C-4 PATHWAY

USMAN SUMO FRIEND TAMBUNAN

ARLI ADITYA PARIKESIT

EVI KRISTIN WULANDARI

BIOINFORMATICS GROUP

DEPARTMENT OF CHEMISTRY

FACULTY OF MATHEMATICS AND SCIENCE

UNIVERSITY OF INDONESIA

C-4 Plants

- The C-4 plants are plants which typically grow at high light intensity and high temperature.
- Characteristics of C-4 Plants:
  - High photosynthetic rates
  - High growth rates
  - Low photorespiration rates
  - Low rates of water loss
  - A specialized leaf structure
- Examples: millet, sugarcane, and sorghum.

Photosynthesis of C-4 Plants

- Photosynthesis in the leaves of C-4 plants involves two cell types: mesophyll and bundle-sheath cell.

C-4 Pathway

- C-4 plants capture carbon dioxide using an enzyme called PEP Carboxylase that adds carbon dioxide to the three carbon molecule Phosphoenolpyruvate (PEP) creating the 4-carbon molecule oxaloacetic acid.
- This reactions occurs in the cytosol of leaf mesophyll cells.

C-4 Pathway

- The oxaloacetate thus formed is either reduced to malate at the expense of NADPH or converted to aspartate by transamination:
- Oxaloacetate + α-amino acid $\rightarrow$ L-aspartate + α-keto acid
- The malate or aspartate formed in mesophyll cells then passes into neighboring bundle-sheath cell through plasmodesmata, protein-lined channels that connect two plants cells and provide a path of movement of metabolites and even small proteins between cells.

C-4 Pathway

- In the bundle-sheath cells, malate is oxidized and decarboxylated to yield pyruvate and carbon dioxide by the action of malic enzyme, reducing NADP+.
- In plants that use aspartate as the carbon dioxide carrier, aspartate arriving in bundle-sheath cells is transaminated to form oxaloacetate and reduced to malate, then the carbon dioxide is released by malic enzyme or PEP carboxykinase.
- The free carbon dioxide released in the bundle sheath cells is the same carbon dioxide molecule originally fixed into oxaloacetate in the mesophyl cells.

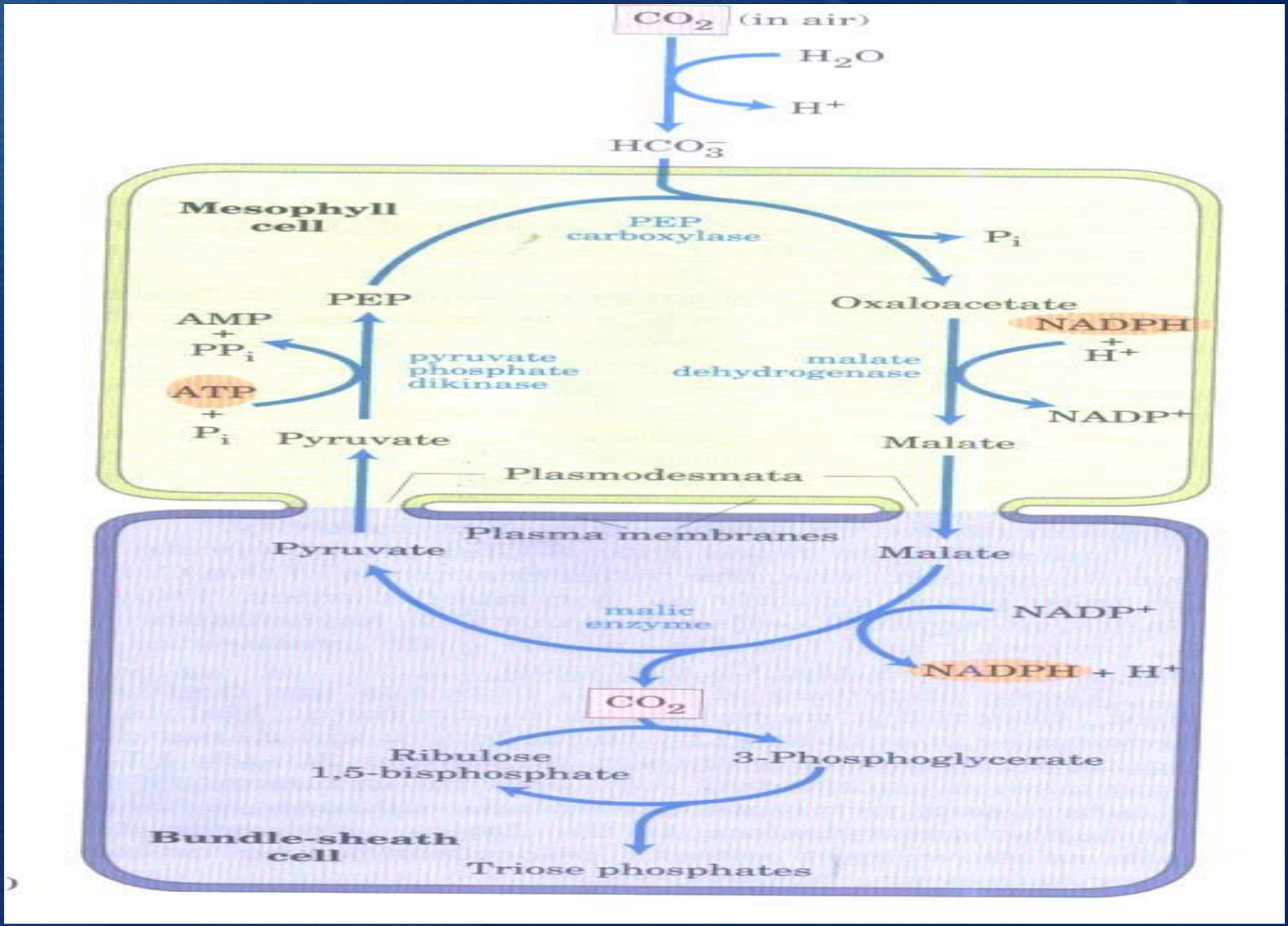
C-4 Pathway

- The carbon dioxide then enters the calvin cycle, with PEP returning to the mesophyll cell.
- The synthesize starch and sucrose by the C-3 pathway.
- The resulting sugars are now adjacent to the leaf veins and can readily be transported throghout the plant.

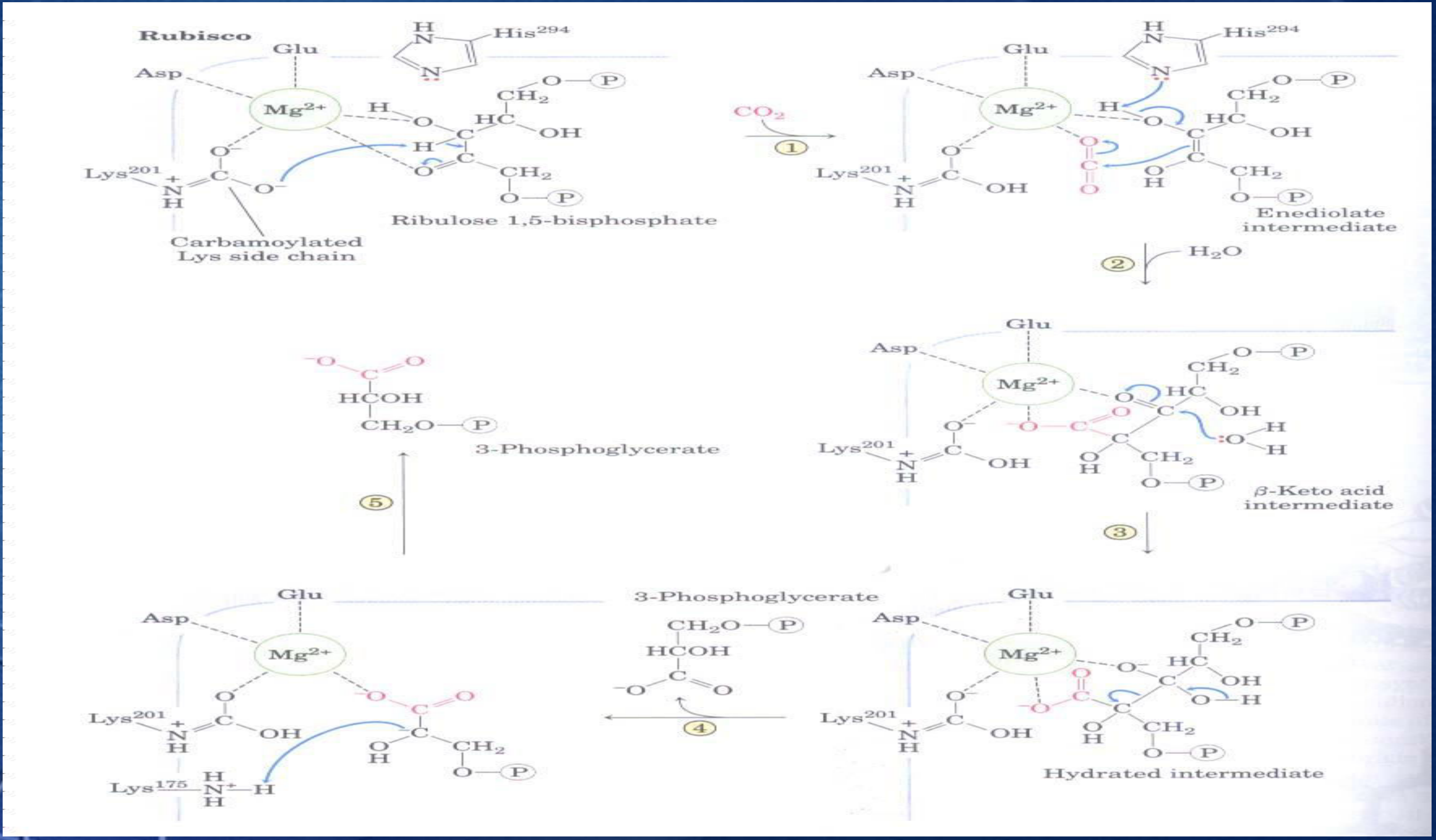
C-4 Pathway

- Picture 1.doc

Carbon Assimilation in C-4 Plants



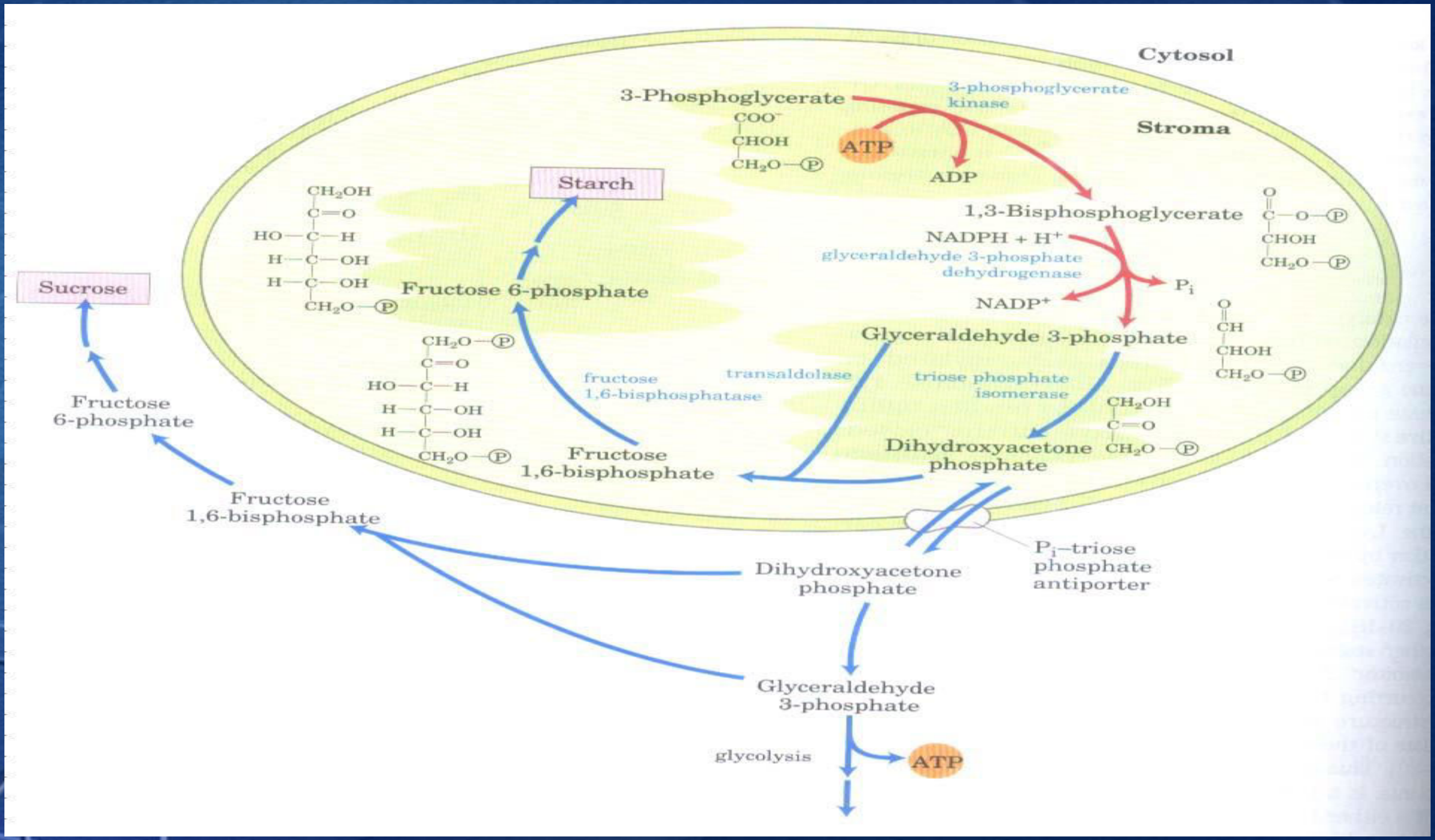
1st Stage of Carbon Dioxide Assimilation



1st Stage of Carbon Dioxide Assimilation

- The carbon dioxide fixation reaction is catalyzed by ribulose 1,5-biphosphate carboxylase/oxygenase (rubisco).
- Ribulose 1,5 bisphosphate forms an enediolate at the active site.
- The carbon dioxide, polarized by the proximity of the Mg2+ ion, undergoes nucleophilic attack by the enediolate, producing a branched six-carbon sugar.
- Hydroxylation at C-3 of this sugar, followed by aldol cleavage,
- Forms one molecule of 3-phosphoglycerate, which leaves the enzyme active site.
- The carbanion of the remaining 3-carbon fragment is protonated by the nearby side chain of Lys175, generating a second molecule of 3-phosphoglycerate.
- The overall reaction therefore accomplishes the combination of one carbon dioxide and one ribulose 1,5-bisphosphate to form two molecules of 3-phosphoglycerat, one of which contains the carbon atom from carbon dioxide.

2nd Stage of Carbon Dioxide Assimilation



2nd Stage of Carbon Dioxide Assimilation

- 3-phosphoglycerate is converted to glyceraldehyde 3-phosphate.
- A small fraction of the “extra” glyceraldehyde 3-phosphate may be used immediately as a source of energy, but most is converted to sucrose for transport or is stored in the chloroplast as starch.
- In the latter case, glyceraldehyde 3-phosphate condenses with dihydroxyacetone phosphate in the stroma to form fructose 1,6-bisphosphate, a precursor or starch.
- In other situations the glyceraldehyde 3-phosphate is converted to dihydroxyacetone phosphate, which leaves the chloroplast via a specific transporter and in the cytosol, can be degraded glycolytically to provide energy or used to form fructose 6-phosphate and hence sucrose.

PEP Carboxylase

- The PEP Carboxylase of mesophyll cells has a high affinity for HCO_3^- (can fix CO_2 more efficiently than can rubisco)
- Unlike rubisco, it does not use O_2 as an alternative substrate , so there is no competition between CO_2 and O_2

Photorespiration

- Picture 2.doc

The Differences Between C-3 and C-4

- The pathway of CO_2 assimilation has a greater energy cost in C-4 plants than in C-3 plants.
- For each molekul of CO_2 assimilated in the C-4 pathway, a molecule of PEP must be regenerated at the expense of two high energy phosphate groups of ATP. Thus C-4 plants need five ATP molecules to assimilate one molecule of , whereas C-3 plants need only three(nine per triose phosphate)
- C-4 plants can produce more sugar than C-3 plants in conditions of strong light and high temperature.
- C-4 plants outgrow most C-3 plants during the summer.

Anatomical differences between C3 and C4 leaves

- Picture 3.doc

CAM (*Crassulaceae* Acid Metabolism) PLANTS

- Plants which grow at the very hot and very dry environment, such as cactus and pineapple, have an other variation on photosynthetic carbon dioxide fixation.
- The plants reduces loss of water vapor throgh the pores (stomata) by which CO_2 and O_2 must enter the leaf tissue.
- Instead of separating the initial trapping of CO_2 and its fixation by rubisco across space (as do the C-4 plants), they separate these two events over time.

CAM (*Crassulaceae* Acid Metabolism) PLANTS

- At night, when the air is cooler and moister, the stomata open to allow entry of CO_2, which is then fixed into oxaloacetate by PEP carboxylase.
- The oxaloacetate reduced to malate and stored in the vacuoles, to protect cytosolic and plastic enzyme from the low pH produced by malic acid dissociation.

CAM (*Crassulaceae* Acid Metabolism) PLANTS

- During the day the stomata close, preventing the water loss that would result from high day time temperatures, and the CO_2 trapped overnight in malate is released as CO_2 by the NADP-linked malic enzyme.
- This CO_2 is now assimilated by the action of rubisco and the Calcin cycle enzymes.

Conclusion

- In C-4 plants, the carbon assimilation pathway minimizes photorespiration: CO_2 is first fixed in mesophyll cells into a four-carbon compound, which passes into bundle-sheath cells and releases CO_2 in high concentrations.
- The CO_2 is fixed by rubisco, and the remaining reactions of the Calvin cycle occur as in C-3 plants.
- In CAM plants, CO_2 is fixed into malate in the dark and stored in vacuoles until day light, when the stomata are closed (minimizing water loss) and malate serves as a source of CO_2 for rubisco.

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Thank You

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