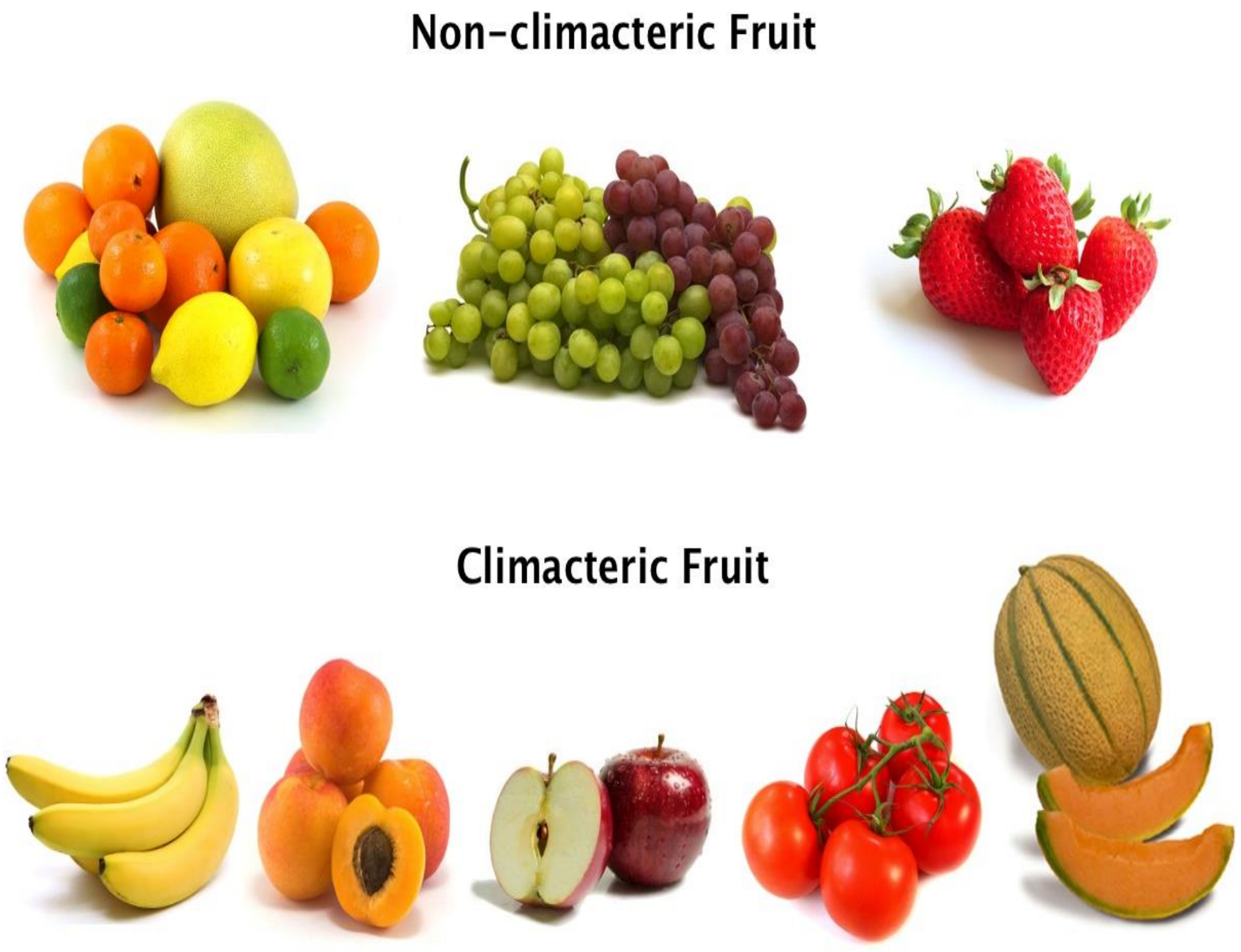
Fruit Growth

- After fruit set, fruit growth results from both cell division and expansion.
- Rapid cell division in all parts of the fruit at the initial period, caused by growth regulators produced by developing seeds.
- Fruits usually do not grow very much during this stage even though the number of the cells is increasing dramatically.
- Final fruit size is often highly correlated with the number of seeds.
- Lopsided and misshapen fruit formation is directly related with the seed abortion.
- Parthenocarpic fruits do not have seeds and how their growth is regulated is not well understood.
- Fruits gradually shift from cell division into a period of cell expansion which accounts for the greatest increase in fruit size.



Fruit Ripening

- Fruits are considered mature if they will ripen once removed from the parent plant.
- Fruit ripening is the process of becoming edible after maturity.
- Crops (fruits) can be harvested mature but not ripe (pear), or mature ripe (grape).
- In general, ripening coincides with embryo maturation.
- Fleshy fruits are either climacteric or non-climacteric.
- Climacteric fruits ripen after harvesting, such as *apple, pear, quince, peach & nectarine, kiwi, banana, mango, guava, fig, melon, papaya, persimmon, tomato.*
- Non-climacteric fruits do not ripen after harvesting, such as *grape, orange, lemon, grapefruit, strawberry, apricot, watermelon, pomegranate, cherry, rambutan, litchi*.
- Ethylene is the hormone regulating ripening and senescence.
- During ripening, color changes, increase in sugars and decrease in acids, and tissue softening take place.
- Ultimately fruit quality will decrease as the fruit begins to senesce after ripening.



Seed Formation and Development

- Seed set (formation) starts with the fertilization of egg cell.
- Seed set is characterized by a sharp increase of GAs, auxins and cytokinins, each playing an important role in further fruit and seed growth.
- Seeds are an essential source of food for human and animal consumption.
- They consist of three major regions – *Seed Coat, Endosperm, and Embryo* – which have different genetic origins, unique functions, and distinct developmental pathways.
- *Seed Coat* transfers nutrients from the maternal plant to the embryo during seed development, and protects the seed during dormancy.
- *Endosperm* has two very important roles in seed development: (i) a source of embryo nutrition, particularly during early embryogenesis (ii) partially directing the development of the seed.
- *Embryo*, is the newly developing plant inside the seed. Embryo development is often divided into three overlapping stages: (i) morphogenesis, (ii) maturation, (iii) desiccation.
- On the other hand, embryo differentiates into axis and cotyledon leaves – the former giving rise to the mature plant after germination, while the latter is terminally differentiated and accumulates storage reserves that are used as an energy source for the germinating seedling.