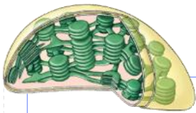
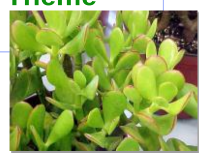
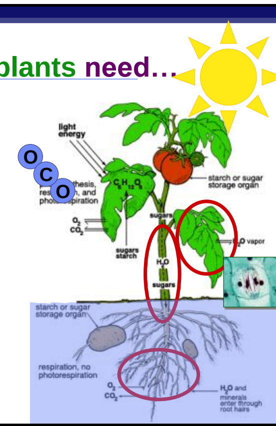


Photosynthesis:
Variations on the Theme



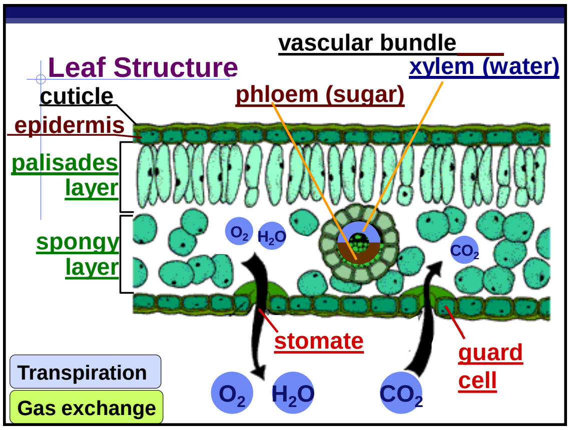
Remember what plants need…

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



What structures have plants evolved to supply these needs?

Leaf Structure



Transpiration

Gas exchange

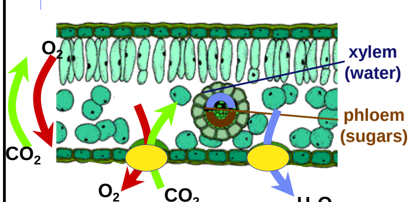
Controlling water loss from leaves

- **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!

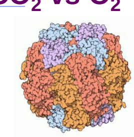
When stomates close…

- **Closed stomates lead to…**
  - O_2 build 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
    - CO_2 is the optimal substrate
    - reduction of RuBP
    - building sugars

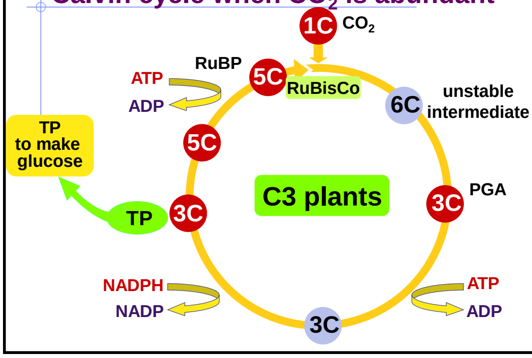


photosynthesis

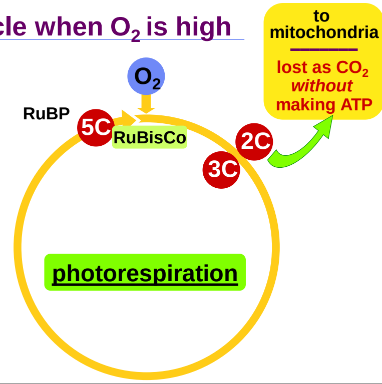
  - when O_2 concentration is high
    - RuBisCo bonds O to RuBP
    - O_2 is a competitive substrate
    - oxidation of RuBP
    - breakdown sugars

photorespiration

Calvin cycle when CO_2 is abundant



Calvin cycle when O_2 is high



Impact of Photorespiration

- Oxidation of RuBP
  - short circuit of Calvin cycle
  - loss of carbons to CO_2
    - can lose 50% of carbons fixed by Calvin cycle
  - reduces production of photosynthesis
    - no ATP (energy) produced
    - no $C_6H_{12}O_6$ (food) produced
  - if photorespiration could be reduced, plant would become 50% more efficient
    - strong selection pressure to evolve alternative carbon fixation systems

Reducing photorespiration

- Separate carbon fixation from Calvin cycle
  - C4 plants
    - PHYSICALLY separate carbon fixation from Calvin cycle
      - different cells to fix carbon vs. where Calvin cycle occurs
      - store carbon in 4C compounds
    - different enzyme to capture CO_2 (fix carbon)
      - PEP carboxylase
    - different leaf structure
  - CAM plants
    - separate carbon fixation from Calvin cycle by TIME OF DAY
    - fix carbon during night
      - store carbon in 4C compounds
    - perform Calvin cycle during day

C4 plants

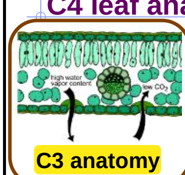
- A better way to capture CO_2
  - 1st step before Calvin cycle, fix carbon with enzyme PEP carboxylase
    - store as 4C compound
  - adaptation to hot, dry climates
    - have to close stomates a lot
    - different leaf anatomy
  - sugar cane, corn, other grasses…

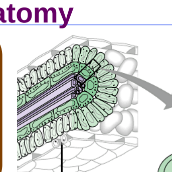

corn

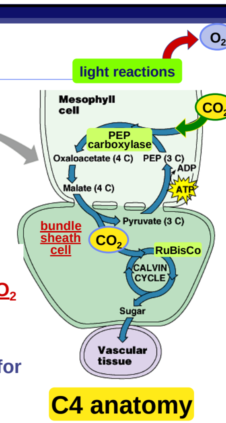

sugar cane

PEP (3C) + CO_2 → oxaloacetate (4C)

C4 leaf anatomy



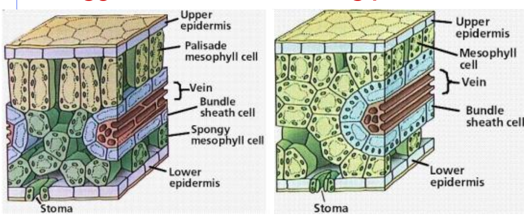




- PEP carboxylase enzyme
  - higher attraction for CO_2 than O_2
    - better than RuBisCo
  - fixes CO_2 in 4C compounds
  - regenerates CO_2 in inner cells for RuBisCo
    - keeping O_2 away from RuBisCo

Comparative anatomy

C3 **C4**



PHYSICALLY separate C fixation from Calvin cycle

How? Krantz anatomy! Bundle sheath cells have chloroplasts without grana, thus no ETC, no light reactions, and no O_2 waste!

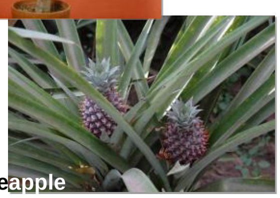
CAM (Crassulacean Acid Metabolism) plants

- **Adaptation to hot, dry climates**
  - **separate carbon fixation from Calvin cycle by TIME**
    - close stomates during day
    - open stomates during night
  - **at night**: open stomates & fix carbon in 4C "storage" compounds
  - **in day**: release CO_2 from 4C to Calvin cycle
    - increases concentration of CO_2 in bundle sheath cells
  - succulents, some cacti, pineapple

CAM plants

cacti

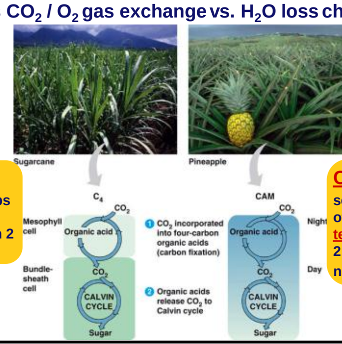
succulents



pineapple

C4 vs CAM Summary

solves CO_2 / O_2 gas exchange vs. H_2O loss challenge



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

CAM plants
separate 2 steps of C fixation temporally = 2 different times night vs. day

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

Questions??