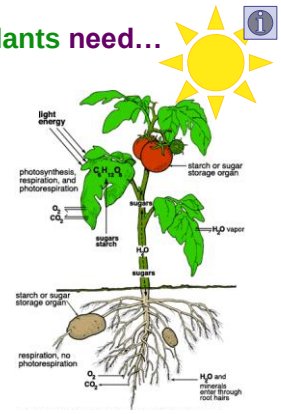
Chapter 8

Photosynthesis: Variations on the Theme

Remember what plants need…

- Photosynthesis
  - light reactions
  - Calvin cycle
    - light ← sun
    - H_2O ← ground
    - CO_2 ← air



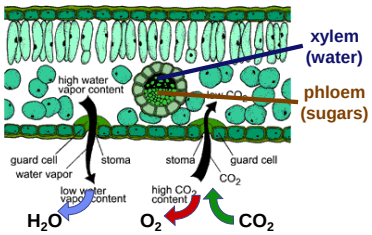
A look at stomates…

- Gas exchange
  - CO_2 in → for Calvin cycle
  - O_2 out → from light reactions
  - H_2O vapor out

photosynthesis

O_2 CO_2

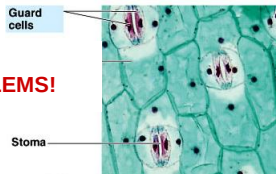
gas exchange water loss



Controlling water loss from leaves

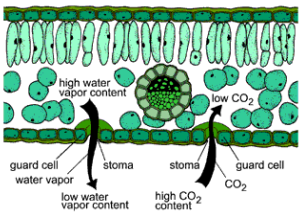
- Hot or dry days
  - stomates close to conserve water
  - guard cells
    - gain H_2O = stomates open
    - lose H_2O = stomates close
  - adaptation to living on land, but…

creates PROBLEMS!



Stomates

- closed stomates lead to…
  - O_2 builds up (from light reactions)
  - CO_2 is depleted (in Calvin cycle)
    - causes problems in Calvin Cycle



Inefficiency of Rubisco: CO_2 vs O_2

- Rubisco in Calvin cycle
  - carbon fixation enzyme
    - normally bonds C to RuBP
    - reduction of RuBP
    - building sugars

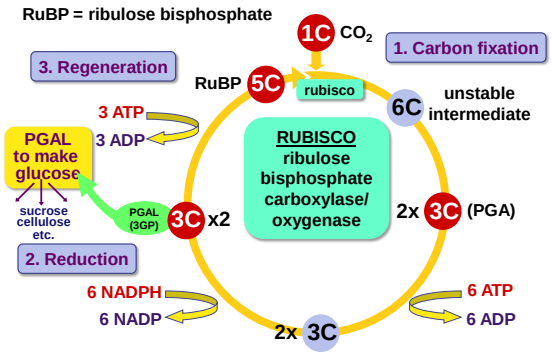
photosynthesis

  - when O_2 concentration is high
    - Rubisco bonds O to RuBP
    - O_2 is alternative substrate
    - oxidation of RuBP
    - breakdown sugars

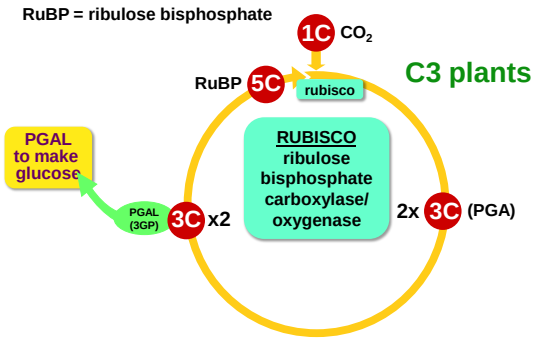
photorespiration

RUBISCO: ribulose bisphosphate carboxylase/oxygenase

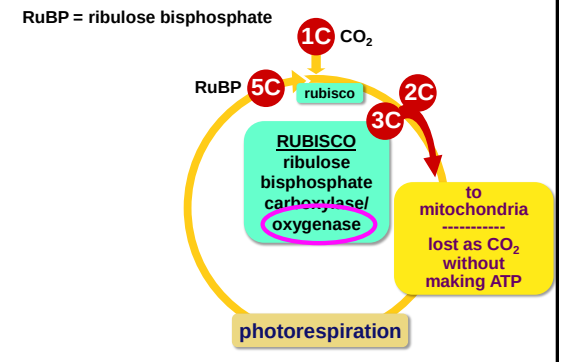
Calvin Cycle Review



Calvin Cycle Review



Calvin Cycle—with ↑[O_2]



Impact of Photorespiration

- Oxidation of RuBP
  - short circuit of Calvin cycle
  - decreases photosynthetic output by siphoning off carbons
    - no ATP (energy) produced
    - no $C_6H_{12}O_6$ (food) produced
  - loss of carbons to CO_2
    - can lose 50% of carbons fixed by Calvin cycle
  - if photorespiration could be reduced, plant would become 50% more efficient
    - strong selection pressure

Reducing Photorespiration

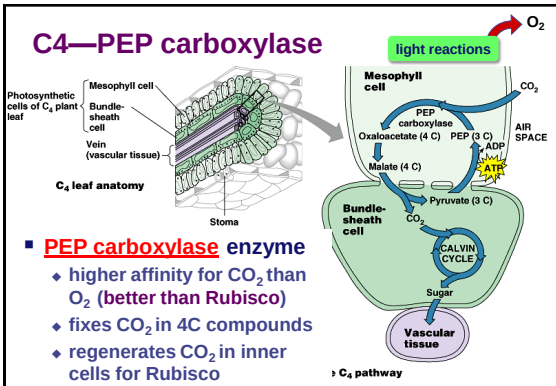
- Separate carbon fixation from Calvin cycle
  - C4 plants
    - physically separate carbon fixation from Calvin cycle
    - different enzyme to capture CO_2
      - PEP carboxylase stores carbon in 4C compounds
    - different leaf structure
  - CAM plants
    - temporally separate carbon fixation from Calvin cycle
    - fix carbon (capture CO_2) during night
      - store carbon in organic acids
    - perform Calvin cycle during day

C4 Plants

- A better way to capture CO_2
  - before Calvin cycle, fix carbon with enzyme PEP carboxylase
    - store as 4-C compound
  - adaptation to hot, dry climates
    - have to close stomates a lot
    - different leaf anatomy
  - sugar cane, corn, other grasses…

C4 Plants

C4—PEP carboxylase

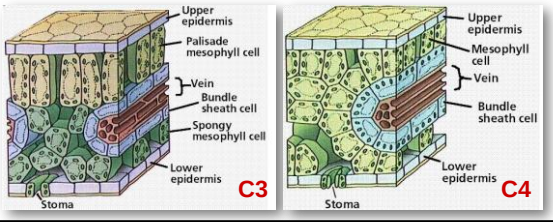


- PEP carboxylase enzyme
  - higher affinity for CO_2 than O_2 (better than Rubisco)
  - fixes CO_2 in 4C compounds
  - regenerates CO_2 in inner cells for Rubisco

phosphoenolpyruvate (3C) + CO_2 → oxaloacetate (4C)

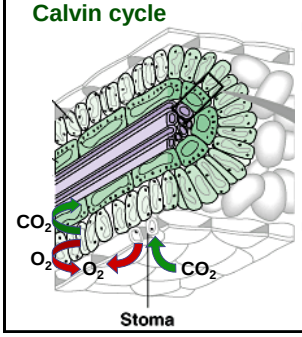
Comparative anatomy

- Separate reactions in different cells
  - light reactions
  - carbon fixation
  - Calvin cycle



C4 photosynthesis

Physically separated carbon fixation from Calvin cycle



- Outer cells
  - light reaction & carbon fixation
  - pumps CO_2 to inner cells
  - keeps O_2 away from inner cells
    - away from Rubisco
- Inner cells
  - Calvin cycle
  - glucose to veins

CAM (Crassulacean Acid Metabolism) plants

- Different adaptation to hot, dry climates
  - succulents, some cacti, pineapple
  - separate carbon fixation from Calvin cycle by time
    - close stomates during day
    - open stomates during night
  - at night, open stomates & fix carbon in "storage" compounds
    - organic acids: malic acid, isocitric acid
  - in day, close stomates & release CO_2 from "storage" compounds to Calvin cycle
    - increases concentration of CO_2 in cells

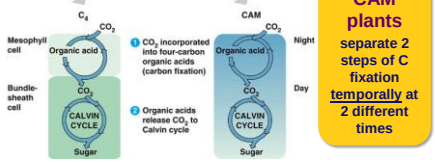
CAM (Crassulacean Acid Metabolism) plants

C4 vs CAM Summary

- Different adaptation to hot, dry climates

Sugarcane

Pineapple



C4 plants
separate 2 steps of C fixation anatomically in 2 different cells

CAM plants
separate 2 steps of C fixation temporally at 2 different times

Why the C3 problem?

- Possibly evolutionary baggage
  - Rubisco evolved in high CO_2 atmosphere
    - there wasn't strong selection against active site of Rubisco accepting both CO_2 & O_2
- Today it makes a difference
  - 21% O_2 vs. 0.03% CO_2
  - photorespiration can drain away 50% of carbon fixed by Calvin cycle on a hot, dry day
  - strong selection pressure to evolve better way to fix carbon & minimize photorespiration

Any Questions??