Plant Body Systems

Transport in Plants

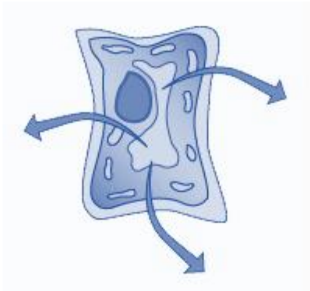
(1) Types of osmosis

Depending upon the movement of water into or outward of the cell, osmosis is of two types.

(a) **Endosmosis:** The osmotic inflow of water into a cell, when it is placed in a solution, whose solute concentration is less than the cell sap, is called endosmosis *e.g.,* swelling of raisins, when they are placed in water.

(b) **Exosmosis:** The osmotic outflow of water from a cell, when it is placed in a solution, whose solute concentration is more than the cell sap, is called exosmosis. *e.g.,*shrinkage of grapes when they are placed in strong sugar solution.

(2) Osmotic concentrations (Types of solutions)



A solution can be termed as hypotonic, hypertonic and isotonic depending upon its osmotic concentration, with respect to another solution or cell sap.

(a) **Hypotonic solution** (*hypo* = less than). A solution, whose osmotic concentration (solute potential) is less than that of another solution or cell sap is called hypotonic solution. If a cell is placed in such a solution, water start moving into the cell by the process of endosmosis, and cell become turgid.

(b) **Hypertonic solution** (*hper* = more than). A solution, whose osmotic concentration (solute potential) is more than that of another solution or cell sap is called hypertonic solution. If a cell is placed in such a solution, water comes out of the cell by the process of exosmosis and cell become flaccid. If potato tuber is placed in concentrated salt solution it would become shrink due to loss of water from its cell.

(c) **Isotonic solution** (*iso* = the same). A solution, whose osmotic concentration (solute potential) is equal to that of another solution or cell sap, is called isotonic solution. If a cell is placed in isotonic solution, there is no net change of water between the cell and the solution and the shape of cell remain unchanged. The normal saline (0.85% solution of $NaCl$) and 0.4 m to 0.5 m solution of sucrose are isotonic to the cell sap.

(3) Significance of osmosis in plants

(a) The phenomenon of osmosis is important in the absorption of water by plants.

(b) Cell to cell movement of water occurs throughout the plant body due to osmosis.

(c) The rigidity of plant organs (*i.e.,* shape and form of organism) is maintained through osmosis.

(d) Leaves become turgid and expand due to their OP.

(e) Growing points of root remain turgid because of osmosis and are thus, able to penetrate the soil particles.

(f) The resistance of plants to drought and frost is brought about by osmotic pressure of their cells.

(g) Movement of plants and plant parts, for example, movement of leaflets of Indian telegraph plant, bursting of many fruits and sporangia, etc. occur due to osmosis.

(h) Opening and closing of stomata is affected by osmosis.

(4) Turgor pressure (TP)

The plant cell, when placed in pure water, swells but does not burst. Because of negative osmotic potential of the vacuolar solution (cell sap), water will move into the cell and will cause the plasmalemma be pressed against the cell wall.

(5) Wall pressure (WP)

Due to turgor pressure, the protoplast of a plant cell will press the cell wall to the outside. The cell wall being elastic, presses back the protoplast with a pressure equal in magnitude but opposite in direction. This pressure is called **wall pressure**. Wall pressure (WP) may, therefore, be defined as '*the pressure exerted by the cell wall over the protoplast to counter the turgor pressure*.

(6) Plasmolysis (Gr. Plasma = something formed; lysis = loosing)

If a living plant cell is placed in a highly concentrated solution (*i.e.* hypertonic solution), water comes out of the cell due to exosmosis, through the plasmamembrane. The loss of water from the cell sap causes shrinkage of the protoplast away from the cell wall in the form of a round mass in the centre. "*The shrinkage of the protoplast of a living cell from its cell wall due to exosmosis under the influence of a hypertonic solution is called plasmolysis*".

(7) **Water potential (*y*)**

The movement of water in plants cannot be accurately explained in terms of difference in concentration or in any other linear expression. The best way to express spontaneous movement of water from one region to another is in terms of the difference of free energy of water between two regions. Free energy is the thermodynamic parameter that determines the direction in which physical and chemical changes must occur. The potential energy of water is called water potential. *e.g.,* water is stored behind a dam.

(8) Differences between diffusion pressure deficit and water potential

S.No.	Diffusion Pressure Deficit (DPD)	Water Potential (*y*)
(1)	The DPD was originally described by the term suction force (*Saugkraft*) by Renner. Other synonyms of the term are suction pressure (SP), enter tendency (E) and osmotic equivalent (E).	Water potential is the chemical potential of water which is equivalent to DPD with negative sign. The term water potential was coined by Slatyer and Taylor (1960).
(2)	The diffusion pressure deficit is abbreviated as DPD. The term was coined by Meyer (1938).	The symbol for water potential is a Greek letter*psi*, which is designated as *y*.

(9) Differences between active and passive absorption of water

S.No.	Active absorption	Passive absorption
(1)	Force for absorption of water is generated in the cells of root itself.	Force for absorption of water is created in the mesophyll cells.
(2)	Osmotic and non-osmotic forces are involved in water absorption.	Water is absorbed due to transpiration pull.
(3)	Water is absorbed according to DPD changes.	Water is absorbed due to tension created in xylem sap by transpiration pull.
(4)	Water moves through symplast.	Water moves mainly through apoplast.
(5)	Rate of absorption is not affected significantly by temperature and humidity.	Its rate is significantly affected by all those factors which influence the rate of transpiration.
(6)	Metabolic inhibitors if applied in root cells decrease the rate of water absorption.	No effect of metabolic inhibitors if applied in root cells.
(7)	Occurs in slow transpiring plants which are well watered.	Occurs in rapidly transpiring plants.
(8)	Rate of absorption is slow.	Very fast rate of water absorption.

(10) Differences between transpiration and evaporation

S.No.	Transpiration	Evaporation
(1)	It is a physiological process and occurs in plants.	It is a physical process and occurs on any free surface.
(2)	The water moves through the epidermis with its cuticle or through the stomata.	Any liquid can evaporate. The living epidermis and stomata are not involved.
(3)	Living cells are involved.	It can occur from both living and non-living surfaces.
(4)	Various forces (such as vapour pressure, diffusion pressure, osmotic pressure, etc) are involved.	Not much forces are involved.
(5)	It provides the surface of leaf and young stem wet and protects from sun burning.	It causes dryness of the free surface.

(11)**Types of stomata**

On the basis of orientation of subsidiary cells around the guard cells, **Metcalfe** and **Chalk** classified stomata into following types :

(i) **Anomocytic :** The guard cells are surrounded by a limited number of unspecialised subsidiary cells which appear similar to other epidermal cells. *e.g.*, in Ranunculaceae family.

(ii) **Anisocytic :** The guard cells are surrounded by three subsidiary cells, two of which are large and one is very small. *e.g.,* in Solanaceae and Cruciferae families.

(iii) **Paracytic :** The guard cells are surrounded by only two subsidiary cells lying parallel to the guard cells *e.g.*, Magnoliaceae family.

(iv) **Diacytic :** The guard cells are surrounded by only two subsidiary cells lying at right angles to the longitudinal axis of the guard cells. *e.g.*, Acanthaceae and Labiatae families.

(v) **Actinocytic :** The guard cells are surrounded by four or more subsidiary cells and which are elongated radially to stomata.

(12)Differences between transpiration and guttation

MineralNutrition

(1) **Macronutrients (Macroelements or major elements):** Nutrients which are required by plants in larger amounts (Generally present in the plant tissues in concentrations of 1 to 10 *mg per* gram of dry matter).

(2) The macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium, magnesium.

(3) **Micronutrients (Microelements or minor elements or trace elements):** Nutrients which are required by plants in very small amounts, *i.e.,* in traces (equal to or less than 0.1 *mg* per gram dry matter).

(4) The micronutrients include iron, manganese, copper, molybdenum, zinc, boron and chlorine. Recent research has shown that some elements, such as cobalt, vanadium and nickel, may be essential for certain plants.

(5) The usual concentration of essential elements in higher plants according to D.W. Rains (1976) based on the data of Stout are as follows:

Major Role of Nutrients

Various elements perform the following major role in the plants:

(1) **Construction of the plant body:** The elements particularly C, H and O construct the plant body by entering into the constitution of cell wall and protoplasm. They are, therefore, referred to as **frame work elements**. Besides, these (C, H and O) N, P and S also enter in the constitution of protoplasm. They are described as**protoplasmic elements**.

(2) **Maintenance of osmotic pressure:** Various minerals present in the cell sap in organic or inorganic form maintain the osmotic pressure of the cell.

(3) **Maintenance of permeability of cytomembranes:** The minerals, particularly Ca^{++}, K^{+} and Na^{+} maintainthe permeability of cytomembranes.

(4) **Influence the pH of the cell sap:** Different cations and anions influence on the *pH* of the cell sap.

(5) **Catalysis of biochemical reaction:** Several elements particularly *Fe, Ca, Mg, Mn, Zn, Cu, Cl* act as metallic catalyst in biochemical reactions.

(6) **Toxic effects:** Minerals like *Cu, As,* etc. impart toxic effect on the protoplasm under specific conditions.

(7) **Balancing function:** Some minerals or their salts act against the harmful effect of the other nutrients, thus balancing each other.

Specific Role of Macronutrients

The role of different elements is described below:

(1) **Carbon, hydrogen and oxygen:** These three elements though cannot be categorized as mineral elements, are indispensible for plant growth. These are also called **'framework elements'**.

(2) **Nitrogen:** Nitrogen is an essential constituent of proteins, nucleic acids, vitamins and many other organic molecules as chlorophyll. Nitrogen is also present in various hormones, coenzymes and ATP etc.

    (i) **Deficiency symptoms:** The symptoms of nitrogen deficiency are as follows:

        (a) Impaired growth
        (b) Yellowing of leaves due to loss of chlorophyll, *i.e.*, **chlorosis**.
        (c) Development of anthocyanin pigmentation in veins, sometimes in petioles and stems.
        (d) Delayed or complete suppression of flowering and fruiting.

(3) **Phosphorus**

(a) Phosphorous is present abundantly in the growing and storage organs such as fruits and seeds. It promotes healthy root growth and fruit ripening by helping translocation of carbohydrates.

(i) **Deficiency symptoms**

(a) Leaves become dark green or purplish.

(b) Sometimes development of anthocyanin pigmentation occurs in veins which may become necrotic (**Necrosis** is defined as localised death of cells).

(c) Premature fall of leaves.

(4) **Sulphur**

(i) **Functions**

(a) Sulphur is a constituent of amino-acids like cystine, cysteine and methionine; vitamins like biotin and thiamine, and coenzyme A.

(ii) **Deficiency symptoms**

(b) Leaf tips and margins roll downwards and inwards *e.g.*, tobacco, tea and tomato.

(c) Premature leaf fall.

(d) Delayed flowering and fruiting.

(5) **Potassium**

(i) **Functions**

(a) It differs from all other macronutrients in **not being a constituent** of any metabolically important compound.

(b) It is the **only monovalent cation** essential for the plants.

(c) It acts as an activator of several enzymes including DNA polymerase.

(ii) **Deficiency symptoms**

(a) **Mottled chlorosis** followed by the development of necrotic areas at the tips and margins of the leaves.

(b) K^+ deficiency inhibits proteins synthesis and photosynthesis. At the same time, it increases the rate of respiration.

(c) The internodes become shorter and root system is adversely affected.

(6) **Calcium**

(i) **Functions**

(a) It is necessary for formation of middle lamella of plants where it occurs as calcium pectate.

(b) It is necessary for the growth of apical meristem and root hair formation.

(c) It acts as activator of several enzymes, *e.g.*, ATPase, succinic dehydrogenase, adenylate kinase, etc.

(ii) **Deficiency symptoms**

(a) Ultimate death of meristems which are found in shoot, leaf and root tips.

(b) Chlorosis along the margins of young leaves, later on they become necrotic.

(c) Distortion in leaf shape.

(7) **Magnesium**

(i) **Functions**

(a) It is an important constituent of **chlorophyll**.

(b) It is present in the **middle lamella** in the form of magnesium pectate.

(c) It plays an important role in the metabolism of carbohydrates, lipids and phosphorus.

(ii) Deficiency symptoms

(a) **Interveinal** chlorosis followed by anthocyanin pigmentation, eventually necrotic spots appears on the leaves. As magnesium is easily transported within the plant body, the deficiency symptoms first appear in the mature leaves followed by the younger leaves at a later stage.

(b) Stems become hard and woody, and turn yellowish green.

(c) Depression of internal **phloem** and extensive development of **chlorenchyma**.

Specific Role of Micronutrients

(1) **Iron**

(i) **Functions**

(a) Iron is a structural component of ferredoxin, flavoproteins, iron prophyrin proteins (Cytochromes, peroxidases, catalases, etc.)

(b) It plays important roles in energy conversion reactions of photosynthesis (phosphorylation) and respiration.

(c) It acts as activator of nitrate reductase and aconitase.

(ii) **Deficiency symptoms**

(a) Chlorosis particularly in younger leaves, the mature leaves remain unaffected.

(b) It inhibits chloroplast formation due to inhibition of protein synthesis.

(c) Stalks remain short and slender.

(2) **Manganese**

(i) **Functions**

(a) It acts as activator of enzymes of...

Photosynthesis in Higher Plants

Chloroplast-The site of photosynthesis:

The most active photosynthetic tissue in higher plants is the mesophyll of leaves. Mesophyll cells have many chloroplasts. Chloroplast is present in all the green parts of plants and leaves. There may be over half a million chloroplasts per square millimetre of leaf surface. In higher plants, the chloroplasts are discoid or lens-shaped. They are usually 4-10*mm* in diameter and 1-3*mm* in thickness.

Chloroplast pigments:

Pigments are the organic molecules that absorb light of specific wavelengths in the visible region due to presence of conjugated double bonds in their structures. The chloroplast pigments are fat soluble and are located in the lipid part of the thylakoid membranes.

(i) **Chlorophylls:** The chlorophylls, the green pigments in chloroplast are of seven types *i.e.*, chlorophyll *a, b, c, d, e*, bacteriochlorophyll and bacterioviridin

(ii) **Carotenoids :** The carotenoids are unsaturated polyhydrocarbons being composed of eight isoprene (C_5H_8) units. They are made up of two six-membered rings having a hydrocarbon chain in between. They are sometimes called lipochromes due to their fat soluble nature.

Difference between Photosystem I and Photosystem II

S.No.	Photosystem I	Photosystem II
(1)	PS I lies on the outer surface of the thylakoids	PS II lies on the inner surface of the thylakoid.
(2)	In this system molecular oxygen is not evolved.	As the result of photolysis of water molecular oxygen is evolved.
(3)	Its reaction center is P700.	Its reaction center is P680.
(4)	NADPH is formed in this reaction.	NADPH is not formed in this reaction.
(5)	It participate both in cyclic and noncyclic photophosphorylation.	It participates only in noncyclic photophosphorylation.
(6)	It receives electrons from photosystem II.	It receives electrons from photolytic dissociation of water.
(7)	It is not related with photolysis of water.	It is related with photolysis of water.

Difference between C_3 Plants and C_4 Plants

S.No.	Characters	C_3 plants	C_4 plants
(1)	CO_2 acceptor	The CO_2 acceptor is Ribulose 1, 5 diphosphate.	The CO_2 acceptor is phosphoenol-pyruvate.
(2)	First stable product	The first stable product is phosphoglyceric acid.	Oxaloacetate is the first stable product.
(3)	Type of chloroplast	All cells participating in photosynthesis have one type of chloroplast.	The chloroplast of parenchymatous bundle sheath is different from that of mesophyll cells. Leaves have 'Kranz' type of anatomy. The bundle sheath chloroplasts lack grana. Mesophyll cells have normal chloroplasts.
(4)	Cycles	Only reductive pentose phosphate cycle is found.	Both C_4-dicarboxylic acid and reductive pentose phosphate cycles are found.
(5)	Optimum temperature	The optimum temperature for the process is 10-25°C.	In C_4 plants, it is 30-45°C.
(6)	Oxygen inhibition	Oxygen present in air (=21% O_2) markedly inhibit the photosynthetic process as compared to an external atmosphere containing no oxygen.	The process of photosynthesis is not inhibited in air as compared to an external atmosphere containing no oxygen.
(7)	PS I and PS II	In each chloroplast, photosystems I and II are present. Thus, the Calvin cycle occurs.	In the chloroplasts of bundle sheath cells, the photosystem II is absent. Therefore, these are dependent to mesophyll chloroplast for the supply of NADPH + H^+
(8)	Enzymes	The Calvin cycle enzymes are present in mesophyll chloroplast.	Calvin cycle enzymes are absent in mesophyll chloroplasts. The cycle occurs only in the chloroplasts of sheath cells.
(9)	Compensation point	The CO_2 compensation point is 50-150ppm.	CO_2 compensation point is 0-10ppm.
(10)	Photorespiration	Photorespiration is present and easily detectable.	Photorespiration is present only to a slight degree and difficult to detect.
(11)	Net rate	Net rate of photosynthesis in full sunlight (10,000-12,000 ft.c) is 15-35mg. of CO_2 per dm^2 of leaf area per h.	It is 40-80mg. of CO_2 per dm^2 of leaf area per h. That is photosynthetic rate is quite high. The plants are efficient.
(12)	Saturation intensity	The saturation intensity reached in the range of 100-4000 ft.c.	It is difficult to reach saturation even in full sunlight.

Respiration in Plants

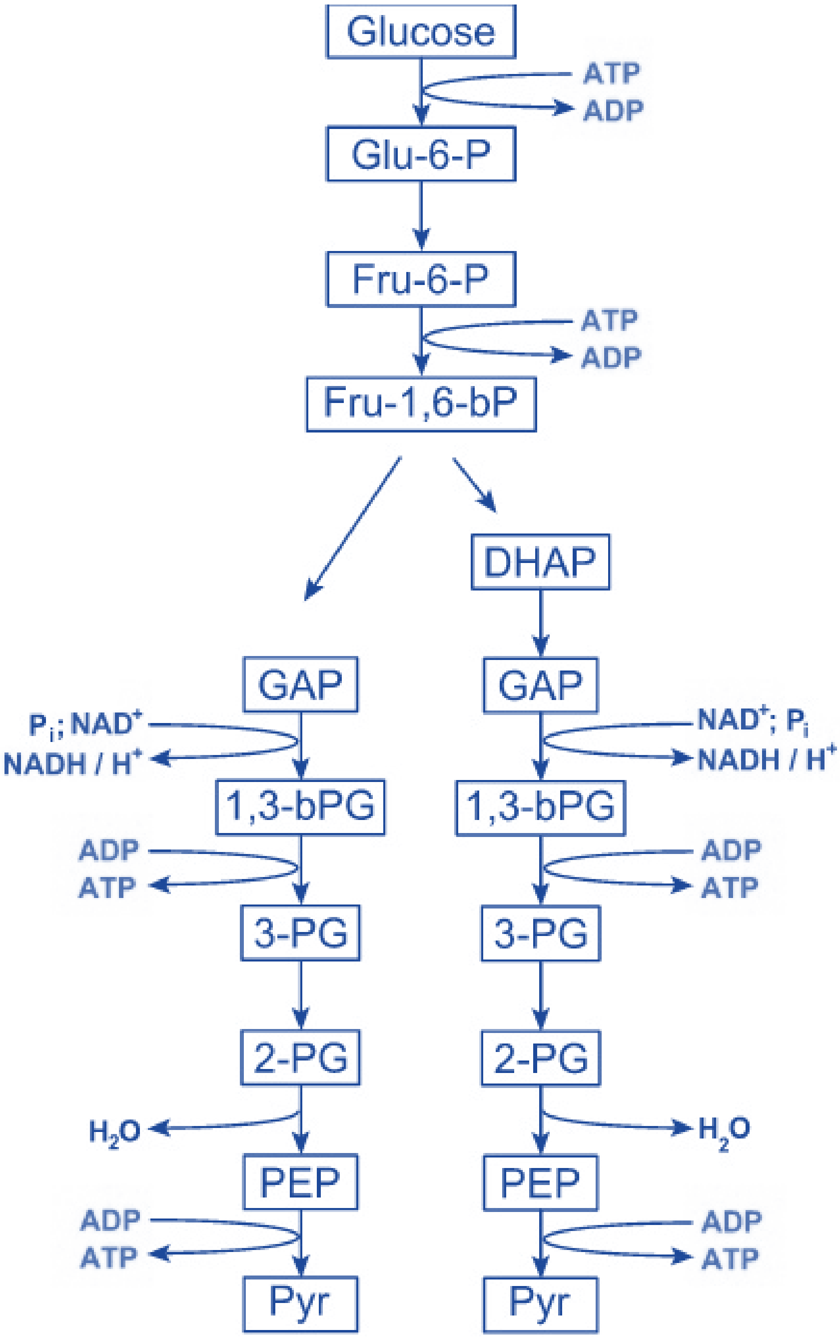
Differences between Photosynthesis and Respiration

Photosynthesis	Respiration
Occurs only in chlorophyll containing cells of plants.	Occurs in all plant and animal cells.
Takes place only in the presence of light.	Takes place continually both in light and in the dark.
During photosynthesis, radiant energy is converted into potential energy.	During respiration, potential energy is converted into kinetic energy.
Sugars, water and oxygen are products.	CO_2 and H_2O are products.
Synthesizes foods.	Oxidizeds foods.
CO_2 and H_2O are raw materials.	O_2 and food molecules are raw materials.
Photosynthesis is an endothermal process.	Respiration is an exothermal process.
Stores energy.	Releases energy.
It includes the process of hydrolysis, carboxylation etc.	It includes the process of the dehydrolysis, decarboxylation, etc.
Results in an increase in weight.	Results in a decrease in weight.
It is an anabolic process.	It is a catabolic process.
Require cytochrome.	Also require cytochrome.

(viii)	**Intermediates**	A number of intermediates are produced.	No intermediate is produced.

Glycolysis cycle

Enzymes of glycolysis and their co-factors

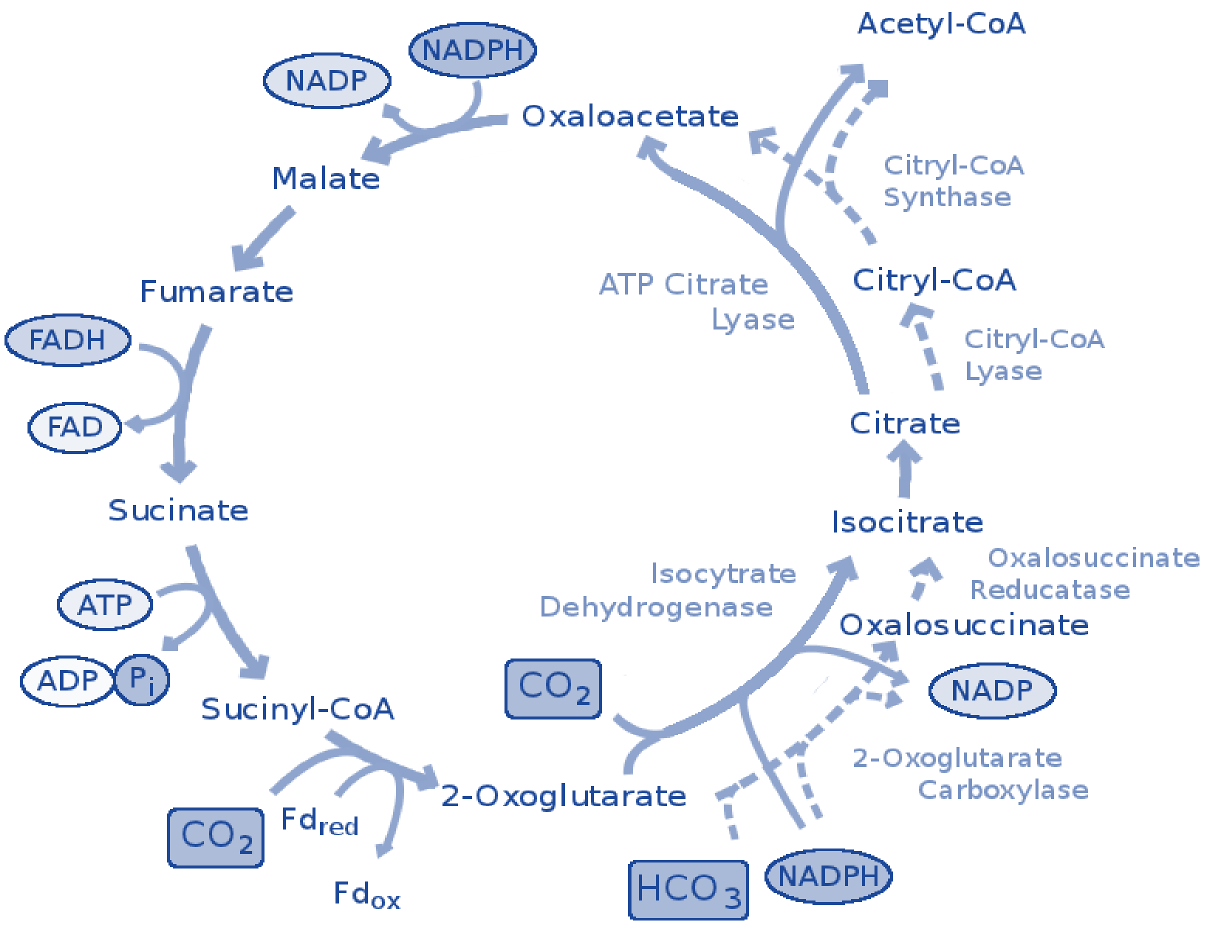


S. No.	Enzyme	Coenzyme (s) and cofactor	Activator (s)	Inhibitor (s)	Kind of reaction catalyzed
(i)	Hexokinase	Mg^{2+}	ATP^{4-}, Pi	Glucose 6-phopshate	Phosphoryl transfer
(ii)	Phosphogluco-isomerase	Mg^{2-}	-	2-dioxyglucose 6-phosphate	Isomerization
(iii)	Phosphofructo-kinase	Mg^{2+}	Fructose 2, 6-diphosphate, AMP, ADP, cAMP, K^+	ATP $^{4-}$, citrate	Phosphoryl transfer
(iv)	Aldolase	Zn^{2+} (in microbes)	-	Chelating agents	Aldol cleavage
(v)	Phosphotriose isomerase	Mg^{2+}	-	-	Isomerization
(vi)	Glyceraldehyde 3-phosphate dehydrogenase	NAD	-	Iodoacetate	Phosphorylation coupled to oxidation
(vii)	Phosphoglycerate kinase	Mg^{2+}	-	-	Phosphoryl transfer
(viii)	Phosphoglycerate mutase	Mg^{2+} 2,3-diphos phoglycerate	-	-	Phosphoryl shift
(ix)	Enolase	Mg^{2+}, Mn^{2+}, Zn^{2+}, Cd^{2+}	-	Fluoride+ phosphate	Dehydration
(x)	Pyruvate kinase	Mg^{2+}, K^+	-	Acetyl CoA, analine, Ca^{2+}	Phosphoryl transfer

Total input and output materials in glycolysis

Total Inputs	Total Outputs
1 molecule of glucose (6 *C*)	2 molecules of pyruvate (2×3 *C*)
2 ATP	4 ATP
4 ADP	2 ADP
2 × NAD	2× NADH + $2H^+$
2 Pi	$2\times H_2O$

Kreb's Cycle



Acetyl-CoA
NADPH
NADP
Oxaloacetate
Malate
Citryl-CoA
Synthase
Fumarate
ATP Citrate
Lyase
Citryl-CoA
FADH
Citryl-CoA
Lyase
FAD
Citrate
Sucinate
Isocitrate
Isocytrate
Dehydrogenase
Oxalosuccinate
Reducatase
ATP
Oxalosuccinate
ADP
P i
CO_2
NADP
Sucinyl-CoA
2-Oxoglutarate
Carboxylase
2-Oxoglutarate
CO_2
Fd red
Fd ox
HCO_3
NADPH

Enzymes of Kreb's cycle

Step	Enzyme	(Location in mitochondria)	Coenzyme(s) and cofactor (s)	Inhibitor(s)	Type of reaction catalyzed
(a)	Citrate synthetase	Matrix space	CoA	Monofluoro-acetyl- CoA	Condensation
(b)	Aconitase	Inner membrane	Fe^{2+}	Fluoroacetate	Isomerization
(c)	Isocitrate dehydrogenase	Matrix space	NAD^+, $NADP^+$, Mg^{2+}, Mn^{2+}	ATP	Oxidative decarboxylation
(d)	alpha-ketoglutarate dehydrogenase complex	Matrix space	TPP,LA,FAD,CoA, NAD^+	Arsenite,Succinyl-CoA, NADH	Oxidative decarboxylation
(e)	Succinyl-CoA synthetase	Matrix space	CoA	-	Substrate level phosphorylation
(f)	Succinate dehydrogenase	Inner membrane	FAD	Melonate, Oxaloacetate	Oxidation
(g)	Fumarase	Matrix space	None	-	Hydration
(h)	Malate dehydrogenase	Matrix space	NAD^+	NADH	Oxidation

Products formed during aerobic respiration by Glycolysis and Kreb's cycle

ATP formation in Glycolysis			
	Steps	**Product of reactions**	**In terms of ATP**
ATP formation by substrate phosphorylation	1, 3-diphosphoglyceric acid (2 moles) ® 3 phosphoglyceric acid (2 moles) Phosphoenolpyruvic acid (2 moles) ® Pyruvic acid (2 moles)	2 ATP 2 ATP	2 ATP 2 ATP
		Total	4 ATP
ATP formation by oxidative phosphorylation or ETC	1, 3 - disphosphoglyceraldehyde (2 moles) 1, 3 – diphosphoglyceric acid (2 moles)	2 $NADH_2$	6 ATP
	Total ATP formed	4 + 6 ATP =	10 ATP
ATP consumed in	Glucose (1 mole) ® Glucose 6 phosphate (1	– 1 ATP	– 1 ATP

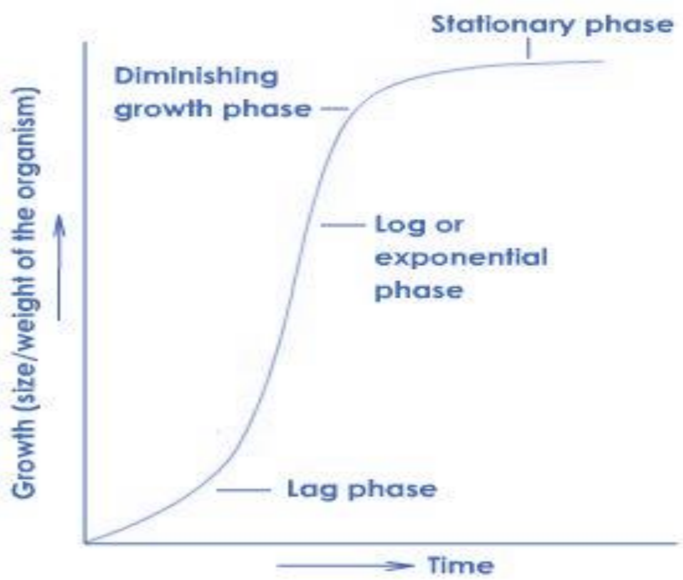
Glycolysis	mole) Fructose 6 phosphate (1 mole) ® Fructose 1, 6-diphosphate (1 mole)	– 1 ATP	– 1 ATP
		Total	2 ATP
	Net gain of ATP = total ATP formed – Total ATP consumed	**10 ATP – 2ATP**	**8 ATP**
ATP formation in Kreb's cycle			
ATP formation by substrate phosphorylation	Succinyl CoA (2 mols) ® Succinic acid (2 mols)	2 GTP	2 ATP
		Total	2 ATP
ATP formation by oxidative phosphorylation or ETC	Pyruvic acid (2 mols) ® Acetyl CoA (2 mols)	2 $NADH_2$	6 ATP
	Isocitric acid (2 mols) ® Oxalosuccinic acid (2 mols)	2 $NADH_2$	6 ATP
	a-Ketoglutaric acid (2 mols) ® Succinyl CoA (2 mols)	2 $NADH_2$	6 ATP
	Succinic acid (2 mols) ® Fumaric acid (2 mols)	2 $FADH_2$	4 ATP
	Malic acid (2 mols) ® Oxaloacetic acid (2 mols)	2 $NADH_2$	6 ATP
		Total	28 ATP
	Net gain in Kreb's cycle (substrate phosphorylation + oxidative phosphorylation)	2ATP + 28 ATP	30 ATP
Net gain of ATP in glycolysis and Kreb's cycle	Net gain of ATP in glycolysis + Net gain of ATP in Kreb's cycle	8 ATP + 30 ATP	38 ATP
Over all ATP production by oxidative phosphorylation or ETC	ATP formed by oxidative phosphorylation in glycolysis + ATP formed by oxidative phosphorylation or ETC.	6 ATP + 28 ATP	34 ATP

Aerobic, Anaerobic Respiration and Fermentation

Aerobic Respiration	Anaerobic Respiration	Fermentation
Molecular oxygen is the ultimate electron acceptor for biological oxidation. The ETS serves to transfer electrons from oxidisable donor to molecular oxygen. The early enzymatic steps involve dehydrogenation whereas the final steps are mediated by a group of enzyme called cytochromes. Ultimately the electrons are transferred to oxygen which is reduced to water. During aerobic respiration ATP is generated by coupled reaction	The ultimate electron acceptor is an inorganic compound other than oxygen. The compounds accepting the hydrogen (electrons) are nitrates, sulphates, carbonates orCO_2. Anaerobic respiration produces ATP through phosphorylation reaction involving electron transfer systems. (mechanism not known)	The final electron acceptors are organic compounds. Both electron donors (oxidizable substrate) and electron acceptors (oxidizing agent) are organic compounds and usually both substrates arise from same organic molecules during metabolism. Thus part of the nutrient molecule is oxidised and part reduced and the metabolism results in intramolecular electron rearrangement. ATP is generated by substrate level phosphorylation. This reaction differs from oxidative phosphorylation because oxygen itself is not required for ATP generation.

Plant Growth and Development

(1) The analysis of growth curve shows that it can be differentiated into three phases:



- **(i) Lag phase:** It represents initial stages of growth. The rate of growth is very slow in lag phase. More time is needed for little growth in this phase.
- **(ii) Log phase (Exponential phase):** The growth rate becomes maximum and more rapid**.** Physiological activities of cells are at their maximum. The log phase is also referred to as **grand period of growth**.

(iii) Final steady state (Stationary phase) or Adult phase: When the nutrients become limiting, growth slows down, so physiological activities of cells also slows down. This phase is indicated by the maturity of growth system. The rate of growth can be measured by an increase in size or area of an organ of plant like leaf, flower, fruit etc. The rate of growth is called efficiency index.

(2) P**hytohormones:-**

(i) Growth hormones also called **phytohormones**

(ii) Term given by Thimann (1948),

(iii) It can be defined as 'the organic substances which are synthesized in minute quantities in one part of the plant body and transported to another part where they influence specific physiological processes'.

Growth Hormones and Growth Regulators

(1) Auxins:

(i) Auxins (Gk. *auxein* = to grow) are weakly acidic growth hormones having an unsaturated ring structure and capable of promoting cell elongation, especially of shoots (more pronounced in decapitated shoots and shoot segments) at a concentration of less than 100 *ppm* which is inhibitory to the roots. Among the growth regulators, auxins were the first to be discovered.

(ii) Types of auxins: There are two major categories of auxins natural auxins and synthetic auxins:

- **(a) Natural auxins:** These are naturally occurring auxins in plants and therefore, regarded as **phytohormones**. Indole 3-acetic acid (IAA) is the best known and universal auxin. It is found in all plants and fungi.
- **(b) Synthetic auxins:** These are synthetic compounds which cause various physiological responses common to IAA. Some of the important synthetic auxins are 2, 4-D (2, 4-dichlorophenoxy acetic acid) is the weedicide. IBA is both natural and synthetic auxin.

(iii) Functions of auxins: Auxins control several kinds of plant growth processes. These are as follows:

- **(a) Cell elongation:** Auxins promote elongations and growth of stems and roots and enlargement of many fruits by stimulating elongation of cells in all directions.
- **(b) Apical dominance:** In many plants, the apical bud grows and the lower axillary buds are suppressed. Removal of apical bud results in the growth of lower buds. The auxin (IAA) of the terminal bud inhibits the growth of lateral buds. This phenomenon is known as apical dominance.
- **(c) Weed control:** Weeds are undesirable in a field with a crop. By the spray of 2, 4-D, broad-leaved weeds can be destroyed but 2, 4-D does not affect mature monocotyledonous plants.
- **(d) Root differentiation**

(e) **Control of lodging**

(f) **Parthenocarpy:** Parthenocarpy can be induced by application of IAA in a paste form to the stigma of a flower or by spraying the flowers with a dilute solution of IAA.

(2) Gibberellins:

(i) Gibberellins are weakly acidic hormones having gibbane ring structure which cause cell elongation of intact plants in general and increased internodal length of genetically dwarfed plants (i.e., corn, pea) in particular.

(ii) **Functions of gibberellin**

(a) **Stem elongation:** The gibberellins induce elongation of the internodes.

(b) **Leaf expansion:** In many plants leaves become broader and elongated when treated with gibberellic acid.

(c) **Reversal of dwarfism:** One of the most striking effects of gibberellins is the elongation of genetic dwarf (mutant) varieties of plants like corn and pea.

(d) **Bolting and Flowering:** Gibberellins induce stem elongation in 'rosette plants' e.g., cabbage, henbane, etc. Such plants show retarded internodal growth and profuse leaf development. In these plants just prior to the reproductive phase, the internodes elongate enormously causing a marked increase in stem height. This is called bolting.

(e) **Enzyme formation:** One of the most dramatic effects of GA is its induction of hydrolytic enzymes in the aleurone layer of endosperm of germinating barley seeds and cereal grains. GA stimulates the production of digestive enzymes like proteases, a-amylases, lipases which help to mobilise stored nutrients.

(f) **Breaking of dormancy:** Gibberellins overcome the natural dormancy of buds, tubers, seeds, etc. and allow then to grow. In this function, gibberellins act antagonistically to abscisic acid (ABA).

(g) **Parthenocarpy:** Gibberellins have been considered to be more effective than auxins for inducing parthenocarpy in fruits like apple, tomato and pear. GA application has also resulted in the production of large fruits and bunch length in seedless grapes.

(h) **Sex expression:** Gibberellins control sex expression in certain plants. In general, gibberellin promotes the formation of male flowers either in place of female flowers in monoecious plants such as cucurbits or in genetically female plants like *Cannabis, Cucumis*.

(3) Cytokinins (Phytokinins):

(i) Cytokinins are plant growth hormones which are basic in nature, either aminopurine or phenyl urea derivatives that promote cell division (cytokinesis) either alone or in conjugation with auxin.

(ii) **Functions of cytokinins**

(a) **Cell division:** Cytokinins are essential for cytokinesis and thus promote cell division. In presence of auxin, cytokinins stimulate cell division even in non-meristematic tissues.

(b) **Cell enlargement and Differentiation:** Under some conditions cytokinins enhance the expansion of leaf cells in leaf discs and cotyledons. These cells considered to be mature and under normal conditions do not expand.

(c) **Delay in senescence:** Cytokinin delay the senescence (ageing) of leaves and other organs by controlling protein synthesis and mobilization of resources (Disappearance of chlorophyll). It is called Richmond Lang effect.

(d) **Counteraction of apical dominance:** Auxins and cytokinins act antagonistically in the control of apical dominance. Auxins are responsible for stimulating growth of apical bud.

(e) **Breaking of dormancy:** Cytokinins breaks seeds dormancy of various types and thus help in their germination.

(f) **Accumulation and Translocation of solutes**

(4) Ethylene:

(i) Ethylene is a gaseous hormone which stimulates transverse growth but retards the longitudinal one.

(ii) Functions of ethylene

- **Fruit growth and Ripening:** Ethylene promotes fruit growth and its ripening. The harmone is used in the artificial ripening of climacteric fruits (e.g., Apple, Banana,