Physiological Dynamics in Animals & Plants – Lecture 5 – Photosynthesis

I. The process in which energy of sunlight is used to combine carbon dioxide and water to make sugars is photosynthesis.

A. Photosynthetic organisms are autotrophs - specifically, photoautotrophs.

B. Nonphotosynthetic organisms are called heterotrophs.

C. Photosynthesis and cellular respiration are complimentary processes.

II. Photosynthesis occurs in two stages.

A. Conversion of light energy into chemical energy = light reactions of photosynthesis.

1. Chemical energy is stored in covalent bonds of ATP and as "reducing power" in NADPH (nicotinamide adenine dinucleotide phosphate)

B. Conversion carbon dioxide into sugars using stored chemical energy and reducing power from light reactions = "dark" reactions = Calvin cycle = light independent reactions = photosynthetic carbon reduction pathway

1. During Calvin cycle, chemical energy stored in bonds of ATP is released and used to form covalent bonds between atoms of sugar molecules.

III. Organization of light reactions

A. Light reactions occur in the thylakoid membranes of chloroplasts.

B. Light energy is absorbed by pigments attached to proteins embedded in the thylakoid membranes.

III.B. (cont.)

1. The major light absorbing pigment is chlorophyll, of which there are two major forms, chlorophyll a (Chla) and chlorophyll b (Chlb).

2. Both forms of chlorophyll absorb red and blue light but not green, yellow, etc.

3. Other pigments, called accessory pigments, absorb other colors = wavelengths of light.

C. Chlorophyll and accessory pigments are organized in thylakoids in clusters of several hundred molecules called photosystems = PS.

1. There two distinct photosystems: photosystem I (PSI) and photosystem II (PSII)

2. Each photosystem has two parts: a light harvesting complex (= LHC or antenna) and a reaction center

D. In both photsystems, energy collected by accessory pigments and Chlb in the LHC is transferred to Chla molecules in the reaction center.

E. PSII is connected to PSI by an electron transport chain (ETC) = a series of enzymes that are sequentially reduced (gain electrons) and the oxidized (lose electrons).

F. There is a second ETC beyond PSI.

IV. During light reactions:

A. Electrons are ejected from Chla in the reaction center of PSII; they are used to reduce a primary electron acceptor called quinone A = QA.

B. Simultaneously, electrons are ejected from Chla in the reaction center of PSI. They are used to reduce a different primary acceptor called ferrodoxin.

C. Electrons flow from Chla of PSII through the ETC to replace those lost from Chla in the reaction center of PSI.

D. Electrons from Chla of PSI flow from its electron acceptor, ferrodoxin, to $NADP^+$, reducing it to NADPH + H^+.

E. Electrons lost from Chla in reaction centers of PSII are replaced with electrons from water as it is "split" into protons (H^+), electrons (e^-), and molecular oxygen (O_2).

1. Water splitting = photolysis.

F. During electron transport, protons accumulate inside the thylakoid membrane, making the inside more acidic than the stroma of the chloroplast.

G. The difference in pH on the two sides of the thylakoid membrane activates and ATP synthase enzyme that is also embedded in the thylakoid membrane.

1. ADP + Pi $\rightarrow$ ATP

2. Proton-dependent ATP synthesis = chemiosmosis

3. Bacteria and mitochondria also produce ATP by chemiosmosis.

V. Calvin cycle occurs in the stroma of the chloroplast.

A. $CO_2 + H_2O$ + energy $\rightarrow$ sugar

B. Sugar production requires ATP and electrons from NADPH made in the light reactions.

V. (cont.)

C. First reaction: atmospheric CO_2 entering leaf through stomata is taken up by mesophyll cells and becomes covalently bonded to a 5-carbon molecule call ribulose bis-phosphate = ribulose 1,5-diphosphate = RuBP = RuDP.

1. Stomata open in response to light and lowered intercellular concentrations of carbon dioxide in the leaf.

2. The enzyme that catalyzes the reaction is ribulose bis-phosphate carboxylase-oxygenase = Rubisco.

3. The process of "capturing" carbon dioxide and converting it from a gas to a solid molecular form is called carbon "fixation."

D. The 6-carbon molecule formed immediately splits to form two, 3-carbon molecules of phosphoglyceric acid = PGA.

1. Plants that use this method of photosynthesis are called C3 plants.

E. PGA is converted to phosphoglyceraldehyde (PGAL) using energy from ATP hydrolysis and electrons from NADPH.

F. PGAL molecules are used to produce:

1. glucose/fructose → sucrose

2. more RuBP to keep the cycle running

G. 6 RuBP + 6 CO_2 + 18 ATP + 12 NADPH → 6 RuBP + 18 ADP + 18 Pi + 12 $NADP^+$ + one 6-carbon sugar (glucose or fructose)

1. must run the cycle two times to make one sucrose molecule

VI. C4 metabolism and crassulacean acid metabolism (CAM) help plants in drier climates conserve water and minimize carbon loss to photorespiration as they photosynthesize, improving their water use efficiency (WUE).

A. Both convert CO_2 to 4-carbon organic acids first, using the enzyme phosphoenolpyruvate carboxylase (PEPC).

B. C4 plants open their stomata during the day and fix the CO_2 into malic acid (malate ion) in mesophyll cells. They then transport the malic acid to the bundle sheath cells where it is decarboxylated and fixed again by Calvin cycle.

1. Oxygen competes with carbon dioxide for the catalytic site on Rubisco. Thus, in the absence of carbon dioxide, Rubisco will consume oxygen in the light = photorespiration.

a. Carbon fixation using PEPC increases the effective concentration of CO_2 that can be delivered to Rubisco, making it more competitive with oxygen for the catalytic site.

2. C4 open their stomata less than C3 plants while accomplishing the same amount of photosynthesis; thus, they lose less water than do C3 plants for the same amount of sugar produced.

3. Corn and grasses are good examples of C4 plants.

C. CAM plants open their stomata at night and fix CO_2 into malic acid (malate ion) in mesophyll cells; in the daytime, they decarboxylate malic acid and convert the CO_2 into sugars by Calvin cycle in the same mesophyll cells in which it was originally fixed the previous night.

a. Many desert plants (e.g., cacti) have CAM.