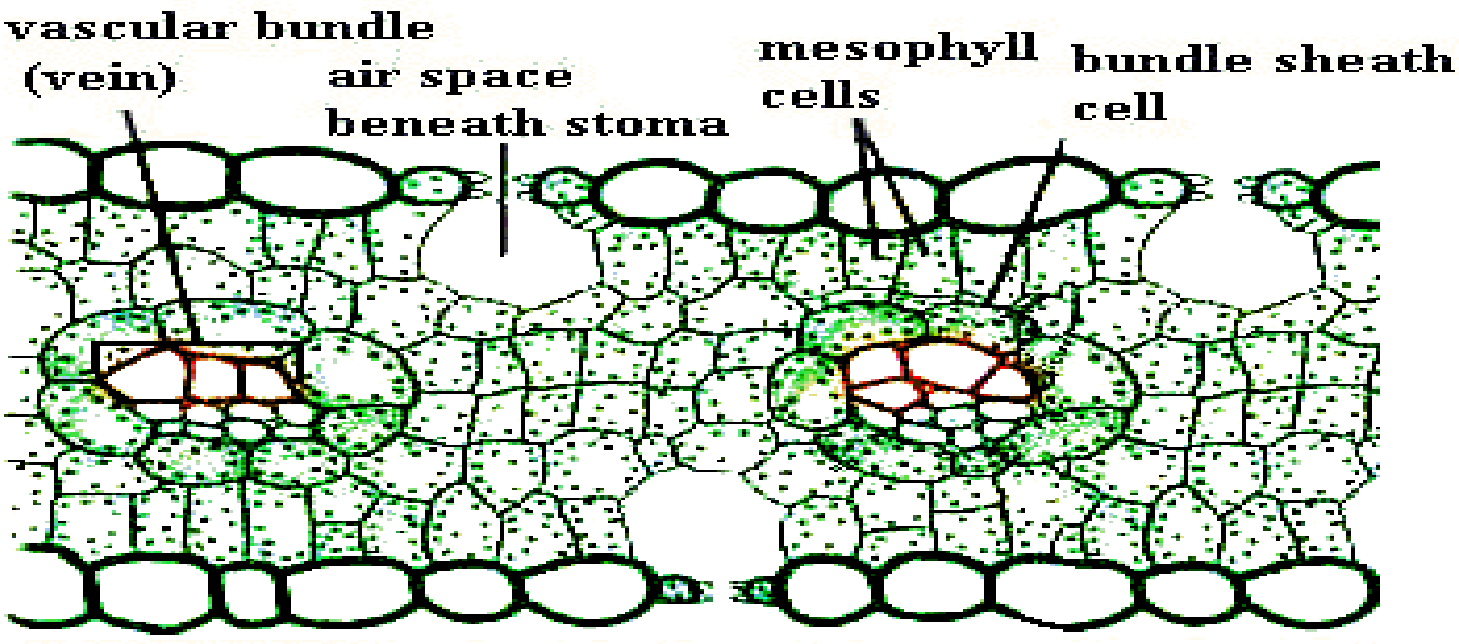
C4 CYCLE/HATCH & SLACK PATHWAY /CO2 CONCENTRATING MECHANISM

For B.Sc. Part II (Subs) Group C (Plant Physiology)



Presented by

Dr. Ankit Kumar Singh

Assistant Professor

Department of Botany

Marwari College

Lalit Narayan Mithila University

Darbhanga

ankitbhu30@gmail.com

Lecture No.08

C4 cycle/Hatch & Slack Pathway /CO2 concentrating mechanism

- Hatch & Slack (1967). Studies in detail and proposed pathway for dark reactions in sugarcane & mize leaves.
- First stable product of this reaction is OAA. Which is 4C, DCA (Dicarboxylic Acid), thus Hatch & Slack pathway is called as C4 cycle or DCA cycle.
- There are differences in leaf anatomy between plants that have a C4 carbon cycle (called C4 plants) and those that photosynthesize solely via the Calvin photosynthetic cycle (C3 plants).

- Kranz(Wreath) anatomy - present in leaves of C4 plants.
  - ✓ Green bundle sheath cells present around the vascular bundles.
  - ✓ Dimorphic choroplast present in leaf cells.
  - ✓ Chloroplast of B.S. cells or Kranz cells are larger and without grana.
  - ✓ Mesophyll chloroplast are small and with grana.

- C4-cycle occurs in 1500 sps. of 19 families of angiosperm, but most of the plants are monocots, which belong to Graminae & Cyperaceae (sugarcane, Maize, Sorghum, Oat, *Chloris*, *Sedges*, Bajra, *Panicum*, etc.)
- *Atriplex hastata* & *A. Patula* are temperate sps., which are C3 – plants.
- Dicots with C4 cycle are Euphorbia sps., *Amaranthus*, *Chenopodium*, *Borhaevia*, *Atriplex rosea*, *Portulaca*, *Tribulus.*
- Rubisco present in BS cells, while PEPC are in mesophyll cells.

- In the C4-Plant, C3-cycle occurs in bundle sheath cells, while C4-cycle occurs in mesophylls.
- Thus operation of Hatch and Slack pathway require cooperation of both Photosynthetic cell i.e. mesophyll cells and BS cells.

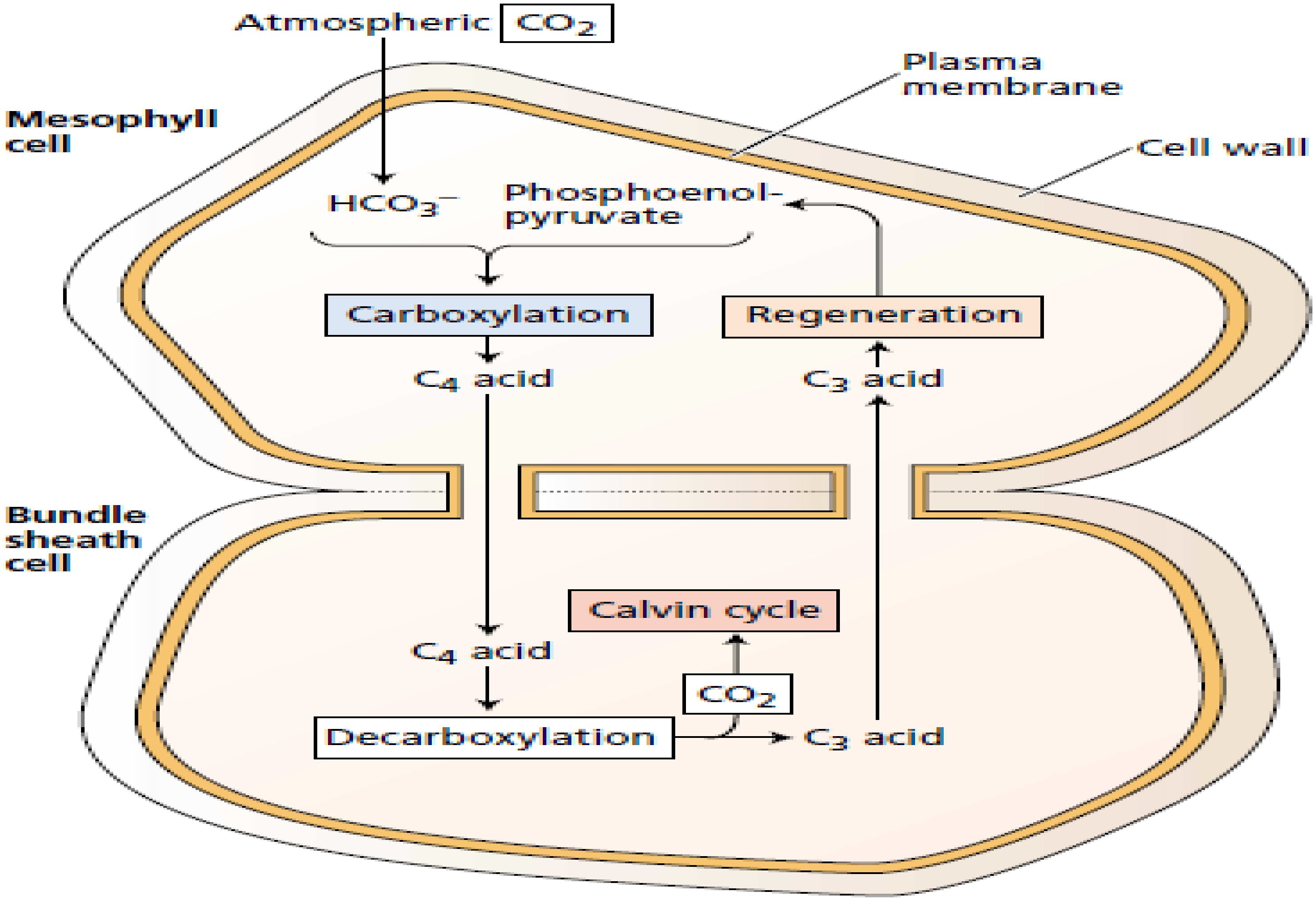


Figure: The basic C4 photosynthetic carbon cycle involves four stages in two different cell types.

- The basic C4 cycle consist of four stages

1. Fixation of CO_2 by the carboxylation of phosphoenolpyruvate in the mesophyll cells to form a C4 acid (malate and/or aspartate).

2. Transport of the C4 acids to the bundle sheath cells

3. Decarboxylation of the C4 acids within the bundle sheath cells and generation of CO_2, which is then reduced to carbohydrate via the Calvin cycle

4. Transport of the C3 acid (pyruvate or alanine) that is formed by the decarboxylation step back to the mesophyll cell and regeneration of the CO_2 acceptor phosphoenolpyruvate

- The primary carboxylation is catalyzed not by rubisco, but by PEP (phosphoenylpyruvate) carboxylase .
- The participating enzymes occur in one of the two cell types: PEP carboxylase and pyruvate–orthophosphate dikinase are restricted to mesophyll cells; the decarboxylases and the enzymes of the complete Calvin cycle are confined to the bundle sheath cells. With this knowledge, Hatch and Slack were able to formulate the basic model of the cycle.

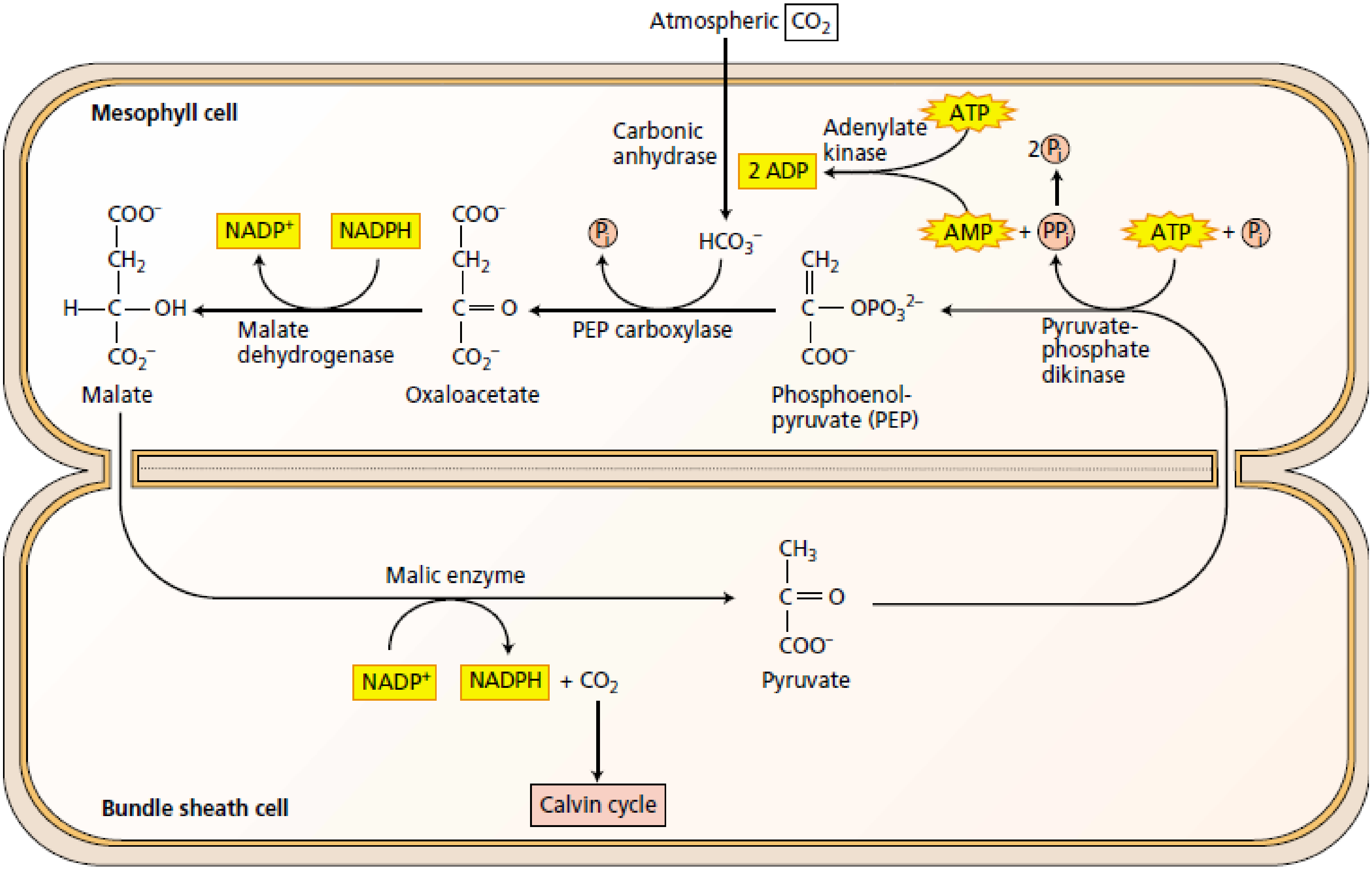


Figure: The C4 photosynthetic pathway. The hydrolysis of two ATP drives the cycle in the direction of the arrows, thus pumping CO2 from the atmosphere to the Calvin cycle of the chloroplasts from bundle sheath cells.

- One interesting feature of the cycle is that regeneration of the primary acceptorphosphoenol pyruvate consumes two “high-energy” phosphate bonds: one in the reaction catalyzed by pyruvate–orthophosphate dikinase and another in the conversion of PPi to 2Pi catalyzed by pyrophosphatase.
- Shuttling of metabolites between mesophyll and bundle sheath cells is driven by diffusion gradients along numerous plasmodesmata, and transport within the cells is regulated by concentration gradients and the operation of specialized translocators at the chloroplast envelope.
- The cycle thus effectively shuttles CO2 from the atmosphere into the bundle sheath cells.
- This transport process generates a much higher concentration of CO2 in the bundle sheath cells than would occur in equilibrium with the external atmosphere.
- This elevated concentration of CO2 at the carboxylation site of rubisco results in suppression of the oxygenation of ribulose-1,5-bisphosphate and hence of photorespiration.

Phosphoenolpyruvate + H_2O + NADPH + CO_2 (mesophyll)	→	malate + $NADP^+$ + P_i (mesophyll)
Malate + $NADP^+$	→	pyruvate + NADPH + CO_2 (bundle sheath)
Pyruvate + P_i + ATP	→	phosphoenolpyruvate + AMP + PP_i (mesophyll)
PP_i + H_2O	→	2 P_i (mesophyll)
AMP + ATP	→	2ADP
Net: CO_2 (mesophyll) + ATP + 2 H_2O	→	CO_2 (bundle sheath) + 2ADP + 2 P_i
Cost of concentrating CO_2 within the bundle sheath cell = 2 ATP per CO_2		

Table: Energetics of C4 cycle

➢Studies of a PEP carboxylase deficient mutant of *Amaranthus edulis clearly* showed that the lack of an effective mechanism for concentrating CO2 in the bundle sheath markedly enhances photorespiration in a C4 plant.

➢ CO2- concentrating process consumes two ATP equivalents (2 "high-energy" bonds) per CO2 molecule transported.

➢Thus the total energy requirement for fixing CO2 by the combined C4 and Calvin cycles is five ATP plus two NADPH per CO2 fixed

- Because of this higher energy demand, C4 plants photosynthesizing under nonphotorespiratory conditions (high CO_2 and low O_2) require more quanta of light per CO_2 than C3 leaves do.
- In normal air, the quantum requirement of C3 plants changes with factors that affect the balance between photosynthesis and photorespiration, such as temperature

Special features of C4 plants :

- C4 plants are more efficient plants at present CO_2 concentration
- Present level of atomospheric CO_2 is generally not limiting factor for C4 plants.
- C4 plants posses low CO_2 compensation points
- The productivity (fertility) does not increase in C4 plants, when CO_2 concentration is increases because :
- Mesophyll cells provide more CO_2 for Calvin cycle.
- The concentration of CO_2 around the site of Rubisco is higher in C4 plants, thus little or no chance of photorespiration.

Reference: Plant Physiology, by Lincoln Taiz and Eduardo Zeiger

Thank You !!