CPA COLLEGE OF ARTS & SCIENCE, PUTHANATHANI

DEPARTMENT OF BOTANY –

COMPLEMENTARY COURSE-PLANT PHYSIOLOGY, ECOLOGY AND GENETICS

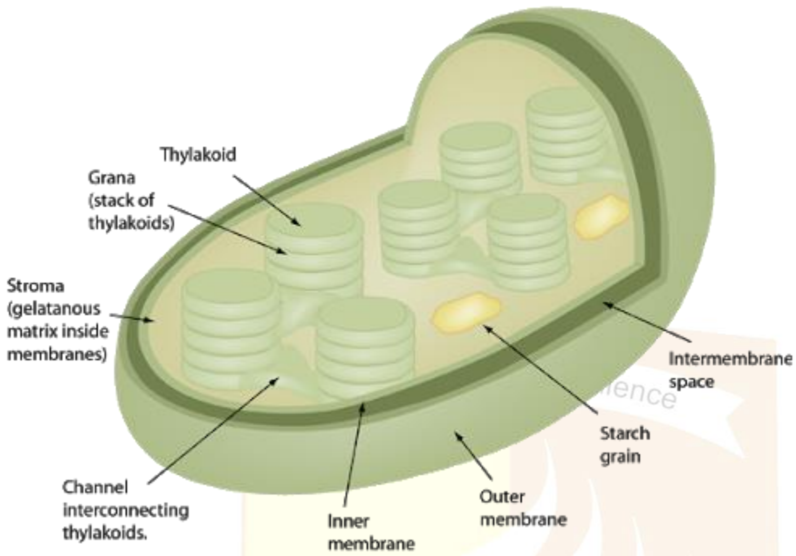
4^{th} SEMESTER ZOOLOGY

Module 2: Photosynthesis

- The term photosynthesis derived from Greek word
  Photon=light, synthesis= putting together
- Photosynthesis is an anabolic process by which chlorophyll –bearing autotrophs synthesize carbohydrate and release molecular oxygen, using carbon dioxide, water, light energy and chlorophyll.

  $6CO_2+12H_2O \longrightarrow C_6H_{12}O_6+6H_20+6O_2$
- The produced carbon dioxide used in various metabolic activity.
- Leaf is the principle organ for photosynthesis, it have some definite characters like
  1. Broad area of leaf margin will absorb maximum light.
  2. Efficient gas exchange through stomata.
  3. Well organized transport system present in the leaf.
- In addition to green plants algae like red, green, brown, diatoms, sulphur bacteria, purple bacteria carryout photosynthesis. These organisms are abundant in oceans, so 90% of photosynthesis occurs in oceans.
- Significance of photosynthesis
  - ✓ Photosynthesis maintains more over less equilibrium level of CO2 and O2 in atmosphere.
  - ✓ It provides food for biological world.
  - ✓ Photosynthesis purifies air by taking CO2 and releasing oxygen.
  - ✓ It brings energy fixation and thereby initiate the dynamics of ecosystems.
  - ✓ It serves as a link between plants and animals.
  - ✓ Photosynthesis transformed primitive anaerobic atmosphere to present aerobic atmosphere.
  - ✓ Fossil fuels such as coal, petrol, natural gas are photosynthetic product.

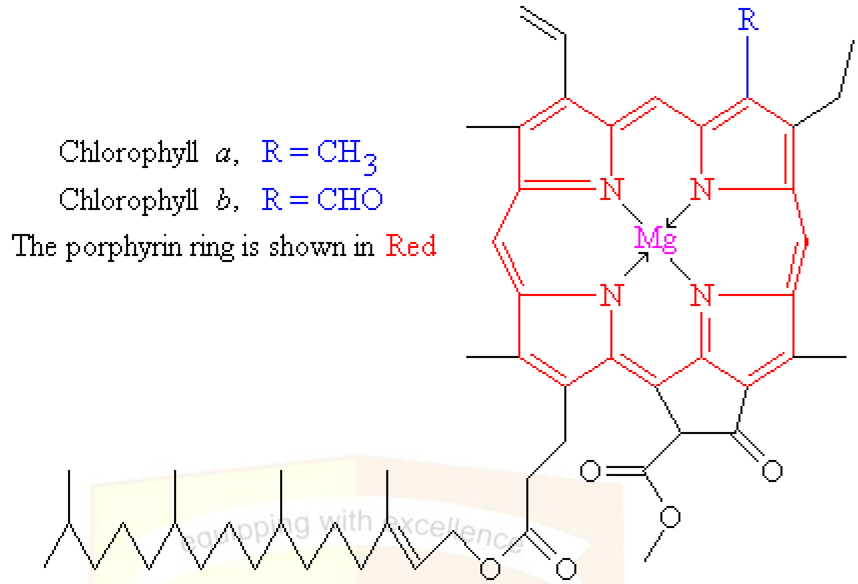
- Chloroplast is the centre of photosynthesis.



- Pigment systems
  - ✓ Pigments are the light sensitive molecule present in the thylakoid membrane. They absorb only specific wavelength of light.
  - ✓ Pigments are classified into
    1. Principal pigment
       - Chlorophyll a (green plants), bacteriocholorophyll (purple and green bacteria), chlorobium chlorophyll (green bacteria), bacterio-rhodopsin.
    2. Accessory pigment
       - Chlorophyll b, c, d, carotenoid (xanthophyll and carotene).

CHLOROPHYLL

- Structure of chlorophyll
  - ✓ They have a porphyrin (4 N_2containing pyrol ring) head and phytol tail. The porphyrin head with a central Mg atom.
  - ✓ Porphyrin is hydrophobic in nature.
  - ✓ This loke haemoglobin, instead of Fe magnesium is present.



- Kinds of pigments
  1. chlorophyll

     I. Chlorophyll a and chlorophyll b
     - Found in higher plants, cyanobacteria and algae.
     - Chlorophyll a has CH_3 in the second pyrol ring instead of CHO in chlorophyll b.
     - Chemical formula of chlorophyll b

       $C_{55}H_{70}O_6N_4Mg$

Chlorophyll a	Chlorophyll b
Principal pigment	Accessory pigment
Blue-green in pure state	It is olive green
$C_{55}H_{72}O_5N_4Mg$	$C_{55}H_{70}O_6N_4Mg$
In the first position side group at the third carbon is CH_3 (2^{nd} ring)	Here it is CHO
Molecular weight is 873.	Molecular weight is 907.

     II. Chlorophyll c
     - Found in brown algae, diatoms and dianoflegellate (Pinnularia, Noctiluca).
     - Chlorophyll c lacks phytol tail.

     III. Chlorophyll d
     - Found in red algae.
     - Instead of $CH_2=CH_2$ in first ring, O-CHO is present. That is the reason why they appear in green.

2. Carotenoids
  - Red, orange, yellow, brown coloured pigments.
  - They absorbs violet and blue light.
  - It impart autumn colour of leaf and it also gives colour to carrot and tomato.
  - It is lipid soluble hydrocarbon.
  - Those seen along with chlorophyll pigments in chloroplast.
  - Carotenoids are two types

1.Carotene	2.xanthophyll
Red, orange colored pigment.	Brown/ yellow colored pigment
Alpha, beta, gama, delta, lycopyne, phytotene types of carotene.	It is the oxygenated carotene.
Lycopene gives colour to tomato.	Xanthophyll is more abundant than carotene
Beta carotene is immediate precursor of vitamin A.	Leutin, zeaxanthin,fucoxanthin violoxanthin
	Fucoxanthin present in brown algae Alphacarotene → leutin Betacarotene → zeaxanthin

  - Significance of carotenoid
    - ✓ Since it is an accessory pigment, it can absorb light energy and transmit to chlorophyll a by resonance effect.
    - ✓ It protects chlorophyll from photo oxidation by absorbing excess blue light.

3. Phycobilins
  - It is found in red algae and cyanobacteria.
  - They can absorb green light, so they see as in black colour.
  - Accessory pigment.
  - Water soluble pigment. Others are insoluble in water.
  - Structure similar to chlorophyll but it lacks Mg. the tetra pyrol ring arranged linearly. And it side chains are covalently bonded with protein. This protein portion called apoprotein. The tetra pyrol ring portion called chromophore. It can absorb the light.
  - 4 types of phycobilins.
    1. Phycocyanin
    2. Phycoerythrin
    3. Allophycocyanin
    4. phytochromobilins
  - phycoerythrin can absorb dim light from deep ocean.

- Red algae appear as black. Because phycoerythrin and chlorophyll absorbs all light.

PHOTOSYNTHETIC UNIT (PSU)

- Smallest group of light harvesting molecule capable of carrying out photochemical reaction.
- Also called Quantasome.
- PSU has two units

1. Reaction centre (RC)
    - Consist of 4-6 chlorophyll a
    - These are 3 types

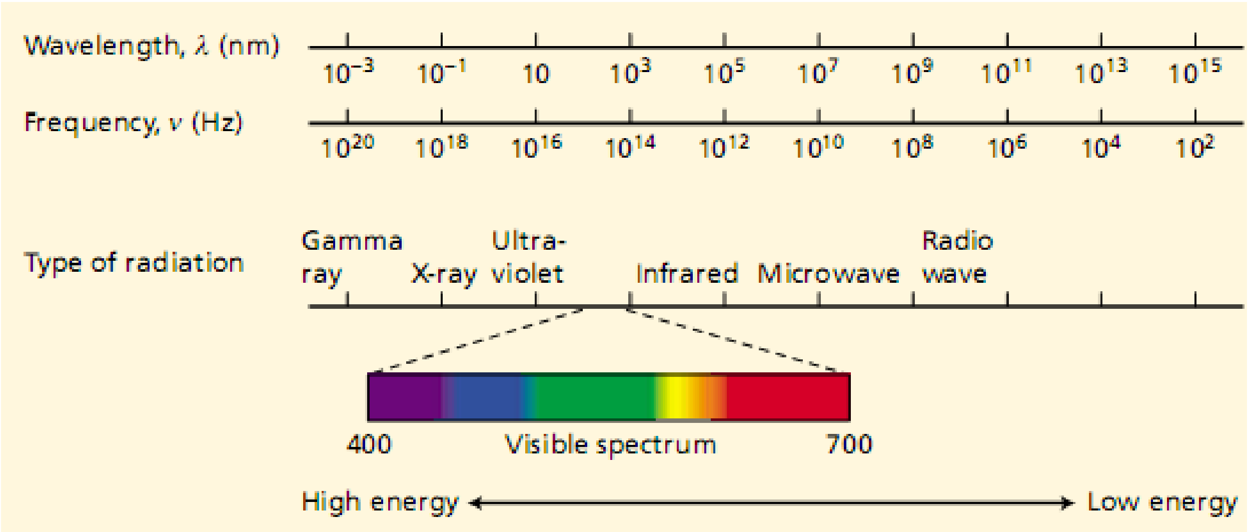
      P_{700}- with absorption maxima is 700nm.

      P_{680}- with absorption maxima is 680nm

      P_{870}- with absorption maxima is 870nm
    - RC is surrounded by LHPM.
2. Light harvesting pigment molecule (LHPM)
    - LHPM are two type
        1. Core molecule
        2. Antenna molecule
    - LHPM absorb the light energy and transfer to reaction centre (through resonance transfer).
    - Core molecule situated close to reaction centre. Antenna molecule are surrounds the core molecule. Antenna molecule is 200-400 in number.
    - LHPM have carotenoid, chlorophyll c, d etc.
    - A single reaction centre increases in the efficiency in collection and utilization of light energy.

ELECTROMAGNETIC RADIATION

- Solar radiations are electromagnetic in nature are called electromagnetic radiation.
- Radiation enters into the biosphere called solar radiation flux.
- The solar light emitted from the sun called electromagnetic spectrum.

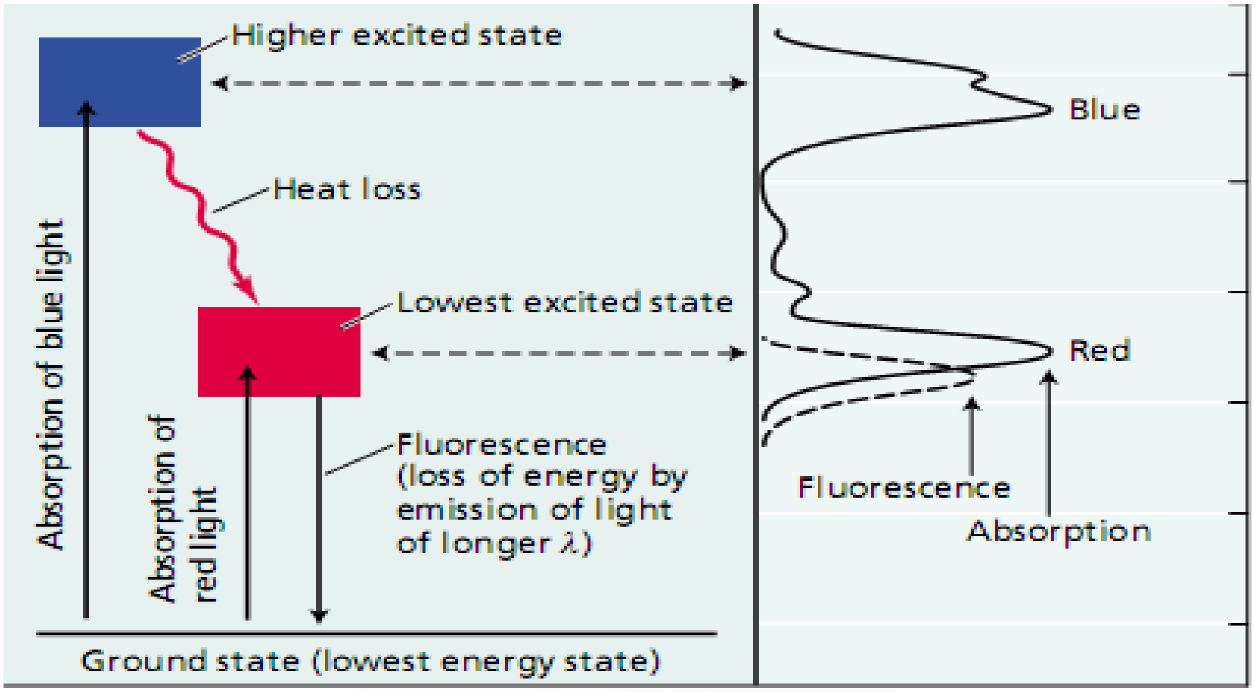


Electromagnetic spectrum

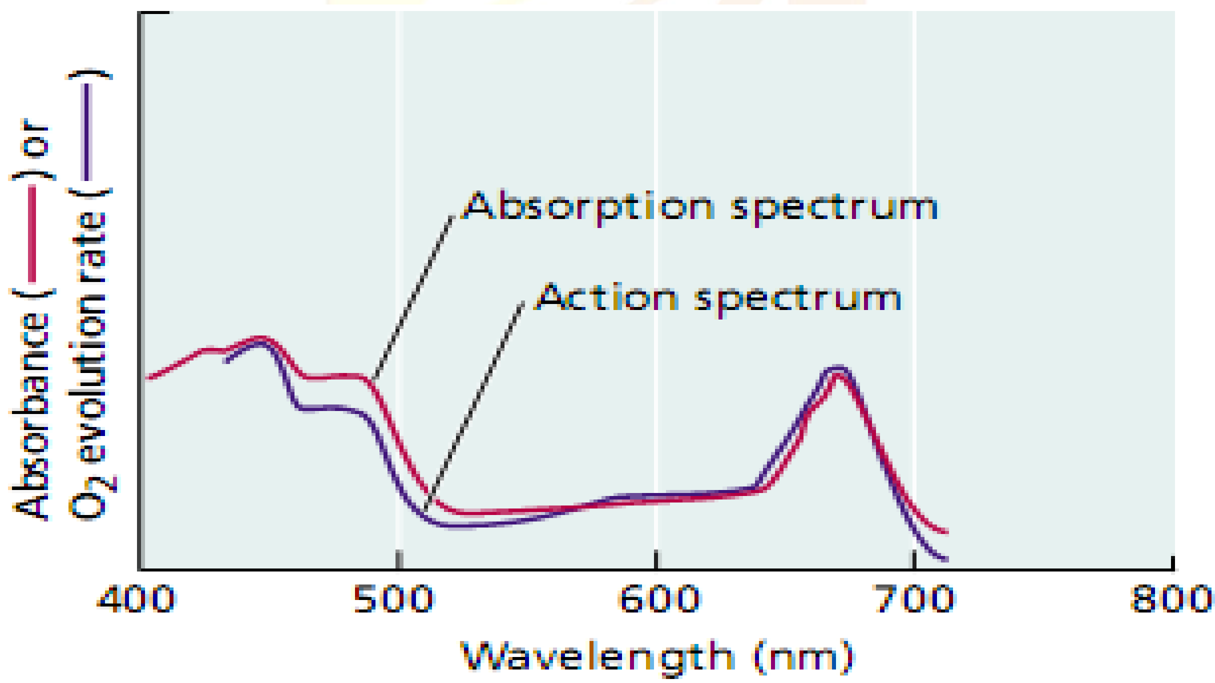
- Photosynthetically active radiation- visible spectrum used for photosynthesis.
- Usually light travel as a tiny or small energy packet called photons.
- The energy contains in a photon called quanta.
  Quanta are inversely propositional to wavelength.
- Photon or quanta required for the production of one molecule oxygen called quantum requirement.
- The smallest number or amount of pigment unit for the production of one quantum called quantasomes.
- Photosynthesis can be measured on the number of oxygen produced called quantum yield.

ABSORPTION & ACTION SPECTRUM

- Pigments are highly specific; chlorophyll a has two absorption peak ie blue and red.
- Carotenoids has also absorption peak on violet and blue.
- The amount of light absorbed by a pigment can be plotted. Graphical representation of different wavelength of light absorbed by pigment is called absorption spectra.



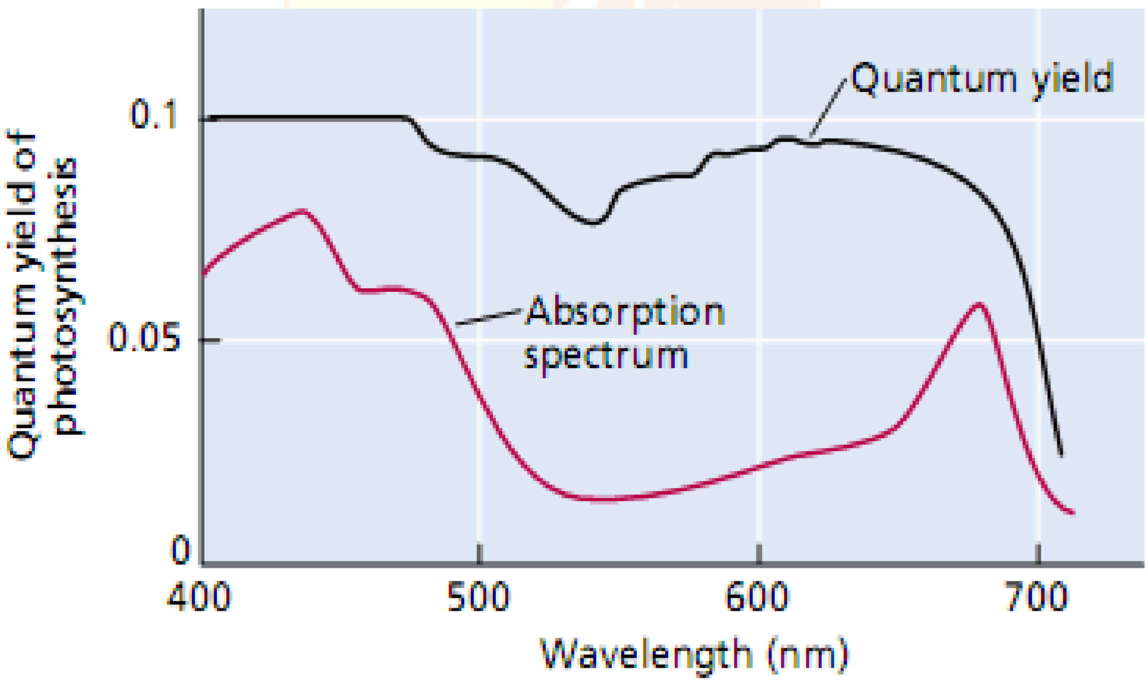
- An action spectrum is the graphical representation of effect of different wavelength of light on photosynthesis.



- Chlorophyll a is the primary trapping molecule.
- Rate of photosynthesis is directly propositional to efficiency to absorb blue and red.
- Certain part of the visible light are not absorbed by chlorophyll and have no role in photosynthesis.

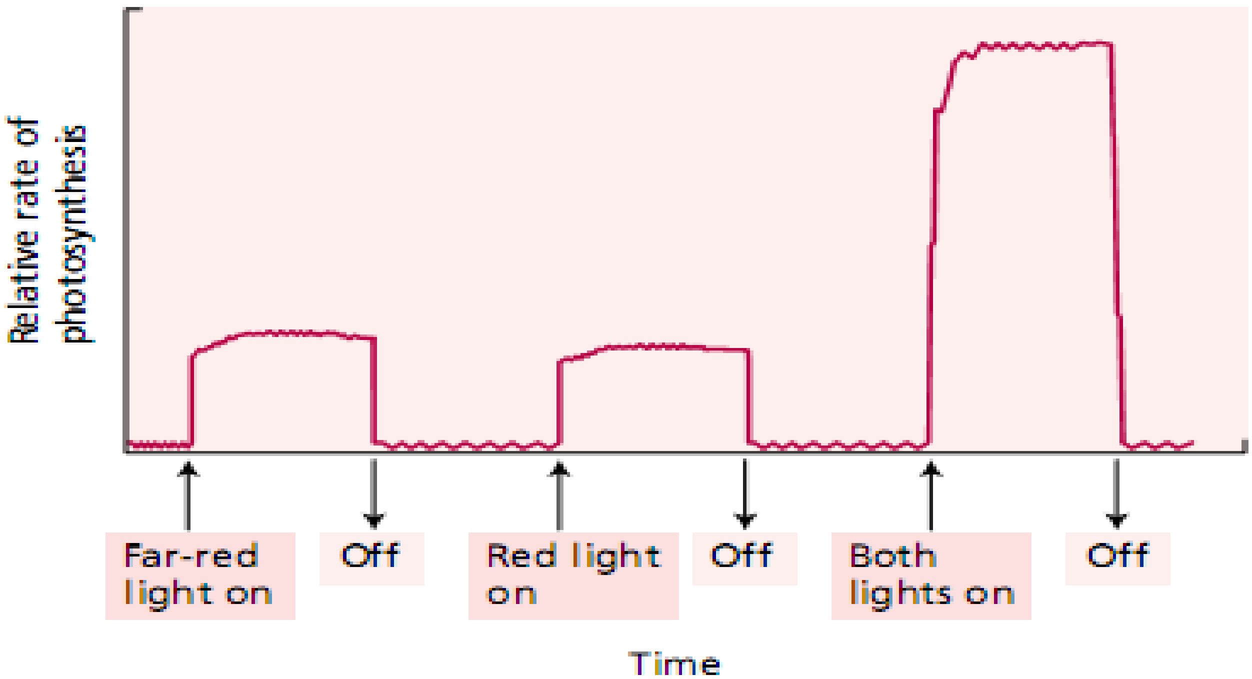
RED DROP AND EMERSON'S ENHANCEMENT EFFECT

- 8 quantum of light is required for the photosynthetic production of 1 molecule oxygen and reduction of CO_2 to carbohydrate.
- While studying they exposed chlorella to monochromatic light and measured quantum yield.
- They plotted a graph according to this in terms of oxygen evolution against different wavelength of light.
- It aims to determine a particular wavelength at which oxygen evolution and quantum yield in maximum. But the yield was constant.
- In almost all region except a dip in 440-520nm (blue), it is due to absorption by carotenoids. It was constant till 680nm. But it shows a sudden drop at region above 680nm (far red). This sudden fall in far red region called Emerson red drop.



- The scientist further extended their study. They supply short wavelength along with long wavelength (above and below 680nm).
- The photosynthetic yield was enhanced.
- This enhancement of photosynthetic yield due to combined effect of short and long wavelength of light Emerson's enhancement effect.

- It is an example of synergism; combined effect was much higher than the sum total of their separate effect.
- They concluded that there exist two photosystems-
  -One driven by short wavelength below 680nm).
  -Another one driven by long wavelength (above 680nm).
- Red drop occurs when photosystems drive by shorter wavelength failed to functional beyond 680nm. When both lights are given both pigments started in function.



MECHANISMS OF PHOTOSYNTHESIS

- According to Blackman & Hill photosynthesis includes both light and dark reactions.
- Evidences:
  1. Flashing light experiments
     Warburg exposed one set of chlorella to continuous light and second set to intermitted light (alternating light and dark).
     Total timing of light was same in both, but duration was different. he measured photosynthesis and observed that those set showing intermitted light show high photosynthesis, indicate the efficient light utilization product of light reaction consumed.
     During continuous light the product of light reaction is accumulated.
  2. CO_2 reduction in darkness

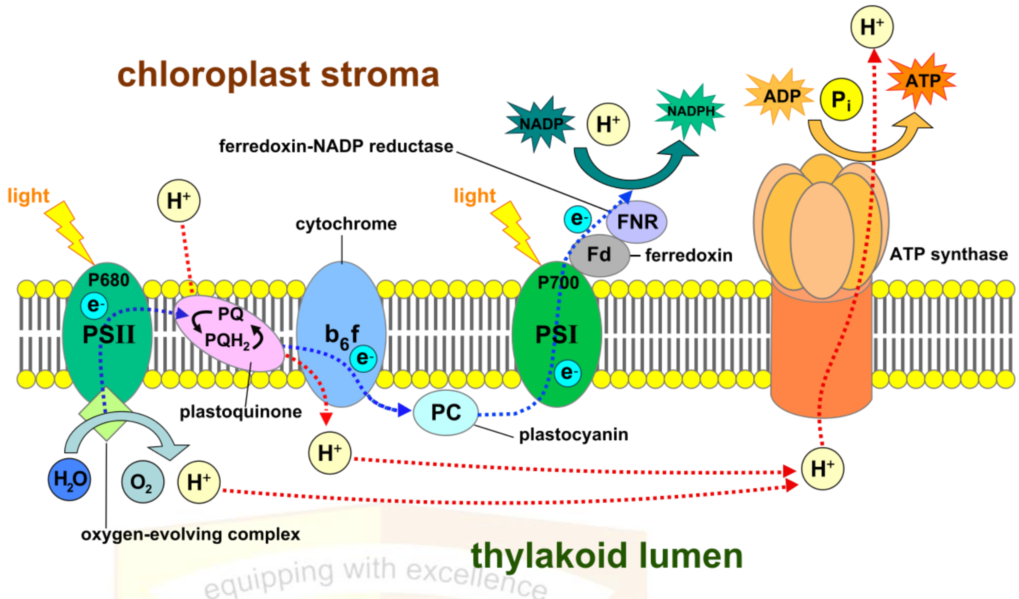
Calvin exposed plants to light in the absence of CO_2. Then it is transferred to darkness and provided $^{14}CO_2$. The reduced carbohydrate contains $^{14}CO_2$ it indicates CO_2 fixation takes place in dark also.

- Two different reaction in photosynthesis
  1. Light reaction- light dependent phase of photosynthesis.
  2. Dark reaction- light independent phase of photosynthesis
- During light reaction ATP & NADPH formed.
- Dark reaction, CO_2 reduced to carbohydrate using ATP & NADPH.

LIGHT REACTION

- It is the light dependent phase, takes place in grana thylakoids of chloroplast.
- Also known as photochemical reaction ie chemical reaction in the presence of light.
- 4 steps in photosynthesis
  I. Photo excitation of chlorophyll
  II. Photophosphorylation of ADP to ATP
  III. Photo-reduction of NADP TO NADPH
  IV. Photolysis of water
  1. Photo excitation of chlorophyll
     - ✓ Light reaction begins with excitation of chlorophyll.
     - ✓ Once the photons are absorbed by antenna molecules they get excited into a high energy state. This high energy state is unstable and short living. So it have a tendency to return to ground state by transferring the energy of next molecule.
     - ✓ Finally excitation energy reaches to chlorophyll a through resonance transfer.
     - ✓ So now chlorophyll a get excited and transforms to a new energy state. Soon the pigment molecule returns to its low energy and state by emiting high electron from it.
     - ✓ High energy electron emitted from reaction centre would be accepted by primary electron acceptor, the exact chemical nature is not known and it is believed to be pheophytin in PS I.
     - ✓ From the reduced primary electron acceptor electrons travel downhill result a series of redox reaction, these redox reactions are coupled to synthesis of ATP.
     - ✓ PSI – surrounded by chlorophyll a, b carotenoids. Located in stroma thylakoids and non-appressed regions of grana. They can carry out cyclic and non-cyclic photophosphorylations.
     - ✓ PSII – surrounded by chlorophyll a, b, carotenoids located at the appressed regions of grana thylakoid involved only in non-cyclic photophosphorylation.

2. Electron transport and oxidative phosphorylation
   1. Non –cyclic photophosphorylation
      - ✓ Result reduction of NADPH
      - ✓ Formation of ATP
      - ✓ Release of O2
      - ✓ It is also called Z-scheme due to its z shape.
      - ✓ In this PSI, PSII and electron carriers are arranged on thylakoid membrane.
      - ✓ The transport actually begins with the arrival of excitation energy at PSII. So it get excited and passes into primary electron acceptors.
      - ✓ From the primary electron acceptor ions are carried to PSI through 3 ions are carried through 3 ions carriers such as PQ, Cyt $_{b6/f}$ and Pc.
      - ✓ ATP synthesis coupled to electron transport through thylakoid membrane- chemiosmotic hypothesis (Mitchell hypothesis)
      - ✓ It is based upon a fundamental requirements
        1. Energy transducing membranes are impermeable to H^+
        2. Electron carriers are organized asymmetrically in thylakoid membrane.
      - ✓ So, in addition to transporting electrons. Some carriers also serve to translocate protons across the membrane against concentration gradients. It is called proton pumb.
      - ✓ In chloroplast protons are pumbed across the thylakoid membrane, from stroma to lumen. It creates a potential gradient but, low proton conductance of the thylakoid membrane will not allow the proton to simply diffuse back.
      - ✓ In fact, the return of proton of stroma is restricted to highly specific proton lined channels that extends through the membrane, and are part of ATP synthesizing enzyme ATP synthase.
      - ✓ ATP synthase also known as coupling factor or CF_0-$CF_{1,}$ consist of 2 multipeptide complexes ie, CF_0 and CF_1. CF_0 forms H^+ channels across the membrane.
      - ✓ As the energy rich proton gradient collapse through CF_0-CF_1complex, conserved energy is utilized for ATP synthesis.



2. Cyclic photophosphorylation
   - ✓ A continuous ATP supply is required to carry out various metabolic activity of chloroplast, such as
     1. Synthesis of various proteins in stroma.
     2. Transport of protein and metabolites across the membranes.
   - ✓ Features
     - Single photosystem PSI is involved.
     - Electron move from P_{700}, first to ferrodoxin, then to cytochrome complex, and plastocyanin(Pc).
     - The transport of electron through cytochrome complex is coupled with the proton pumb across the membrane (stroma to lumen). It creates proton gradient.
     - ATP synthase present on thylakoid membrane produce ATP as proton diffuse back through it from lumen to stroma.
   - ✓ At last de-energized electrons return back from Pc to PSI.
   - ✓ No O_2 evolution, No photolysis, No NADPH production.

DARK REACTION

- It takes place in the stroma of thylakoid.
- This is also called biosynthetic phase of photosynthesis or PCR- photosynthetic carbon reduction cycle or Blackman's reaction.
- The synthesis of carbohydrate called CO_2 fixation or carbon assimilation.

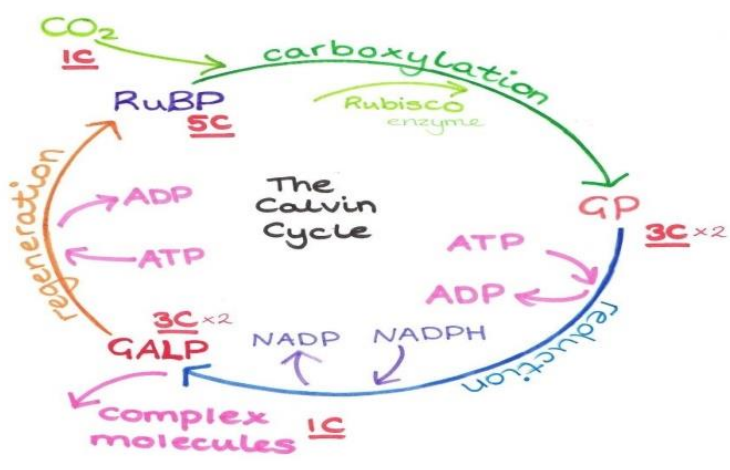
- CO_2 fixed in 4 pathways

1. C_3 cycle
   - It is also called Calvin cycle (Melvin Calvin).
   - The first stable compound is C_3 carbon is 3PGA (3-phosphoglyceric acid).
   - C_3 plants show C_3 cycle.
   - 3 major steps involved in C_3 cycle.

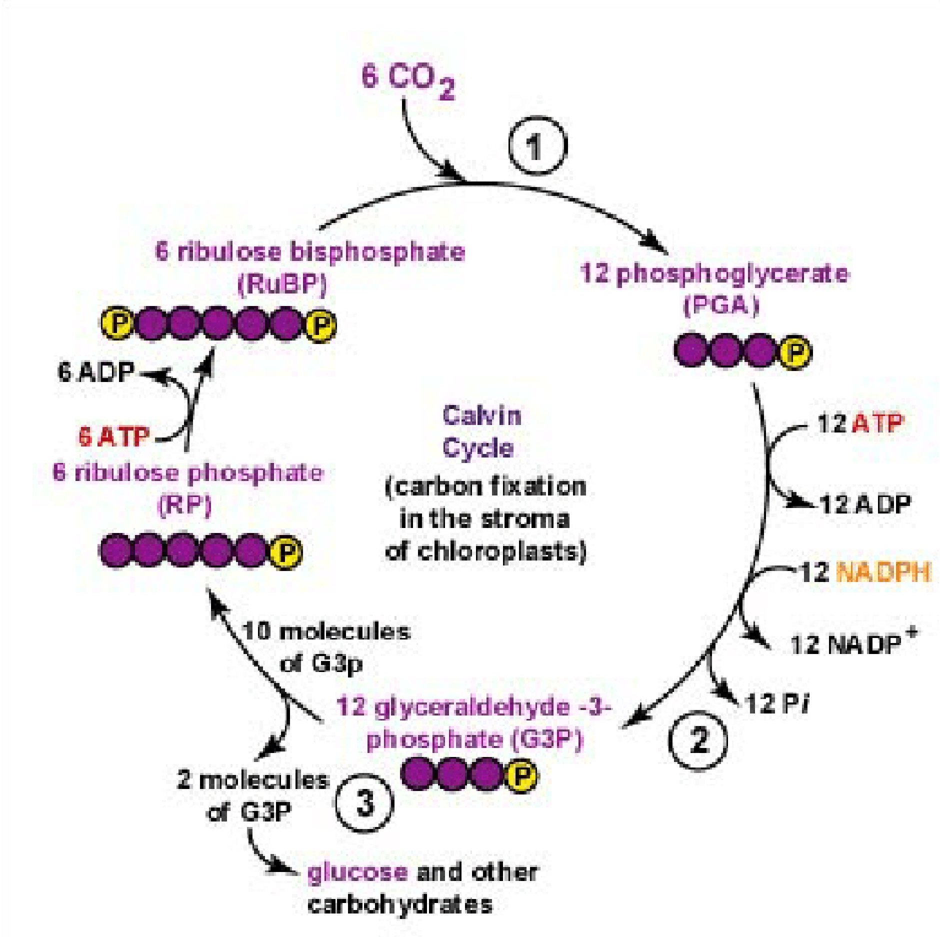
     1.Carboxylation.

     2.Reduction/glycolytic reversal

     3.Regeneration



Calvin cycle is given below:

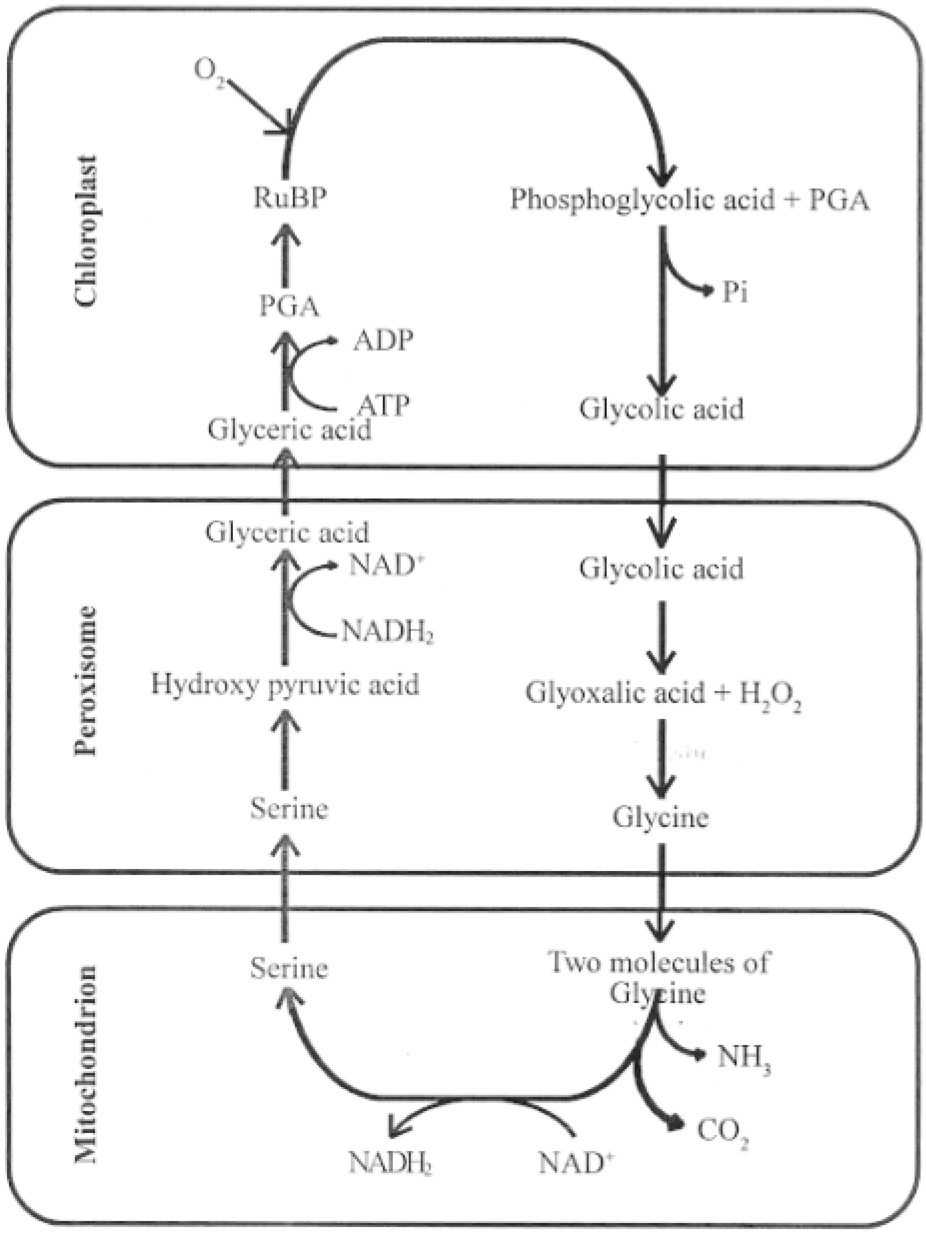


- The overall reaction
  6RUBP+6CO$_2$+18ATP+12NADPH $\longrightarrow$ 6RUBP+C6H12O$_6$+18ADP+ 18Ip+ 12NADP

2. C2 cycle
   - It is the photosynthetic carbon oxidation reaction.
   - It also called **photorespiration**.
   - It takes place in 3 cell organelles
     Chloroplast
     Peroxisome
     Mitochondria
   - It is an alternative pathway of C3 cycle.
   - It may takes place at some condition in C3 plants like

- High oxygen concentration
- High intensity light
- Age of the plant
- High temperature

▪ C3 cycle first discovered by Dicker & Tio.
▪ The first stable compound is 2 carbon compound is Phosphoglycolate.

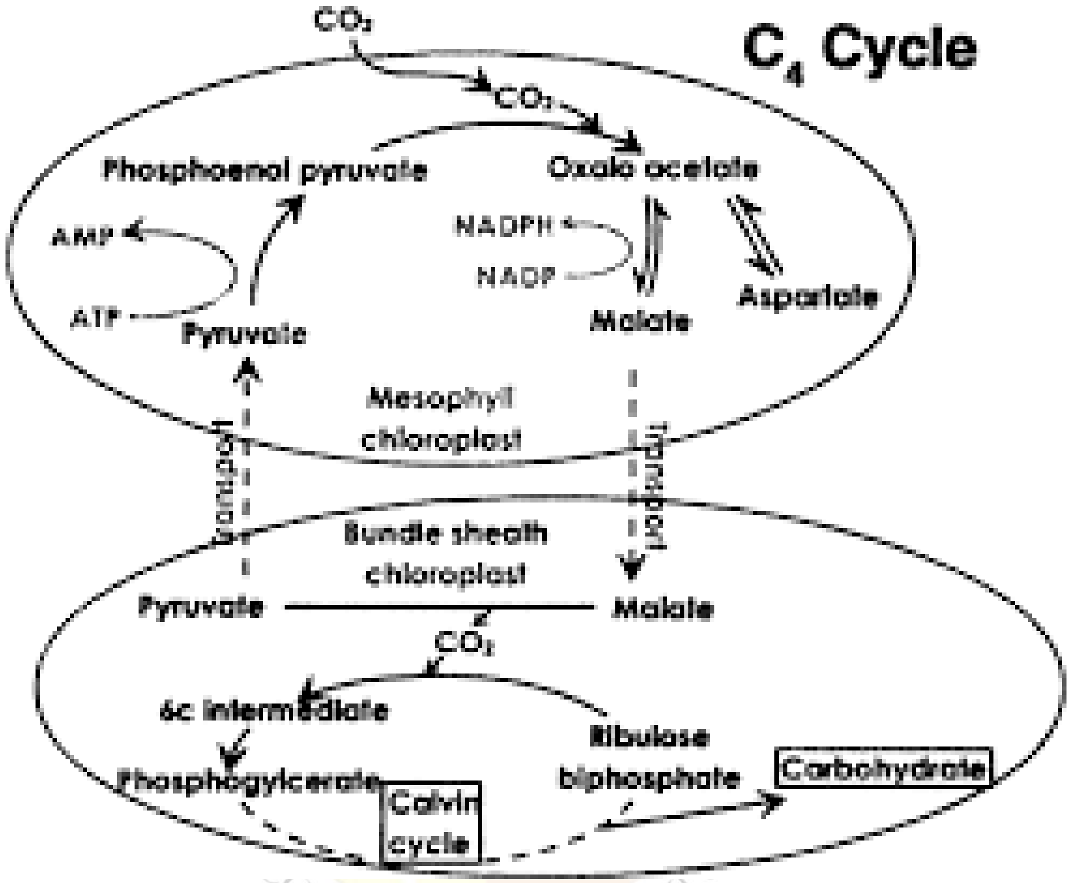


▪ 2 molecule of glycine converted to 1 CO2 and I molecule of serine (3C).

- The ATP and NADPH in C2 is approximately equals to C3. But there is a loss of 1 carbon. So C2 is an inefficient process with respect to energy and CO2.
- But it has scavengers' functions; for each two turn two phosphoglycolate are formed. Of this 4 carbon, one lost as CO2 and other three returned to chloroplast. So it recovers 75% of carbon that would otherwise lost as glycolate.

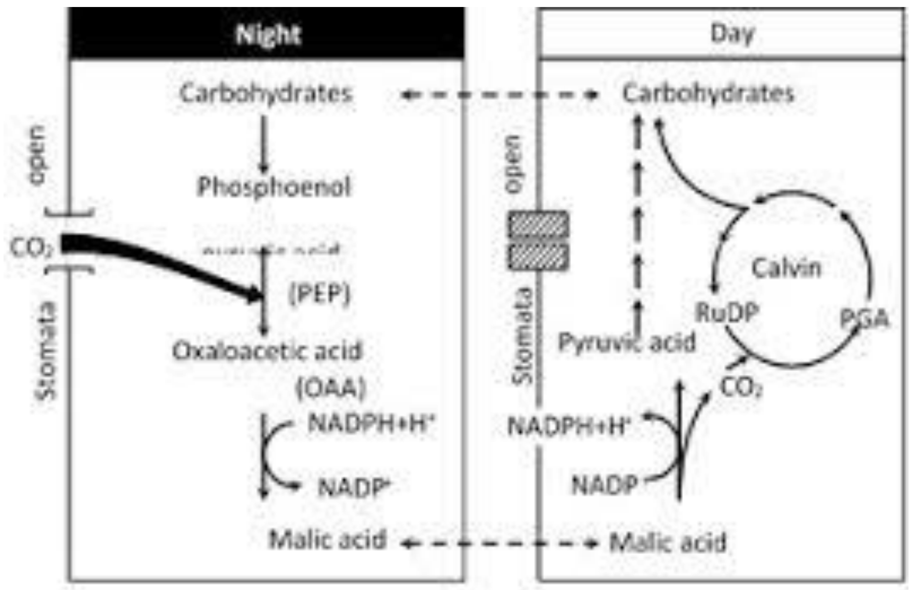
3. C4 cycle
   - C4 plants (Maize, Amaranthus, Sugarcane) are shows C4 cycle.
   - First stable compound is OAA (Oxalo acetic acid). 4 carbon compound. It is a dicarboxylic acid. Hence it is called dicarboxylic acid cycle.
   - Bundle sheath cell look like a reeth. It is known as to be Kranz. Hence it is called Kranz anatomy.
   - In C4 plants the cells surrounded the bundle sheath not differentiated into spongy and palisade.
   - Starch grains present in chlorophyll and Rubisco is absent.
   - Bundle sheath surrounded by isodiametric cells. Normal chloroplast is present.
   - Instead of Rubisco, Pepco is present.
   - Bundle sheath cells are large. They have centripetally arranged. In this pepco is absent but Rubisco is present.
   - Steps involved in C4 cycle
     1. Carboxylation of PEP/ fixation of CO2 in mesophyll cells as OAA.
     2. Transport of 4 carbon acid from mesophyll to bundle sheath cells.
     3. Decarboxylation of 4c acid. So concentration of CO2 increases in bundle sheath cells.
     4. Transport of 3 carbons back to mesophyll cell and regeneration of PEP.
   - Advantages and disadvantages
     - ✓ C4 is energetically expensive, it requires 30 ATP (18ATP (C3) + 12ATP (C4)). But it an adaptation to overcome C2. Because C2 causes decrease of 30-40% of photosynthetic yield.
     - ✓ It concentrates CO2 in bundle sheath cells to carryout normal C3. So it serves as CO2 pumb for C3 cycle.
     - ✓ C4 requires 5ATP + 2NADPH/ NADH to fix one CO2. Whereas C3 requires 3ATP+ 2NADPH.
     - ✓ C4 has 2 to 3 times more yield than C3.
     - ✓ C4 can absorb CO2 at very low concentration when C3 fails to absorb it.
     - ✓ C4 can maintain high CO2 fixation under water stress condition.

✓ C4 requires high intensity light than C3. So it is better adopted to tropical plants.



4. CAM pathway
   - CAM- Crassulacean acid metabolism
   - First discovered in a Crassulaceae member *Bryophyllum calycinum*.
   - Plants showing CAM is called CAM plants.
   - Here the first stable product is malic acid.
   - It is an adaptation to carryout photosynthesis in xerophytes.
   - In xerophytes, during night CO2 is fixed as malic acid, during day time malic acid under decarboxylation yield CO2. This CO2 is used for C3 cycle.
   - CAM Cycle is significant in 2 aspects.
     - ✓ It built an internal CO2 concentration for C3 cycle.
     - ✓ Internal CO2 causes stomata to open for less time in light/ day time. So it reduces transpiration loss of water.
     - ✓ CAM pathway includes 2 phases
       1. Acidification

2. Deacidification



CAM pathway

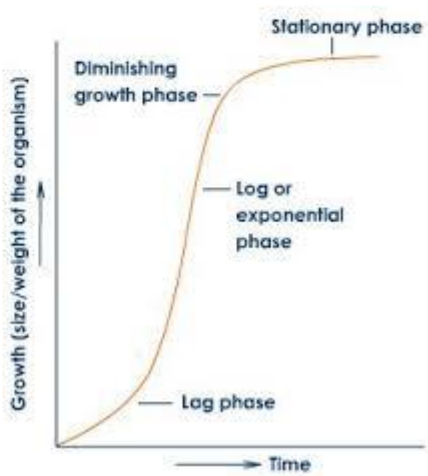
- Difference with C4 cycle
    1. C4 is separated by special anatomy called Kranz anatomy, whereas CAM was separated by the time.
    2. There is no closed cycle in CAM. And PEP is obtained from stored starch

Module 3: plant growth

- It is the irreversible increase in size, mass and weight of the body.
- Plant growth restricted to root and shoot meristems.
- Growth involves an increase in the number and size of cells, called quantitative phenomenon.
- Plant growth
    1. Primary growth- elongation of plant body, due to activity of apical and intercalary meristem.
    2. Secondary growth-thickening of plant body, due to activity of lateral meristem.
- Plant growth involves three genetically programmed events
    1. Cell division
    2. Cell enlargement

3. Cell differentiation

- Phases of plant growth- different phases in growth.
  1. Lag phase
  2. Log phase
  3. Deceleration phase
  4. Stationary phase
- Growth curve
  - ✓ Graphic representation of growth phases of organs or organisma.
  - ✓ S-shaped curve or sigmoid curve or logistic curve.



- Growth hormones or phytohormones
  - ✓ Organic substance synthesized in minute quantities in a part of the plant body and transported to another part where they influence specific physiological processes.
  - ✓ There are natural as well as synthetic growth hormones.

    1. Auxin
    2. Cytokinin
    3.Gibberellins
    4.Ethylene
    5. Abscisic acid
- Abscission
  - ✓ Natural detachment or dislodging of plant organs, such as leaf, flower and leaf etc. from the parent plant.
  - ✓ Abscission restricted to a distinct region, called abscission zone.
  - ✓ Just before abscission, there develops a special layer of cells within the abscission zone, called abscission layer.
  - ✓ Abscission is controlled by a balanced interaction between auxins and abscissic acid.

- ✓ Auxins inhibit abscission and abscisic acid stimulates abscission. So high level of abscisic acid promote abscission. It includes extreme level of temperature and water, increased respiration, short photoperiods, attacks of parasites and ethylene.
- ✓ Absission is self- pruning process, removes aged and injured organs from the plant body.
- ✓ It helps in disseminating fruits and vegetative propagules.
- ✓ It removes plant part contains waste materials.

- Senescence
  - ✓ Types of senescence
    1. Whole plant senescence
    2. Organ senescence
    3. Shoot senescence
    4. Sequential senescence
    5. Simultaneous senescence
  - ✓ Physiology of senescence- includes different structural and physiological changes
    1. Regression of cells and disorganization of cell organelles by the lysosomal activity of vacuoles. Vacuoles act as lysosomes and release hydrolytic enzymes.
    2. Disintegration of chlorophyll, falls in photosynthetic rate, and decrease in the starch content of the cells.
    3. Synthesis and accumulation of anthocyanins and change in colour of leaves from green to yellow.
    4. Reduction in the protein content of cells due to fall in protein synthetic rate and also due to the increased activity of proteolytic enzymes.
  - ✓ Significance of senescence.
    1. Enables continuous replacement of old and inefficient organs by new and young leaves.
    2. Enables plants to escape from seasonal adversities.
    3. Leaf fall adds leaf litter to the surface layer of soil and increases mineral content in soil.
    4. Leaf fall in winter reduces the transpiratory loss of water.
    5. It enables recovery or withdrawal of nutrients from senescing organs for the rest of the plant.

Module : Photoperidism & Vernalization, Seed Dormancy & Germination

PHOTOPERIODISM AND VERNALIZATION

Photoperiodism

- Flower initiation begins with the formation of flower primordial (flower bud) in the apical and lateral shoot meristems.
- Flowering is the process mainly controlled by the
  1. Duration, quality, and intensity of day light
  2. Temperature.
- A light controlled development and flowering is generally called photomorphogenesis.
- Photoperiodism is the response of a plant to the relative length of day and night. Duration of light period or length of daytime is called photoperiod.
- Plants exhibit photoperiodism called photoperiodic plants.
- Based on the photoperiodic responses flowering plants are classified into three.
  1. Short day plants (SDP) or long night plants
     - ✓ Flowering is induced by exposure to short day length (photoperiod) which is shorter than critical length.
     - ✓ Plants require a cyclic exposure to short light periods and long dark periods eg. Coffee, Cotton, Maize.
  2. Long day plants (LDP) or short night plants
     - ✓ Flowering induced by exposure to long day length, which is longer than the critical length. Eg. Radish, Sugarbeet.
  3. Day- neutral plants (DNP)
     - ✓ Flowering not influenced by the length of day or night. Do not require a specific photoperiod for flowering. Eg. Tomato, Cucumber.
- flowering responses of short day plants
  1. Flowering occurs when dark period is uninterrupted and longer than the critical day length.
  2. No flowering occurs when the duration of dark period and light period is the same.
  3. No flowering occurs when the dark period is shorter than the critical day length.
  4. No flowering occurs if dim light is present during the dark period.
  5. No flowering occurs when the longer dark period is interrupted midway by single flash of bright or dim light.
  6. Flowering occurs when the longer dark period is interrupted by a single flash of light either at its beginning or towards the end.
  7. Flowering occurs in continuous darkness , if sucrose is administered to plants
- flowering responses of long day plants
  1. Flowering occurs when the dark period is uninterrupted and shorter than the critical day length.
  2. No flowering occurs when the dark period is longer than the critical day length.
  3. Flowering occurs even under short-day conditions, if the longer dark period is interrupted mid-way by a brief flash of light.
  4. Flowering occurs under shorter photoperiods, if they are followed by still shorter dark periods in a 24 hour cycle.

5. Flowering is maximal during continuous or uninterrupted photoperiods.

- Red light inhibit flowering where as far red light induces flowering. This phenomenon is called red-far red reversible photoreaction.
- Flowering responses depends on the quality of the light of the last exposure. If the last exposure is red light, no flowering occurs, if it is far red light, flowering may occur.
- Phytochromes are the pigments involved in the initiation of flowering.
- Phytochromes are photo-reversible bluish biliprotein that can exist in two inter-convertible forms namely Pr and Pfr. Pr is bluish-green colour, absorbs red light and becomes Pfr form. Pfr light green coloured, absorb far red light and becomes Pr.
- Flowering in short-day plants iss promoted by the Pr form and inhibited by Pfr form. In long days plants, flowering is promoted by Pfr form and inhibited by Pr form.
- Some workers suggested that a flower- producing stimulus is formed in the leaves and then conveyed to meristems.   Some floral hormones like florigen, is synthesized in the leaves under favourable photoperiodic conditions. These hormones will transmit to flowering regions.
- Flowering may also induced by the ineraction between auxins, gibberilins, cytokinins and ethylene.
- Carbohydrate –nitrate ratio also influence flowering. Very high ratio induces very low vegetative growth and flowering. Very low carbohydrate and nitrate ratio will cause the very low vegetative growth and no flowering.

Vernalization

- Vernalization is the low temperature treatment or cold treatment or chilling treatment of seedlings or germinating seeds to increase the flowering and fruiting abilities of plants.
- It requires three environmental conditions
  1. Low temperature
  2. Free oxygen supply
  3. Sufficient water supply
- It was first noticed by Klippart (1857) in two varieties of wheat, namely winter wheat and spring wheat. Winter wheat is sown in winter and flowering in summer. Spring wheat is sown in spring and flowering in summer. He observed that germinated seeds of winter wheat exposed to low temperature, they can behave as spring wheat. That is winter wheat requires low temperature for subsequent flowering.
- Site of cold stimulus is meristematic regions. Low temperature treatment of seed is effective.
- Induction of early flowering in plants is occurred by the shortening of vegetative growth. Very low temperature induces the formation of flowering hormone vernalin.
- Application of gibberellins can replace the cold treatment or vernalization in many plants.
- Vernalization will
  1. Shortens the period of vegetative growth.
  2. Early flowering and fruiting.
  3. Enhances cold-resistances.
- Cold treatment can be nullified by the immediate treatment with high temperature known to be devernalization.

SEED DORMANCY AND GERMINATION

- Seed dormancy is inability or failure of seeds to germinate due to internal factors, even at the optimal temperature.
- Factors causing seed dormancy
  1. Due to hard seed coat
     - ✓ Seed coat is formed of a complex mixture of polysaccharides, hemicellulose, fats, waxes and proteins.
     - ✓ During seed ripening, seed coat becomes dehydrated and forms a hard tough protective covering around embryo. It will prevent seed germination.
     - ✓ Seed coat dormancy due to some reasons like
       - ➢ Impermeability of the seed coat to water.
       - ➢ Impermeability of the seed coat to oxygen.
       - ➢ Mechanical resistance of seed coat against embryonic growth.
  2. Due to absence of light
     - ✓ Some seed like photoblastic seeds require light for germination.
  3. Due to absence of low temperature
     - ✓ Seeds of temperate plants require low temperature treatment for germination. So the absence of low temperature cause seed dormancy.
  4. Due to the state of embryo
     - ✓ Dormancy of the embryo due to;
       1. Immature or underdeveloped state of embryo, when seeds are shed. It delays seed germination until embryonic maturation is completed.
       2. Presence of germination inhibitors in the embryo, endosperm and other tissue of seed or fruit like abscisic acid, phenolic acid, parasorbic acid and coumarin.
- Methods to overcome seed dormancy
  1. Exposure to light
     - ✓ A numbers of seeds like photoblastic seeds require light for germination.
     - ✓ There are three categories of such seeds as follows;

       1. Positive photoblastic seeds- single light exposure promote seed germination.

       2. Negative photoblastic seeds- light inhibit seed germination so that seed require complete darkness for germination.

       3. Non-photoblastic seeds- seeds germinate irrespective light or darkness.

  2. Alternating temperature
     - ✓ It is useful in those seeds in which dormancy due to immature embryos.
     - ✓ Seed germination promoted by alternating temperature. This difference between alternating temperature should not be more than 10- 20^{o}C.
  3. Impaction
     - ✓ Impaction is the treatment of seed by vigorous shaking to remove the plug. In some seeds, water and oxygen are unable to penetrate, because their entry is blocked by a block a cork- like filling in the small opening in the seed coat.
  4. Scarification
     - ✓ Softening or weakening the seed coat is known as scarification.

- ✓ Under natural conditions in the soil, micro-organisms such as fungi and bacteria will decompose seed coat.
- ✓ Mechanical and chemical treatments are used to promote seed germination. It includes cutting or chipping of the seed coat, storage of seeds at high temperature, and use of organic solvents to remove waxy or fatty compounds. Acidic treatment also recommended.

5. Stratification
   - ✓ Some seeds require well aerated moist conditions under low temperature for weeks or months for germination. Such treatment known as stratification.
   - ✓ Here immature embryo requires some chemical changes for the seed germination.

- Advantages of seed dormancy
  1. Enables the embryo to tide over the unfavourable part of the year.
  2. Enables storage of cereals, millets, pulses to be used later for food or sowing in the next season
  3. Serves as an adaptation to ensure that seed germination occurs only under favourable conditions, and also in the right time and at the right place. In nature dormancy periods always coincide with unfavourable seasons.
- Seed germination
  - ✓ It is the process by which a dormant embryo becomes active, grows out of the seed- coat and develops to a seedling. Embryo grows by absorbing water from outside, and stored food from cotyledons or endosperm.
- Changes during germination
  1. Seed coat becomes permeable to water, oxygen and carbon dioxide.
  2. Intake of water and swelling of seed and rupturing of seed coat.
  3. Hydration of protoplasm, activation of enzymes and resumption of physiological activities.
  4. Enzymatic breakdown of insoluble materials to soluble constituents.
  5. Translocation of soluble food materials to growing parts.
  6. Assimilation of food in the growing organs for growth.
- Different kinds of germination
  1. Hypogeal germination
     - ✓ The cotyledons stay beneath the soil surface or just on the soil surface.
     - ✓ Here radicle emerges first and grow deep into the soil and forms the root system. The epicotyl elongates and forms an arch called epicotyl bent. It pushes plumule upwards outward out of the soil.
     - ✓ Plumule grows fast; leaving the cotyledons in the soil. Cotyledons never becomes green. They dry out and fall.
     - ✓ Most common in monocots like wheat, maize, palms.
  2. Epigeal germination
     - ✓ Here hypocotyl elongates rapidly, pushing the cotyledons upward, well above the soil surface.
     - ✓ Here most of the cotyledons become green, flat and leaf like.
     - ✓ In some dicots like castor, cotton and tamarind
- Mechanism of seed germination
  - ✓ Here the dormant embryo within the seed resumes its metabolic activities and grows to a seedling.

- ✓ It occurs under favourable conditions of water, temperature, nutrients, light etc.
- ✓ Seed germination involves four major events;
  1. Water imbibition
  2. Resumption of metabolic activities
  3. Mobilization of food reserves
  4. Breaking of seed dormancy

- Factors affecting seed germination
  1. Water
     - ✓ Helps the hydrolysis and transport of the stored food.
  2. Oxygen
     - ✓ For energy yielding aerobic oxidation. Thus seeds cannot germinate under poor oxygenated soil.
  3. Favourable temperature
     - ✓ Moderate temperature needed for seed germination.
     - ✓ It activates enzymes, accelerate metabolism and stimulate germination.
  4. Light
     - ✓ Photoblastic seeds require an appropriate quantity of light for germination.
  5. Nature of the seed coat
     - ✓ Thick, hard and impermeable seed coat inhibits seed germination. Germination occurs only after it is softened, weakened or broken.
  6. Germination inhibiting substances
     - ✓ abscisic acid, phenolic acid, parasorbic acid and coumarin inhibit seed germination.
     - ✓ Industrial wastes and soil pollutants also inhibit seed germination.
- Vivipary
  - ✓ In-situ seed germination in which the seeds germinates inside unshed fruits.
  - ✓ Viviparous plants like *Rhizophora* shed seedlings, not seeds.
  - ✓ Most common in halophytic mangroves plants.
  - ✓ Vivipary is an adaptation to prevent the seeds from being carried away by tides and waves.

Module: Fruit ripening

FRUIT DEVELOPMENT

- Fruit development is associated with pollen germination. Pollination and fertilization not only provide the major stimulation for the growth of ovary and the development of fruit, but also prevent the abscission of ovary.
- Significance of fruit formation
  - ✓ Seed dispersal – help the dispersal of seed by wind, water current and animals.
  - ✓ Chemical defence – some immature fruits contains unpalatable and repellent chemicals, such as alkaloids, sour acids, and tannins etc. these will provide a chemical defence against animals

- ✓ Seed protection – protect immature seeds from animals and hostile environmental conditions.

- Different stages of the growth and development of fruit
  1. Initiation
  2. Anthesis
  3. Pollination
  4. Fertilization
  5. Growth and maturation
- Initial phase of fruit development before anthesis known as pre-bloom period.
- Post anthesis phase is called post-bloom period.
- In pre-bloom period active cell division, regular synthesis of protoplasm and initiation of flower primordia.
- Post-bloom period involves pollination, fertilization, fruit growth and fruit maturation.
- During pre-bloom period cytokinins and gibberellins are very vital and their synthesis is very high. Metabolites translocate to the developing flowers and fruits from leaves, stem and roots.
- During post-bloom period active cell division, differentiation and enlargement of cells and growth and maturation of fruit.
- The course and stages of fruit development can be graphically represented by an s-shaped or sigmoid growth curve.
- Major changes of fruit development
  1. Ovary enlarges by repeated cell division and cell enlargement, induced by auxins, gibberellins and cytokinins.
  2. Succulent parenchyma cells develop within the ovary.
  3. Cells get loaded with sugars vegetable acids, and flavouring substances.
  4. Dissolution of the existing walls in some cells, and the formation of false septa in others. This alters the nature and appearance of the ovary.
  5. Transformation of ovary wall to pericarp.
  6. Active synthesis and translocations of substances or materials from other parts of maturing fruits.
  7. Multiplication of chloroplasts and increased synthesis of sugars in leaves and the translocation of these sugars to developing fruit to promote fruit growth.
  8. Replacement of chloroplast to chromoplast, and chlorophyll by carotenoids.
  9. Synthesis and accumulation of aromatic esters, alcohols and carboxyl compounds.
  10. Storage of specific chemical compounds to determine the chemical composition of fruit. As carbohydrate in apple, fat in olive fruits and organic acid in lemon, grapes and apple.

FRUIT RIPENING

- It is the process which makes fruits ideal for consumption and makes seeds ready for dispersal.
- Fruit ripening is distinctly different from fruit maturation. In edible fleshy fruits maturation represents the stages of the fruits harvesting and ripening represent the stages of fruit consumptions.
- Fruit ripening is the initial stage of fruits senescence; it is a breaking down process, characterized by irreversible degradative changes.
- In some fruits, there will be a rapid rise in respiratory rate associated with fruit ripening is called respiration climateric or climateric. The phase of this rapid respiration rate known to be climateric

phase. The fruits which exhibiting a climateric phase during the fruit ripening known to climacteric fruits. These fruit ripened only after plucking or harvesting.

- Those fruits without climateric phase known to be non-climateric phase. The ripening of fruit occurs while the fruit remains attached to the parent plant.
- Major changes of fruit ripening
  1. Conversion of starch to sugar.
  2. Increased accumulation of sugars and organic acids.
  3. Production of alcohol, esters, carboxyl compounds, hydrocarbons and terpenoids etc.
  4. Conversion of chloroplast to chromoplast.
  5. Breakdown of chlorophyll.
  6. Increased synthesis of carotenoid in some fruits and anthocyanin in others.
  7. Enhanced synthesis of RNA.
  8. High synthesis and activity of enzymes, especially hydrolytic enzymes.
- Hormonal control of fruit ripening
  - ✓ Abscisic acid and ethylene promote fruit ripening.
  - ✓ Auxins directly inhibit fruit ripening. Indirectly promote fruit ripening by promoting the synthesis of carotenoids.
  - ✓ Gibberellins inhibit fruit ripening by interfering with the degradation of chlorophyll and the synthesis of carotenoids and anthocyanins.
  - ✓ Cytokinin interfere with the chlorophyll breakdown and thereby delay or slow down fruit ripening.