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Excellence of Photosynthesis in Annual Crops

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Abstract

Photosynthesis, the process by which green plants and certain other organisms transform light energy into chemical energy is captured and used to convert water, Carbon dioxide and minerals into oxygen and energy-rich organic compounds.

During the process of photosynthesis, cells use carbon dioxide and energy form the sun to make sugar molecules and oxygen, then, via respiration process, cells use oxygen and glucose, to synthesize energy-rich carrier molecules, such as ATP, and carbon dioxide is produced as a waste product.

Key Word:- Chloroplast, Chlorophyll, Photosynthetic pigment

Oxygen is being constantly consumed and carbon dioxide evolved by the respiration of animals and plants and by the burning of wood, coal, petroleum or natural gas. High carbon dioxide content of the atmosphere is toxic. Lower concentrations of oxygen are equally harmful. Luckily, green plants keep the concentration of the two gases almost constant by absorbing carbon dioxide and evolving oxygen during photosynthesis.

Photosynthesis is the only process which produces enormous quantities of organic matter for sustaining the life on this globe. It is the only known method of manufacture of organic food from inorganic raw materials. Animals including man are directly or indirectly dependent on photosynthetic plants for their food. All flesh is grass.

Photosynthetic products not only build up the bodies of organisms but also provide energy for carrying out metabolic activities and different types of movements. The chemical energy present in the organic food is the converted form of radiant or solar energy. All life is bottled sunshine.

Coal, petroleum and natural gas represent the photosynthetic capital of the past geological ages. They have been formed by the application of heat and compression over the plant and animal bodies in the deeper layers of earth. Along with wood they provide a sufficient portion of energy required for domestic, industrial and transport needs.

Several materials derived from the organic world (and hence photosynthesis) are in our daily use.

Examples: Natural fibres, drugs, vitamins, gums, tannins, turpentine, furniture, etc.

Leaf Structure

Photosynthesis is occurs in the green parts of the plant. For efficient photosynthesis the leaf should be thin and have a large surface area. This helps in absorption of light and gaseous diffusion, and a means of preventing excessive water loss through stomata and epidermis. Large number of chloroplasts in palisade mesophyll cells provide the main photosynthetic tissue.

The space between the irregularly shaped spongy mesophyll cells within leaf permit free diffusion of gases. Turgor changes into guard cells permit gaseous exchange with the atmosphere. Cuticle on the single layered transparent upper and lower epidermis protects the leaf from desiccation and infection.

Chlorophyllic Structure

Structurally all types of chlorophyll resemble one another. All of them contain four pyrrole rings which are linked together by methane bridges (-CH=). The skeleton of each pyrrole ring is esterfied with a long chain alcohol-phytol. This side chain-phytol is long and is composed of insoluble carbon and hydrogen atoms which helps to anchor the chlorophyll molecules with the thylakoids. In plants, there are 2 types of chlorophyll-namely chlorophyll a and b. Chlorophyll molecule looks like a tadpole with porphyrin head and phytol tail. Chlorophyll a has methyl group ($-CH_3$) at position and aldehyde (CHO) group in chlorophyll b.

Chlorophyll a is the major pigment involved in trapping light energy and converting it in to electrical and chemical energy. It acts as a reaction centre.

Chlorophyll b constitutes about $1/4^{th}$ of the total chlorophyll content. It acts as an accessory pigment and helps broaden the spectrum of light absorbed during photosynthesis. Chlorophyll b absorbs a different wavelength of light other than that absorbed by chlorophyll a. On absorbing light,
it becomes excited and transfer its to chlorophyll a molecule.

Another group of pigments are called carotenoids. The carotenoids are red, orange or yellow pigments. In the green leaf, their colour is masked by the chlorophylls, which are more abundant.

Caretenoids like chlorophyll are embedded in the thylakoid membrane of the chloroplasts. They are accessory pigments and harvest light from different regions of the spectrum. The light captured by these pigments are channelled it to the reaction centre, where light energy is converted into electrical energy.

Chloroplasts

These biconvex organelles, containing many flattened, fluid filled membranous sacs called thylakoids and a gel like stroma are enclosed by the two membranes of the chloroplast envelope. Stacks of circular thylakoids called grana linked together by intergranal lamellae, are formed at intervals throughout the chloroplast.

Photosynthetic Pigments

Molecules of chlorophyll-a, chlorophyll-b, carotene and xanthophyll are situated in the thylakoid membranes. For light energy to be used by living systems, it must first be absorbed. A pigment is any substance that absorbs light. Chlorophyll, the pigment that makes leaves green, absorbs light in the violet and blue wavelengths and also in the red because it reflects green light, it appears green. Different pigments absorb light energy at different wavelengths. The absorption pattern of a pigment is known as the absorption spectrum. The absorption spectrum of chlorophyll is between 400 nm and 700 nm. This portion spectrum shows how effective these pigments are in stimulating photosynthesis.

In plants, chlorophyll a is the pigment directly involved in the transformation of light energy to chemical energy.

The Action Spectrum

The Action Spectrum is the curve plotted on a graph paper representing the amount of oxygen evolved or the amount of carbon dioxide fixed or any other action of photosynthesis at different wavelengths of light. It has been observed that the photosynthesis occurs maximum in blue and red regions of visible light. Action spectrum of photosynthesis determined by T.W.Englemann in 1882 using green alga. The scientist measured rate of photosynthesis as the amount of O_2 released, which he detected by using bacteria that are attracted by O_2.

The Absorption Spectrum is the curve plotted on a graph paper representing the amount of light absorbed at each wave length by that pigment.

Relation of the Visible Colour of Leaf to Absorption Spectrum

The leaf is green because wavelengths in this region of the spectrum, 550 nm are less strongly absorbed by leaf. These wavelengths are reflected.

Activity to Extract the Chloroplast Pigments and Separate them by Paper Chromatography

Materials Required

Spinach leaves, pestle and mortar, 80% acetone, calcium carbonate, Buchner funnel, beaker, measuring cylinder, glass jar with a tight cork. Whatmann No.1, filter paper, petroleum ether, acetone, hook, micropipette.

Procedure

Take 50g of fresh spinach leaves in a pestle and mortar. Crush them with 20ml of 80% acetone. Add a pinch of calcium carbonate an again crush. Filter the extract on a Buchner filter. The deep green coloured filtrate containing chlorophylls and carotenoids is obtained. Evaporate the extract to concentrate.

Take a glass jar (about 45 cm high) with a tight cork fitted in it. The cork should have a hole in the centre. Fit a small glass rod having a small hook, in the hole of cork. Now prepare he solvent by mixing 25ml petroleum ether and 3 ml acetone. Pour the solvent into the jar and allow the jar to become saturated. Cut a strip of filter paper of the size which can easily be hung on the hook. Apply a circular spot of pigment extract about 3cm from the base of strip with the help of a micropipette. Now hang the strip inside the jar to the hook of cork and close the cork. Care should be taken that the spot is not dipped in the solvent. Make the apparatus air tight and observe.

Contemplation

The solvent will run on the filter paper. After few hours, the chloroplast pigments will be separated in the form of different spots on the paper. Take out the paper when the solvent reaches upto the upper level. After drying the paper, identify the different pigments with the help of their specific colours. Carotene is yellow, xanthophyll is yellow-brown, chlorophyll-a is blue-green and chlorophyll-b is olive green in colour.

Manifestation of Fluorescence by Chlorophyll

Materials Required

Spinach leaves, pestle and mortar, 80% acetone, calcium carbonate, Buchner funnel, test tube, source of light.

Procedure

Take 25g of fresh spinach leaves in a pestle and morter. Crush them with 10 ml of 80% acetone. Add a pinch of calcium carbonate and crush again. Filter the extract on a Buchner funnel. The drop green coloured filtrate containing chlorophylls is obtained. Pour the filtrate in a test tube. Place the test tube before the source of light and observe.

Observation

The solution appears green when placed between the source of light and eyes of observer is in transmitted light. The solution appears red when source of light is placed behind the observer and solution is placed in front of observer is in reflected light. The phenomenon is called fluorescence.

Photochemical and Biosynthetic Phases

Light Phase consists of photochemical reactions which are carried out by two different photo systems, PS-I and PS-II. In the thylakoids, chlorophyll and other molecules are packed into units called photo systems.

Each photosystem unit contains from 250 to 400 molecules of pigment, which serve as light trapping antennae. Once light energy is absorbed by one of the antenna pigments, it is bounced around among the other pigment molecules of the photosystem until it reaches a special form of chlorophyll-a which is the reaction centre.

In photosystem-I, the reactive chlorophyll-a molecule is known P_{700} (P stands for pigments) because one of the peaks of its absorption spectrum is at 700 nm. It is located in the stroma regions of the thylakoid. The reactive chlorophyll a molecule of photosynthesis-II is P_{680}. They are located in the appressed regions of the grana in the thylakoid.

It is believed that these chlorophyll molecules have unusual properties because of their association with special proteins in the membrane. The main function of these two photosystem is to trap lightenergy and convert it into chemical energy (ATP) which is used by living cells.

The photochemical phase was explained by Arnon and his co-workers in 1958. Whenever a chlorophyll molecule absorbs a photon of light, it is said to move from the ground state to the excited state. The added energy lifts the electrons from the chlorophyll molecule (as given below in the equation) and is ultimately used t reduce $NAPH_2$. The excited state is unstable and the chlorophyll molecule through an electron transfer system and gets back to the ground state. The P_{680} chlorophyll molecule having lost its electron, is avidly seeking replacement. It finds it in the water molecules, which dissociates into protons and oxygen gas.

The P_{700} chlorophyll molecule is oxidized and an electron is boosted to a primary electron acceptor from which it goes downhill to NADP.

Electron Transport System

Electron transport chain refers to the light driven reactions of photosynthesis. They were first formulated in 1939 by Robert Hill. The two photosystems are connected in series with each other by the components of electron transport system. The reaction centres become so excited that they escape high energy electron (e^0) which move to nearby electron acceptor molecules. The electrons move through two pathways-non-cyclic and cyclic. The non-cyclic electron transport system involves participation of both PS-II and PS-I, whereas cyclic electron transport chain involves only PS-I.

Non-Cyclic Electron Transport System

The light energy of specific wavelengths is absorbed by chlorophylls and accessory pigments of PS-II. These pigments transfer their absorbed energy to PS-II reaction centre-P_{680} (chlo 680). This centre become photo excited and exudes an electron with a gain of energy (23 K Cal/mol).

Photolysis of Water (Photo Oxidation of Water)

The PS-II reaction centre (P_{680}) by transferring electron to primary acceptor becomes oxidized.

$$2H_2O \leftrightharpoons 4H^+ + 4e^- + O_2$$

The overall process is called photo-oxidation of water. It requires the presence of Mn^{++}, Ca^{+} and Cl^{-}, a water oxidising enzyme and an unknown substance Z. It is believed that oxygen evolves as oxygen gas. Electrons are accepted by PS-II reaction centre through unknown substance Z and H^{+} temporarily stay in the thylakoid space (loculus). The high energy electrons that leave PS-II are captured by Q which sends them to an electron transport system consisting of PQ, cytochrome complex, PC. Every time electron passes from donor to acceptor, the reduced donor id oxidized and the acceptor is reduced. The electrons of plastocyanin are picked by PS-I.

Simultaneously, the pigment molecules of PS-I complex absorb electronic excitation (energy) to PS-I reaction centre-P_{700}. P_{700} gets excited and exudes an electron, which goes to reduce an electron, which goes to reduce an electrons acceptor A. The oxidized reaction centre of PS-I takes electron form plastocyanin and comes to ground state. The electron emitted from the P_{700} is accepted by an unknown acceptor A which transfers its electron to ferredoxin an iron containing protein positioned at the outer surface of thylakoid membrane. The reduced ferredoxin donates its electrons to $NADP^{+}$ (Nicotinamide Adenine Dinucleotide Phosphate). The $NADP^{+}$ takes electrons from ferredoxin, protons from the medium and gets reduced to $NADPH_2$ in presence of enzymes, Ferredoxin-NADP-reductase.

Sequenced Genome of Chlorobium Tepidum

When early microbes evolved, some species developed ways to convert sunlight into cellular energy and to use that energy to capture carbon from the atmosphere. The origin of this process, known as photosynthesis, was crucial to the later evolution of plants. The publication today of the analysis of the complete genome sequence of an unusual photosynthetic microbe provides important insights into studies of how that light harvesting mechanism evolved and how it works today. The bacterium, Chlorobium tepidum, was originally isolated from a hot spring in New Zealand. It is a member of the green-sulfur bacterial group, so known because of the microbes' colour and their dependence on sulfur compounds to carry out photosynthesis. Biologists say green-sulfur bacteria are important because they perform photosynthesis in a different way from that of other bacteria and that of plants.

For example, instead of the choloroplasts found in plants, green-sulfur bacteria have organelles called chlorosomes that help generate energy through an electron-transport chain in the microbe's cytoplasmic membrane. Inside the chlorosomes, the chlorophyll and carotenoidmolecules that capture light differ from the molecules that other species use to perform photosynthesis. Also, green-sulfur bacteria carry out photosynthesis in the absence of oxygen and do not produce oxygen as a byproduct as plants do. "Because of their unusual mechanisms of harvesting and using the energy of light, the green-sulfur bacteria are important to understanding the evolution and the mechanism of both photosynthesis and cellular energy metabolism," said Jonathan A. Eisen, an evolutionary biologist at The Institute for Genomic Research (TIGR) in Rockville, Maryland. "The ability to carry out photosynthesis in the absence of oxygen is particularly important to evolutionary studies since it is believed that early atmosphere of Earth had little oxygen. That is why some scientists have suggested the green-sulfur bacteria were the first photosynthetic organisms."

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