TEACHING MATERIAL ON

Botany

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LECTURE NOTE ON CARBON FIXATION PATHWAYS - C3 PATHWAY BY DR KAMAL KANT PATRA, ASSOCIATE PROFESSOR, DEPARTMENT OF BOTANY, SCHOOL OF SCIENCE, YBN UNIVERSITY, RANCHI

Introduction to Carbon Fixation

Carbon fixation is the process by which inorganic carbon dioxide (CO_2) is converted into organic compounds by autotrophic organisms, such as plants, algae, and some bacteria. The C3 pathway, also known as the **Calvin Cycle**, is the most common mechanism of carbon fixation in plants.

What is the C3 Pathway?

The C3 pathway is named after the three-carbon compound **3-phosphoglycerate (3-PGA)**, which is the first stable product of carbon fixation in this cycle. It is the primary pathway in most plants, particularly in temperate climates.

Key Characteristics of the C3 Pathway

1. **First Product**: 3-phosphoglycerate (3-PGA), a three-carbon compound.
2. **Enzyme Involved**: Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) is the key enzyme.
3. **Energy Requirement**: Requires ATP and NADPH, which are produced during the light-dependent reactions of photosynthesis.
4. **Optimal Conditions**: Functions efficiently under cool temperatures and moderate light intensity.
5. **Major Limitation**: Photorespiration, which reduces the efficiency of the pathway under high oxygen concentrations and warm temperatures.

Steps of the C3 Pathway (Calvin Cycle)

The C3 pathway occurs in three stages: **Carboxylation**, **Reduction**, and **Regeneration**.

1. Carboxylation

- **Reaction**: Carbon dioxide (CO_2) is fixed by RuBisCO, combining it with ribulose-1,5-bisphosphate (RuBP) to produce two molecules of 3-phosphoglycerate (3-PGA).
- **Equation**:
- **Significance**: This is the initial step of carbon fixation.

2. Reduction

- **Reaction**: ATP and NADPH from light-dependent reactions are used to reduce 3-PGA into glyceraldehyde-3-phosphate (G3P), a three-carbon sugar.
- **Energy Input**:
  - ATP provides the energy.
  - NADPH provides reducing power.
- **Significance**: G3P is a key intermediate that can be converted into glucose and other carbohydrates.

3. Regeneration

- **Reaction**: Some of the G3P molecules are used to regenerate RuBP, the CO_2 acceptor molecule, using ATP.
- **Equation**:
- **Significance**: Ensures the cycle continues.

Summary of Energy Requirements

To fix one molecule of CO_2, the Calvin Cycle requires:

- 3 ATP molecules
- 2 NADPH molecules

For the synthesis of one glucose molecule (6 carbon atoms), the cycle consumes:

- 18 ATP molecules
- 12 NADPH molecules

Photorespiration in C3 Plants

1. **What is Photorespiration?**
   - A process where RuBisCO reacts with oxygen (O_2) instead of carbon dioxide (CO_2), leading to the formation of glycolate, which is metabolically costly.
2. **Conditions Favoring Photorespiration**:
   - High temperature
   - Low CO_2 concentration
   - High O_2 concentration
3. **Consequences**:
   - Reduces photosynthetic efficiency.
   - Wastes energy and carbon.
4. **Adaptations to Reduce Photorespiration**:
   - Some plants (e.g., C4 and CAM plants) have evolved alternative carbon fixation pathways.

Examples of C3 Plants

1. Wheat (*Triticum aestivum*)
2. Rice (*Oryza sativa*)
3. Soybean (*Glycine max*)
4. Barley (*Hordeum vulgare*)
5. Potato (*Solanum tuberosum*)

Environmental and Ecological Significance

1. **Global Carbon Cycle**:
   - C3 plants are major contributors to the global carbon cycle.

2. **Agriculture**:
    - Many staple crops rely on the C3 pathway for growth and productivity.
3. **Climate Sensitivity**:
    - C3 plants are more sensitive to increases in temperature and CO_2 levels compared to C4 plants.

Limitations of the C3 Pathway

1. **Photorespiration**:
    - Leads to a loss of fixed carbon and energy.
2. **Inefficiency in Warm Climates**:
    - Reduced efficiency in hot and dry environments due to stomatal closure, which limits CO_2 availability.
3. **Dependence on Light Reactions**:
    - Requires sufficient ATP and NADPH from light-dependent reactions.

Summary

The C3 pathway is the most widespread and ancient mechanism of carbon fixation, essential for the survival of most plants and the maintenance of life on Earth. While efficient in cool and moderate climates, it faces challenges like photorespiration, which have driven the evolution of alternative pathways in certain plants.