TEACHING MATERIAL ON

Botany

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LECTURE NOTE ON PHOTORESPIRATION BY DR KAMAL KANT PATRA, ASSOCIATE PROFESSOR, DEPARTMENT OF BOTANY, SCHOOL OF SCIENCE, YBN UNIVERSITY, RANCHI

Introduction to Photorespiration

Photorespiration is a process that occurs in plants when the enzyme Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) reacts with oxygen (O_2) instead of carbon dioxide (CO_2) during the Calvin Cycle. This alternative reaction is inefficient, as it reduces the overall photosynthetic output by consuming energy and releasing fixed carbon.

Why Does Photorespiration Occur?

1. **Dual Activity of RuBisCO**:
    - RuBisCO is capable of acting as both a carboxylase (binding CO_2) and an oxygenase (binding O_2).
    - The reaction depends on the relative concentrations of CO_2 and O_2, as well as environmental factors like temperature.
2. **Competition Between CO_2 and O_2**:
    - At higher temperatures and low CO_2 levels, RuBisCO favors oxygenation over carboxylation.
3. **Suboptimal Environmental Conditions**:
    - High temperature and light intensity.
    - Water stress, leading to stomatal closure and reduced CO_2 availability.

Mechanism of Photorespiration

Photorespiration involves three organelles: the chloroplast, peroxisome, and mitochondrion. The process can be summarized in the following steps:

1. **Oxygenation Reaction**:
   - RuBisCO reacts with O_2 instead of CO_2.
   - This reaction converts ribulose-1,5-bisphosphate (RuBP) into one molecule of 3-phosphoglycerate (3-PGA) and one molecule of 2-phosphoglycolate.
2. **Metabolism of 2-Phosphoglycolate**:
   - 2-phosphoglycolate is transported to the peroxisome, where it is converted into glycolate and then into glycine.
3. **Conversion of Glycine**:
   - Glycine is transported to the mitochondrion, where two glycine molecules combine to form serine, releasing CO_2 and NH_3 in the process.
4. **Regeneration of Metabolites**:
   - Serine is converted back into glycerate, which is transported to the chloroplast to re-enter the Calvin Cycle as 3-PGA.

Energy Cost of Photorespiration

Photorespiration is energetically expensive because:

1. **ATP Consumption**:
   - Energy is required to convert glycolate into usable forms and regenerate 3-PGA.
2. **Carbon Loss**:
   - CO_2 is released during the conversion of glycine to serine in the mitochondrion, reducing carbon fixation efficiency.
3. **Reduced Efficiency**:
   - The process does not produce ATP or NADPH, unlike the Calvin Cycle.

Consequences of Photorespiration

1. **Reduced Photosynthetic Output**:
   - Net fixation of carbon is reduced.
2. **Wastage of Energy**:
   - ATP and NADPH are consumed without producing useful sugars.
3. **Adaptation and Survival**:

- Photorespiration can help protect plants from photoinhibition by dissipating excess energy when CO_2 levels are low.

Factors Influencing Photorespiration

1. **Temperature**:
   - Higher temperatures increase the solubility of O_2 relative to CO_2, enhancing photorespiration.
2. **Light Intensity**:
   - High light intensity increases the oxygenation activity of RuBisCO.
3. **CO_2 and O_2 Concentration**:
   - Low CO_2 and high O_2 levels favor photorespiration.
4. **Stomatal Closure**:
   - Stomatal closure during water stress limits CO_2 uptake, promoting photorespiration.

Adaptations to Minimize Photorespiration

1. **C4 Pathway**:
   - Plants like maize and sugarcane spatially separate carbon fixation and the Calvin Cycle to concentrate CO_2 around RuBisCO.
2. **Crassulacean Acid Metabolism (CAM)**:
   - Plants like cacti temporally separate carbon fixation and the Calvin Cycle to minimize water loss and photorespiration.
3. **Improved RuBisCO Efficiency**:
   - Some plants have evolved RuBisCO enzymes with reduced oxygenase activity.
4. **Engineering Solutions**:
   - Genetic modification of plants to reduce photorespiration or enhance alternative pathways.

Ecological and Agricultural Implications

1. **Crop Productivity**:

    - Photorespiration reduces yield in crops like wheat and rice, especially in hot climates.
2. **Global Carbon Cycle**:
    - Influences the balance of carbon fixation and release in ecosystems.
3. **Adaptation to Climate Change**:
    - Understanding photorespiration can help develop crops better suited to future environmental conditions.

Summary

Photorespiration is an alternative pathway catalyzed by RuBisCO that reduces photosynthetic efficiency under certain environmental conditions. While energetically costly, it plays a role in plant survival under stress. Research on minimizing photorespiration is crucial for improving agricultural productivity and understanding plant responses to climate change.