FACTORS AFFECTING PHOTOSYNTHESIS

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Photosynthesis is affected by both environmental and genetic (internal) factors. The environmental factors are light, CO_2, temperature, soil, water, nutrients etc. Internal or genetic factors are all related with leaf and include protoplasmic factors, chlorophyll contents, structure of leaf, accumulation of end product etc.

Some of the important factors are discussed below:

1. Concept of Cardinal Values:

The metabolic processes are influenced by a number of factors of the environment. The rate of a metabolic process is controlled by the magnitude of each factor. Sachs (1860) recognized three critical values, the cardinal values or points of the magnitude of each factor. These are minimum, optimum and maximum. The minimum cardinal value is that magnitudes of a factor below which the metabolic process cannot proceed.

Optimum value is the one at which the metabolic process proceeds at its highest rate. Maximum is that magnitude of a factor beyond which the process stops. At magnitudes below and above the optimum, the rate of a metabolic process declines till minimum and maximum values are attained.

2. Principle of Limiting Factors:

Liebig (1843) proposed law of minimum which states that the rate of a process is limited by the pace (rapidity) of the slowest factor. However, it was later on modified by Blackman (1905) who formulated the "principle of limiting factors". It states that when a metabolic process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace (rapidity) of the slowest factor. This principle is also known as "Blackman's Law of Limiting Factors."

A metabolic process is conditioned by a number of factors. The slowest factor or the limiting factor is the one whose increase in magnitude is directly responsible for an increase in the rate of the metabolic process (here photosynthesis).

To explain it further, say at a given time, only the factor that is most limiting among all will determine the rate of photosynthesis. For example, if CO_2 is available in plenty but light is limiting due to cloudy weather, the rate of photosynthesis under such a situation will be controlled by the light. Furthermore, if both CO_2 and light are limiting, then the factor which is the most limiting of the two, will control the rate of photosynthesis.

Blackman (1905) studied the effect of CO_2 concentration, light intensity and temperature on rate of photosynthesis. All other factors were maintained in optimum concentration. Initially the photosynthetic material was kept at 20°C in an environment having 0.01% CO_2. When no light was provided to photosynthetic material, it did not perform photosynthesis. Instead, it evolved CO_2 and absorbed O_2 from its environment. He provided light of low intensity (say 150 foot candles) and found photosynthesis to occur.

When light intensity was increased (say 800 foot candles), the rate of photosynthesis increased initially but soon it leveled off. The rate of photosynthesis could be further enhanced only on the increase in availability of CO_2. Thus, initially light intensity was limiting the rate of photosynthesis.

When sufficient light became available, CO_2 became limiting factor (Fig. 6.17). When both are provided in sufficient quantity, the rate of photosynthesis rose initially but again reached a peak. It could not be increased further. At this time, it was found that increase in temperature could raise the rate of photosynthesis up to 35°C. Further increase was not possible. At this stage, some other factor became limiting. Therefore, at one time only one factor limits the rate of physiological process.

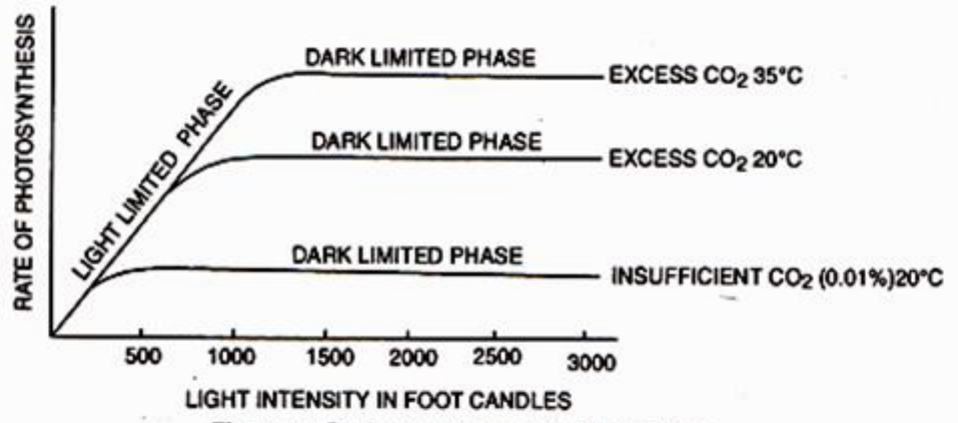

Fig. 6.17. Blackmann's law of limiting factors.

Objections have been raised to the validity of Blackman's law of limiting factors. For instance:

(i) It has been observed that the rate of a process cannot be increased indefinitely by increasing the availability of all the known factors;

(ii) The principle of Blackman is not operative for toxic chemicals or inhibitors and

(iii) Some workers have shown that the pace of reaction can be controlled simultaneously by two or more factors.

3. External Factors:

The environmental factors which can affect the rate of photosynthesis are carbon dioxide, light, temperature, water, oxygen, minerals, pollutants and inhibitors.

1. Effect of Carbon dioxide:

Being one of the raw materials, carbon dioxide concentration has great effect on the rate of photosynthesis. The atmosphere normally contains 0.03 to 0.04 per cent by volume of carbon dioxide. It has been experimentally proved that an increase in carbon dioxide content of the air up to about one per cent will produce a corresponding increase in photosynthesis provided the intensity of light is also increased.

2. Effect of Light:

The ultimate source of light for photosynthesis in green plants is solar radiation, which moves in the form of electromagnetic waves. Out of the total solar energy reaching to the earth, about

2% is used in photosynthesis and about 10% is used in other metabolic activities. Light varies in intensity, quality (wavelength) and duration.

The effect of light on photosynthesis can be studied under following three headings:

(i) Intensity of Light:

The total light perceived by a plant depends on its general form (viz., height of plant and size of leaves, etc.) and arrangement of leaves. Of the total light falling on a leaf, about 80% is absorbed, 10% is reflected and 10% is transmitted. Intensity of light can be measured by lux meter.

Effect of light intensity varies from plant to plant, e.g., more in heliophytes (sun loving plants) and less in sciophytes (shade loving plants). For a complete plant, rate of photosynthesis increases with increase in light intensity, except under very high light intensity where phenomenon of Solarization' occurs, (i.e., photo-oxidation of different cellular components including chlorophyll). It also affects the opening and closing of stomata thereby affecting the gaseous exchange. The value of light saturation at which further increase is not accompanied by an increase in CO_2 uptake is called light saturation point.

(ii) Quality of Light:

Photosynthetic pigments absorb visible part of the radiation i.e., 380 mμ, to 760 mμ. For example, chlorophyll absorbs blue and red light. Usually plants show high rate of photosynthesis in the blue and red light. Maximum photosynthesis has been observed in red light than in blue light followed by yellow light (monochromatic light). The green light has minimum effect. The rate of photosynthesis is maximum in white light or sunlight (polychromatic light). On the other hand, red algae shows maximum photosynthesis in green light and brown algae in blue light.

(iii) Duration of Light:

Longer duration of light period favours photosynthesis. Generally, if the plants get 10 to 12 hrs. of light per day it favours good photosynthesis. Plants can actively exhibit photosynthesis under continuous light without being damaged. Rate of photosynthesis is independent of duration of light.

3. Effect of Temperature:

The rate of photosynthesis markedly increases with an increase in temperature provided other factors such as CO_2 and light are not limiting. The temperature affects the velocity of enzyme controlled reactions in the dark stage. When the intensity of light is low, the reaction is limited by the small quantities of reduced coenzymes available so that any increase in temperature has little effect on the overall rate of photosynthesis.

At high light intensities, it is the enzyme-controlled dark stage which controls the rate of photosynthesis and there the $Q_{10} = 2$. If the temperature is greater than about 30°C, the rate of photosynthesis abruptly falls due to thermal inactivation of enzymes.

4. Effect of Water:

Although the amount of water required during photosynthesis is hardly one percent of the total amount of water absorbed by the plant, yet any change in the amount of water absorbed by a plant has significant effect on its rate of photosynthesis. Under normal conditions water rarely seems to be a controlling factor as the chloroplasts normally contain plenty of water.

Many experimental observations indicate that in the field the plant is able to withstand a wide range of soil moisture without any significant effect on photosynthesis and it is only when wilting sets in that the photosynthesis is retarded. Some of the effect of drought may be secondary since stomata tend to close when the plant is deprived of water. A more specific effect of drought on photosynthesis results from dehydration of protoplasm.

5. Effect of Oxygen:

Excess of O_2 may become inhibitory for the process. Enhanced supply of O_2 increases the rate of respiration simultaneously decreasing the rate of photosynthesis by the common intermediate substances. The concentration for oxygen in the atmosphere is about 21% by volume and it seldom fluctuates. O_2 is not a limiting factor of photosynthesis.

An increase in oxygen concentration decreases photosynthesis and the phenomenon is called Warburg effect. [Reported by German scientist Warburg (1920) in Chlorella algae]. This is due to competitive inhibition of RuBP-carboxylase at increased O_2 levels, i.e., O_2 competes for active sites of RuBP-carboxylase enzyme with CO_2. The explanation of this problem lies in the phenomenon of photorespiration. If the amount of oxygen in the atmosphere decreases then photosynthesis will increase in C_3 cycle and no change in C_4 cycle.

6. Effect of Minerals:

Presence of Mn^{++} and Cl^{-} is essential for smooth operation of light reactions (Photolysis of water/evolution of oxygen) Mg^{++}, Cu^{++} and Fe^{++} ions are important for synthesis of chlorophyll.

7. Effect of Pollutants and Inhibitors:

The oxides of nitrogen and hydrocarbons present in smoke react to form peroxyacetyl nitrate (PAN) and ozone. PAN is known to inhibit Hill's reaction. Diquat and Paraquat (commonly called as Viologens) block the transfer of electrons between Q and PQ in PS II.

Other inhibitors of photosynthesis are monouron or CMU (Chlorophenyl dimethyl urea), diuron or DCMU (Dichlorophenyl dimethyl urea), bromocil and atrazine etc., which have the same mechanism of action as that of violates. At low light intensities potassium cyanide appears to have no inhibiting effect on photosynthesis.

4. Internal Factors:

The important internal factors that regulate the rate of photosynthesis are:

1. Protoplasmic factors:

There is some unknown factor in protoplasm which affects the rate of photosynthesis. This factor affect the dark reactions. The decline in the rate of photosynthesis at temperature.above 30°C or at strong light intensities in many plants suggests the enzyme nature of this unknown factor.

2. Chlorophyll content:

Chlorophyll is an essential internal factor for photosynthesis. The amount of CO_2 fixed by a gram of chlorophyll in an hour is called photosynthetic number or assimilation number. It is usually constant for a plant species but rarely it varies. The assimilation number of variegated variety of a species was found to be higher than the green leaves variety.

3. Accumulation of end products:

Accumulation of food in the chloroplasts reduces the rate of photosynthesis.

4. Structure of leaves:

The amount of CO_2 that reaches the chloroplasts depends on structural features of the leaves like the size, position and behaviour of the stomata and the amount of intercellular spaces. Some other characters like thickness of cuticle, epidermis, presence of epidermal hairs, amount of mesophyll tissue, etc., influence the intensity and quality of light reaching the chloroplast.

5. CO_2 Compensation Point:

It is that value or point in light intensity and atmospheric CO_2 concentration when the rate of photosynthesis is just equivalent to the rate of respiration in the photosynthetic organs so that there is no net gaseous exchange. The value of light compensation point is 2.5 -100 ft. candles for shade plants and 100-400 ft. candles for sun plants. The value of CO_2 compensation point is very low in C_4 plants (0-5 ppm), where as in C_3 plants it is quite high (25-100 ppm). A plant can not survive for long at compensation point because there is net lose of organic matter due to respiration of non-green organs and dark respiration.