

TEACHING MATERIAL ON



Botany

(Department of School of Science)

Dr. Kamal Kant Patra , (Botany) Department of School of Science, YBN University , Ranchi

LECTURE NOTE ON CARBON FIXATION PATHWAYS - C4 PATHWAY DR KAMAL KANT PATRA, ASSOCIATE PROFESSOR, DEPARTMENT OF BOTANY, SCHOOL OF SCIENCE, YBN UNIVERSITY, RANCHI

Introduction

The C4 pathway, also known as the Hatch-Slack Pathway, is an adaptation found in certain plants to efficiently fix carbon dioxide in hot, arid environments. This pathway minimizes photorespiration and enhances photosynthetic efficiency by concentrating CO₂ around the enzyme RuBisCO.

C4 plants, such as maize, sugarcane, and sorghum, have specialized leaf anatomy with distinct **Kranz anatomy**. The mesophyll and bundle sheath cells work in tandem to achieve carbon fixation and the Calvin Cycle.

Key Features of the C4 Pathway

1. Spatial Separation of Processes:

- Initial carbon fixation occurs in mesophyll cells.
- The Calvin Cycle operates in bundle sheath cells.

2. Reduction of Photorespiration:

- By concentrating CO₂ around RuBisCO, oxygenation is minimized.

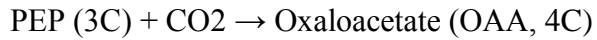
3. Enzyme Specialization:

- PEP carboxylase fixes CO₂ into a 4-carbon compound in the mesophyll cells.
- RuBisCO operates exclusively in bundle sheath cells where oxygen concentration is low.

Steps in the C4 Pathway

1. Carbon Fixation in Mesophyll Cells

- **Enzyme Involved:** Phosphoenolpyruvate (PEP) carboxylase.
- **Reaction:**



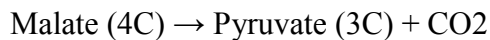
- PEP carboxylase has a high affinity for CO₂ and does not bind O₂, thus avoiding photorespiration.
- Oxaloacetate is converted to **malate** or **aspartate**, both 4-carbon compounds.

2. Transport to Bundle Sheath Cells

- Malate (or aspartate) is transported from the mesophyll cells to the bundle sheath cells via plasmodesmata.

3. Decarboxylation in Bundle Sheath Cells

- **Reaction:**



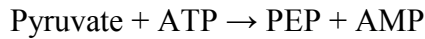
- Enzyme: Malic enzyme.
 - The released CO₂ is concentrated around RuBisCO, facilitating its fixation in the Calvin Cycle.

4. Calvin Cycle in Bundle Sheath Cells

- CO₂ enters the Calvin Cycle and combines with RuBP (Ribulose-1,5-bisphosphate) to form 3-phosphoglycerate (3-PGA).
- The Calvin Cycle proceeds as usual to produce glucose.

5. Regeneration of PEP in Mesophyll Cells

- Pyruvate (3C) is transported back to mesophyll cells.
- **Reaction:**



- Enzyme: Pyruvate phosphate dikinase (PPDK).
- ATP is consumed in this step, contributing to the energy cost of the C4 pathway.

Energetic Cost of the C4 Pathway

- The C4 pathway requires **30 ATP molecules** to synthesize one glucose molecule, compared to 18 ATP molecules in the C3 pathway.
- However, this energy investment is offset by the efficiency gained through reduced photorespiration under high-temperature, high-light conditions.

Kranz Anatomy

- C4 plants exhibit a unique leaf anatomy called **Kranz anatomy**:
 - **Mesophyll cells**:
 - Surround the bundle sheath cells and fix CO₂ initially.
 - **Bundle sheath cells**:
 - Located closer to vascular tissue and contain RuBisCO for the Calvin Cycle.
 - The physical separation of these cells minimizes oxygen interference during the Calvin Cycle.

Adaptations and Advantages of C4 Pathway

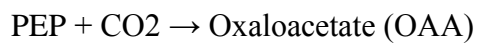
1. **Minimized Photorespiration:**

- The spatial separation of CO₂ fixation and the Calvin Cycle reduces oxygenation by RuBisCO.
- 2. **Efficient Water Use:**
 - Stomata in C₄ plants can remain partially closed, reducing water loss.
- 3. **High Photosynthetic Efficiency:**
 - Effective even in high temperatures and light intensity.
- 4. **Survival in Arid Climates:**
 - C₄ plants dominate in tropical and subtropical regions.

Summary of Reactions

Mesophyll Cells:

1. CO₂ Fixation:

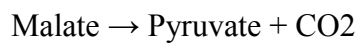


2. Conversion:



Bundle Sheath Cells:

3. Decarboxylation:



4. Calvin Cycle:



Regeneration:

5. PEP Regeneration in Mesophyll:



Diagram Explanation

The diagram for the C₄ pathway should illustrate the following:

1. **Kranz Anatomy:**

- A cross-section of a C₄ leaf showing mesophyll and bundle sheath cells.

2. **Pathway Flow:**

- Highlight the movement of CO₂, PEP, OAA, malate/aspartate, pyruvate, and ATP.
- Indicate spatial separation of processes.

3. **Enzymatic Reactions:**

- Show PEP carboxylase activity in mesophyll cells.
- Depict CO₂ fixation by RuBisCO in bundle sheath cells.

Conclusion

The C₄ pathway represents an evolutionary adaptation to high-temperature and low-CO₂ environments. By concentrating CO₂ around RuBisCO, it minimizes photorespiration and ensures efficient carbon fixation. Understanding this pathway provides insights into plant physiology and adaptation strategies in challenging climates.