Role of light in photosynthesis

Light has a particulate nature and a wave nature. Light represents that part of the radiant energy having wavelengths visible to the naked eye, approximately 390 to 760 nm. This is a very narrow region of the electromagnetic spectrum. The particulate nature of light is usually expressed in statements that light comes in quanta or photons, discrete packets of energy, each having a specific associated wavelength. In other words, light can be defined as electromagnetic energy propagated in discrete corpuscles called quanta or photon. As the energetics of chemical reactions are usually described in terms of kilocalories per mole of the chemicals (1 mole = 6. 02 x 1023 molecules). Therefore, light energies are usually described in terms of kilocalories per mole quantum or per einstein (1 mole quantum or 1 einstein = 6. 02 x 1023 quanta).

The colour of the light is determined by the wavelength (λ) of the light radiation. At any given wavelength, all the quanta have the same energy. The energy (E) of a quantum is inversely proportional to its wavelength. Thus the violet and blue wavelengths are more energetic than the longer orange and red ones. Therefore, the energy of blue light (λ = 420 nm or mμ) is in the order of 70 K-cal/einstein and that of red light (λ = 690 nm or mμ) about 40 K-cal/einstein. The symbol commonly used for quantum, hv, is derived from this relationship. In any wave propagation, the frequency (v) is inversely proportional to the wavelength. Since E α 1/ λ, then E α V. Plank's constant (h) converts this to an equation E = hv. Thus hv, used to designate a quantum, refers to the energy content of the quantum.

A fundamental principle of light absorption, often called as Einstein law, is that any pigment (coloured molecule) can absorb only one photon at a time and that this photon causes the excitation of one electron. Specific valence (bonding) electrons in stable ground state orbitals are then usually exited and each electron can be driven away from the positively charged nucleus for a distance corresponding to an energy exactly equal to the energy of the photon absorbed (Fig. 5-10). The pigment molecule is then in an excited state and it is this excitation energy that is used in photosynthesis. The relationship between the energies of light, both as calories per mole quanta (per Einstein) and as E ‘ O values and the energies required to conduct certain reactions is shown in table 5-2. It is evident that energy of a red quantum is just sufficient to raise an electron from OH- to the reducing level of H2; a uv quantum contains nearly twice this amount of energy. Thus, there is enough energy in a quantum of light (barely enough in a red quantum) to split water.

EMERSON EFFECT

By experiments, it appears that the high energy of blue light absorbed by chlorophyll is not used efficiently. The basic requirement is for a basic number of quanta. Therefore, the energy of the quanta is unimportant provided they can be absorbed by the chlorophyll. Red quanta (40 Kcal/einstein) are as effective as blue quanta (70 Kcal/einstein), the extra energy of the blue quanta is wasted. Presumably if a quantum is of the appropriate wavelength to be absorbed, it will be effective. However, an important exception to this behavior is the so called red drop, a decided decrease in efficiency found in many organisms at the far red end of the absorption spectrum, usually over 685 nm. Emerson, working with an algal system found that two pigment systems and two light reactions participated in photosynthesis. When exposed to a wavelength more than 680 nm, a specific rate of photosynthesis was observed. Likewise when exposed to a wavelength less than 680 nm a little effect on photosynthesis resulted. However, when the system was exposed to light of both the wavelengths at the same time, the effect on photosynthesis exceeded the sum of the two effects caused separately. Thus Emerson concluded that the efficiency of red light at a wavelength of about 700 nm could be increased by adding shorter wavelength light (650 nrn). This proved that the rate of photosynthesis in light of the two wavelengths together was greater than the added rates of photosynthesis in either alone. This is known as the Emerson effect after its inventor. This provided the ground that the two pigment systems worked in cooperation with each other. The resultant increase in photosynthesis was due to synergism (Fig. 5-13).

FACTORS AFFECTING PHOTOSYNTHESIS

Several external and internal factors influence photosynthesis. Of the external factors, influencing photosynthesis, light quality and intensity, CO2 concentration, temperature, oxygen, concentration of water, wind speed and nutrient level, are most important. The internal factors include chlorophyll contents, stomatal behaviour, leaf water content and enzymes. Morphology of the plants also influences photosynthesis. Most of the internal factors are influenced by the external factors. However, several of these interact to influence the rate of photosynthesis. For instance, increase in CO2, concentration enhances photosynthesis but such an increase may also cause closure of stomata. Therefore, no net increase in photosynthetic rate is observed. In summary, it may be understood that no single factor should be taken in account to explain an increase in photosynthesis. Certain specific factors that affect photosynthetic pathways are briefly discussed as under:

Temperature

As described earlier, Blackmann was the first to recognize the interrelations between light intensity and temperature. When CO2 light and other factors are not limiting, the rate of photosynthesis increases with a rise in temperature between the physiological range of 5. 35°C. Between 25-30°C photosynthesis usually has Q10 of about 2. Certain organisms can continue CO2 fixation at extraordinary extremes of temperature some conifers at -20oC and algae that inhabits hot springs, a temperatures in excess of 50°C. But in most plants, photosynthesis ceases or declines sharply beyond the physiological limit. Because above 40°C there is an abrupt fall in the rate and the tissues die. High temperatures, cause inactivation of enzymes thus affecting the enzymaticaily controlled dark reactions of photosynthesis.

Temperature range at which optimum photosynthesis can occur varies with the plant species e. g. some lichens can photosynthesize at 20°C while conifers can assimilate at 35°C.

In nature the maximum rate of photosynthesis due to temperature is not realized because light or CO2 or both are limiting. The response curve of net photosynthesis to temperature is different from those of light and CO2. It shows minimum, optimum and maximum temperatures. Between the C3 and C4 plants, the former species have optimal rates from 20-25°C while the latter from 35-40°C. Similarly, temperature also influences the light (optimum at 30-35°C) and dark respiration (optimum at 40-45°C).

Oxygen

Oxygen affects photosynthesis in several ways. Certain of the photosynthetic electron carriers may transfer electrons to oxygen, and ferredoxin in particular appears to be sensitive to O2. In bright light, high oxygen leads to irreversible damage to the photosynthetic system, probably by the oxidation of pigments. Carotenes in chloroplasts tend to protect chlorophylls from damage by solarization. The reaction of RuBP-case provides the most important site of O2 effect on photosynthesis. Oxygen competitively and reversibly inhibits the photosynthesis of C3 plants over all concentrations of CO2; at high O2 (80% or over) irreversible inhibition also takes place. On the other hand, C4 plants do not release CO2 in photorespiration, therefore, photosynthesis in them is not affected until very high concentrations are reached which cause irreversible damage to the photosynthetic system (Fig. 5-23).

Carbon dioxide concentrations

Under field conditions, CO2 concentration is frequently the limiting factor in photosynthesis. The atmospheric concentration of about 0. 033% (330 ppm) is well below C O2 saturation, for most plants. Some do not saturate until a concentration of 10 to 100 times this is reached. Characteristic CO2 saturation curves are shown in (Fig. 5-24). Photosynthesis is much affected by CO2 at low concentrations but is more closely related to light intensity at higher concentrations. At reduced CO2 concentrations the part of carbon may change dramatically because glycolate production results due to increased relative level of 02.

As CO_2 concentration is reduced, the rate of photosynthesis slows until it is exactly equal to the rate of photorespiration. This CO_2 concentration at which CO_2 uptake and out put are equal, is called the CO_2 compensation point. The CO_2 compensation point of C4 plants, which do not release CO_2 in photorespiration, is usually very low (i. e. from 2-5 ppm CO_2).

Light

The photosyntheticaliy active spectrum of light is between 400-700 nm. Green light (550 nm) plays no important role in photosynthesis. Light supplies the energy for the process and varies in intensity, quality and duration.

Intensity

When CO_2 and temperature are not limiting and light intensities are low, the rate of photosynthesis increases with an increase in its intensity. At a point saturation may be reached, when further increase in light intensity fails to induce any increase in photosynthesis. Optimum or saturation intensities may vary with different plant species e. g. C3 and C4 plants. The former become saturated at levels considerably lower than full sunlight but the later are usually not saturated at full sunlight.

When the intensity of light falling on a photosynthesizing organ is increased beyond a certain point, the cells of that organ become vulnerable to chlorophyll catalyzed photooxidations. Consequently these organs begin to consume O_2 instead of CO_2 and the CO_2 is released. Photooxidation is maximal when O2 is present or carotenoids are absent or CO_2 concentration is low.

Duration

Generally a plant will accomplish more photosynthesis when exposed to long periods of light. Uninterrupted and continuous photosynthesis for relatively long periods of time may be sustained without any visible damage to the plant. If the light source is removed, the rate of CO_2 fixation falls to zero immediately.

The light compensation point is that at which photosynthesis equals respiration and no net gas exchange occurs. The light compensation point of shade tolerant plants is much lower than that of sun plants.

Water

Water is an essential raw material in carbon assimilation. Less than 1% of water absorbed by a plant is used in photosynthesis. Thus decrease of water of the soil from field capacity to permanent wilting percentage (PWP) results in decreased photosynthesis. The inhibitory effect is primarily due to dehydration of protoplasm and also closure of stomata. The removal of water from the protoplasm also affects its colloidal state, impairs enzymatic efficiency, inhibits vital processes like respiration, photosynthesis etc.

The synthesis oforganic compound from carbon dioxide and water (with the reiease of oxygen)using light energy absorbed by chlorophyll is called as photosynthesis. Or through photosynthesis light energy is captured n then that enegy is converted into chemical energy and that energy is the need of organism to survive. plants are autotrophs and they get energy from sun light and they assemble the organic molecules from inorganic resources and this is the reason that's why it is called as photosynthesis. it is a greek word PHOTO means light and SYNTHESIS means to put together.

Ecological considerations in photosynthesis:

Ecological consideration means the effect of light , CO2, water etc. Chlorophyll is not the only pigment found in chloroplasts. There is also a family of orange and yellow pigments called carotenoids. Carotenoids include the carotenes, which are orange, and the xanthophylls, which are yellow. The principal carotene in chloroplasts is beta-carotene, which is located in the chloroplasts along with chlorophyll. At one time, the carotenoids were considered accessory pigments-it was believed that light energy absorbed by carotenoids was transferred to the chlorophylls for use in photosynthesis. It now appears that carotenoids have little direct role in photosynthesis, but function largely to screen the chlorophylls from damage by excess light (see Chapter 6). Carotenoid pigments are not limited to leaves, but are widespread in plant tissues. The color of carrot roots, for example, is due to high concentrations of beta-carotene in the root cells and lycopene, the red-orange pigment of tomatoes, is also a member of the carotenoid family. Lycopene and betacarotene are important because of their purported health benefits. Beta-carotene from plants is also the principal source of vitamin A, which plays an important role in human vision. Lycopene is an antioxidant that may help protect against a variety of cancers. Carotenes and xanthophylls are also responsible for the orange and yellow colors in autumn leaves. In response to shortening day length and cooler temperatures, the chloroplast pigments begins to break down. Chlorophyll, which normally masks the carotenoids, breaks down more rapidly than the carotenoids and the carotenoids are revealed in their entire autumn splendor. The red color that appears in some leaves at this time of the year is due to water-soluble anthocyanins, whose synthesis is promoted by the same conditions that promote the breakdown of chlorophyll. known as CO2 fertilization. In practice, the CO2 content may be increased by 150-200 ppm to a total of perhaps 1. 5 times atmospheric levels, although some foliage plant growers may supplement with CO2 up to a total of 700-1, 000 ppm.