Photosynthesis: Variations on the Theme

Remember what plants need...

- Photosynthesis
  - light reactions
    - light → sun
    - H₂O → ground
  - Calvin cycle
    - CO₂ → air

What structures have plants evolved to supply these needs?

Leaf Structure
- vascular bundle
- xylem (water)
- phloem (sugar)
- cuticle
- epidermis
- palisade layer
- spongy layer
- stomate
- guard cell

Transpiration
Gas exchange

Controlling water loss from leaves
- Hot or dry days
  - stomates close to conserve water
  - guard cells
    - gain H₂O = stomates open
    - lose H₂O = stomates close
  - adaptation to living on land, but...
  - creates PROBLEMS!

When stomates close...
- Closed stomates lead to...
  - O₂ build up → from light reactions
  - CO₂ is depleted → in Calvin cycle
    - causes problems in Calvin Cycle

Inefficiency of RuBisCo: CO₂ vs O₂
- RuBisCo in Calvin cycle
  - carbon fixation enzyme
    - normally bonds C to RuBP
    - CO₂ is the optimal substrate
    - reduction of RuBP
    - building sugars
  - when O₂ concentration is high
    - RuBisCo bonds O₂ to RuBP
    - O₂ is a competitive substrate
    - oxidation of RuBP
    - breakdown sugars
Impact of Photorespiration
- Oxidation of RuBP
  - short circuit of Calvin cycle
  - loss of carbons to CO₂
    - can lose 50% of carbons fixed by Calvin cycle
  - reduces production of photosynthesis
    - no ATP (energy) produced
    - no C₆H₁₂O₆ (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 CO₂ (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 CO₂
  - 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...

C₄ leaf anatomy
- PEP carboxylase enzyme
  - higher attraction for CO₂ than O₂
    - better than RuBisCo
  - fixes CO₂ in 4C compounds
  - regenerates CO₂ in inner cells for RuBisCo
    - keeping O₂ away from RuBisCo
**Comparative anatomy**

**C3**
- Upper epidermis
- Palisade mesophyll cell
- Vein
- Bundle sheath cell
- Spongy mesophyll cell
- Lower epidermis

**C4**
- Upper epidermis
- Mesophyll cell
- Vein
- Bundle sheath cell
- Lower epidermis

**PHYSICALLY separate CO2 fixation from Calvin cycle**

How? Krantz anatomy! Bundle sheath cells have chloroplasts without grana, thus no ETC, no light reactions, and no O2 waste!

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**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 CO2 from 4C to Calvin cycle
      - increases concentration of CO2 in bundle sheath cells
      - succulents, some cacti, pineapple

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**CAM plants**
- cacti
- succulents
- pineapple

**C4 vs CAM Summary**

solves CO2 / O2 gas exchange vs. H2O loss challenge

**Why the C3 problem?**

- **Possibly evolutionary baggage**
  - Rubisco evolved in high CO2 atmosphere
    - there wasn’t strong selection against active site of Rubisco accepting both CO2 & O2
- **Today it makes a difference**
  - 21% O2 vs. 0.03% CO2
  - 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??**