

## Alternative mechanisms of carbon fixation have evolved in hot, arid climates

- One of the major problems facing terrestrial plants is dehydration.
- At times, solutions to this problem conflict with other metabolic processes, especially photosynthesis.
- The stomata are not only the major route for gas exchange (CO<sub>2</sub> in and O<sub>2</sub> out), but also for the evaporative loss of water.
- On hot, dry days plants close the stomata to conserve water, but this causes problems for photosynthesis.
- In most plants initial fixation of CO<sub>2</sub> occurs via rubisco and results in a three-carbon compound, 3-phosphoglycerate.
- We call these plants C<sub>3</sub> plants
  - These plants include rice, wheat, and soybeans.
- When their stomata are closed on a hot, dry day, CO<sub>2</sub> levels drop as CO<sub>2</sub> is consumed in the Calvin cycle, and no additional CO<sub>2</sub> can get in
- At the same time, O<sub>2</sub> levels rise as the light reaction converts light to chemical energy, and no O<sub>2</sub> can get out of the leaf.
- While rubisco normally accepts CO<sub>2</sub>, when the O<sub>2</sub>/CO<sub>2</sub> ratio increases (on a hot, dry day with closed stomata), rubisco can add O<sub>2</sub> to RuBP.
- When rubisco adds O<sub>2</sub> to RuBP, RuBP splits into a three-carbon piece and a two-carbon piece in a process called photorespiration. (*NO 3-phosphoglycerate is produced*)
  - The two-carbon fragment is exported from the chloroplast and degraded to CO<sub>2</sub> by mitochondria and peroxisomes.
  - Unlike normal respiration, this process produces no ATP, nor additional organic molecules (no food).

- Photorespiration decreases photosynthetic output by siphoning organic material from the Calvin cycle.
  - Photorespiration can drain away as much as 50% of the carbon fixed by the Calvin cycle on a hot, dry day.
- Certain plant species have evolved alternate modes of carbon fixation to minimize photorespiration.
  - C4 plants
  - CAM plants

### C<sub>4</sub> Plants

- C4 plants have special adaptations that save water and also prevent photorespiration
- During hot, dry weather, a C4 plant keeps its stomata closed most of the time, thus conserving water (like the C3 plant)
- But, at the same time, it continues to make sugars by photosynthesis using an alternate mode of carbon fixation
- A unique leaf anatomy plays a role in C4 photosynthesis
  - C4 plants have 2 distinct types of photosynthetic cells
    - Bundle-sheath cells – arranged into tightly packed sheaths around the veins of the leaf
    - Mesophyll cells – more loosely arranged
- In the mesophyll cells, the enzyme PEP carboxylase adds CO<sub>2</sub> to phosphoenolpyruvate, forming oxaloacetate, a four-carbon product
- Oxaloacetate gets tweaked and becomes malate, another four-carbon product
- After this fixation occurs, the mesophyll cells export malate (four-carbon product) to bundle sheath cells through the plasmodesmata
- Inside the bundle-sheath cells, the four-carbon compound releases CO<sub>2</sub>, making CO<sub>2</sub> levels high in these cells
- When the CO<sub>2</sub> levels are high, (higher than O<sub>2</sub> levels) rubisco will then accept the CO<sub>2</sub> and the calvin cycle will proceed as normal

- So in a nutshell:

- Carbon fixation and the Calvin cycle occur in different types of cells
- Mesophyll cells of a  $C_4$  plant pump  $CO_2$  into bundle-sheath cells
- $CO_2$  levels stay high in bundle-sheath cells
- Rubisco accepts  $CO_2$  instead of  $O_2$
- Photosynthesis occurs as normal
- Photorespiration is minimized

### CAM Plants

- A second strategy to minimize photorespiration is found in succulent plants, cacti, pineapples, and several other plant families.
  - These plants, known as **CAM plants** for **crassulacean acid metabolism (CAM)**, open stomata during the night and close them during the day.
    - Temperatures are typically lower at night and humidity is higher.
  - During the night, these plants fix  $CO_2$  into a variety of organic acids in mesophyll cells.
  - During the day, the light reactions supply ATP and NADPH to the Calvin cycle and  $CO_2$  is released from the organic acids.
- Both  $C_4$  and CAM plants add  $CO_2$  into organic intermediates before it enters the Calvin cycle.
  - In  $C_4$  plants, carbon fixation and the Calvin cycle are spatially separated – occur in two different types of cells.
  - In CAM plants, carbon fixation and the Calvin cycle are temporally separated – occur in the same cells at different times.
- Both eventually use the Calvin cycle to incorporate light energy into the production of sugar.

## Photosynthesis is the biosphere's metabolic foundation: *a review*

- In photosynthesis, the energy that enters the chloroplasts as sunlight becomes stored as chemical energy in organic compounds.
- Sugar made in the chloroplasts supplies the entire plant with chemical energy and carbon skeletons to synthesize all the major organic molecules of cells.
  - About 50% of the organic material is consumed as fuel for cellular respiration in plant mitochondria.
  - Carbohydrate in the form of the disaccharide sucrose travels via the veins to nonphotosynthetic cells.
  - There, it provides fuel for respiration and the raw materials for anabolic pathways including synthesis of proteins and lipids and building the extracellular polysaccharide cellulose.
- Plants also store excess sugar by synthesizing starch.
  - Some is stored as starch in chloroplasts or in storage cells in roots, tubers, seeds, and fruits.
- Heterotrophs, including humans, may completely or partially consume plants for fuel and raw materials.
- On a global scale, photosynthesis is the most important process to the welfare of life on Earth.
  - Each year photosynthesis synthesizes 160 billion metric tons of carbohydrate per year.