C3 and C4 Pathways

C3 and C4 are photosynthetic pathways present in terrestrial plants. C3 plants use the C3 pathway or Calvin cycle, and C4 plants use the C4 pathway, or Hatch-Slack pathway, for the dark reaction of photosynthesis. Photosynthesis is the process in which different bacteria like cyanobacteria and eukaryotes like green plants, and algae can convert solar energy to chemical energy. In this process, solar energy is absorbed and used to synthesize carbohydrates from carbon dioxide and water.

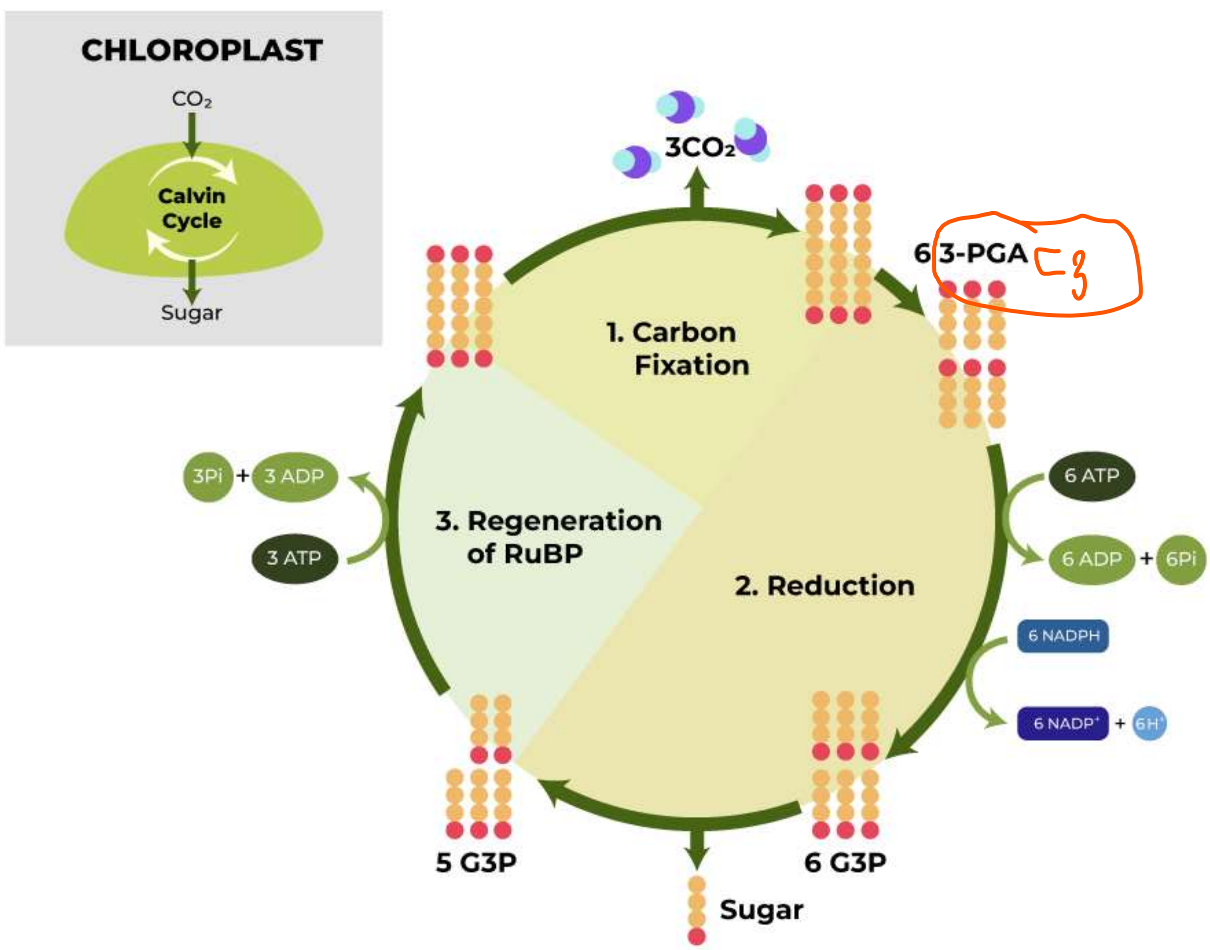
What are C3 and C4 Pathways?

C3 and C4 are photosynthetic processes found in terrestrial plants. The alternative pathway to the Calvin cycle is C4, and C3 is also referred to as the Calvin cycle. As the initial byproduct of carbon dioxide fixation, most plants generate 3-phosphoglyceric acid (PGA), a 3-carbon acid. This kind of process is referred to as the Calvin cycle or C3 pathway. A C4 plant begins the Calvin-Benson cycle of photosynthesis by fixing CO2 into a molecule with four carbon atoms. The Hatch-Slack route is another name for the C4 pathway.

C3 Pathway

C3 carbon fixation is one of the three metabolic pathways involved in carbon fixation in photosynthesis; the others are C4 and CAM. The plants that contain C3 photosynthesis are called C3 plants, and they include 95% of all plants on earth. Plants that exhibit this process depend on those areas where sunlight intensity is moderate, temperature is moderate, and CO_2 is around 200 ppm or higher.

- **Carboxylation**: In C3 fixation, ribulose 1,5-bisphosphate (RuBP) is carboxylated to form three-carbon compounds by activity of RuBisCO. Then, the CO_2 molecule condenses with RuBP to produce a transient six-carbon intermediate that hydrolyzes into two molecules of 3-phosphoglycerate (PGA).
- **Reduction:** PGA is the first stable compound to contain three carbon atoms; this process is called C3 fixation. This reaction leads to the regeneration of ribulose 1,5-bisphosphate with the net production of glyceraldehyde 3-phosphate for the synthesis of sucrose and starch. Three molecules of CO2 are fixed by RuBisCO to produce six molecules of PGA, which will give one molecule of glyceraldehyde 3-phosphate which is a triose phosphate.
- **Regeneration**: After forming six molecules of 3-phosphoglycerate, six ATPs and six NADPH are used to generate six molecules of glyceraldehyde 3-phosphate. Only one of these molecules of glyceraldehyde 3-phosphate is then used to form fructose 6-phosphate and starch. The other five molecules of glyceraldehyde 3-phosphate are converted in a series of steps to three molecules of ribulose 5-phosphate which are then phosphorylated using three molecules of ATP to form three molecules of ribulose 1,5-bisphosphate, for another cycle. After completion of one cycle, taking three molecules of CO2 as one molecule of glyceraldehyde 3-phosphate, requires **6+3=9 ATPs** and **6 NADPHs.**



C4 Pathway

The plants exhibiting the C4 pathway are called C4 plants and comprise 3% of flowering plants, which include maize, sorghum, sugarcane, and some other dicot plants. This pathway is also known as Hatch and Slack cycle because four carbon molecules (oxaloacetate) form as the first product of carbon fixation in plants. The C4 carbon fixation is evolved in such a way that it adapts to high light intensities, high temperatures, and dryness.

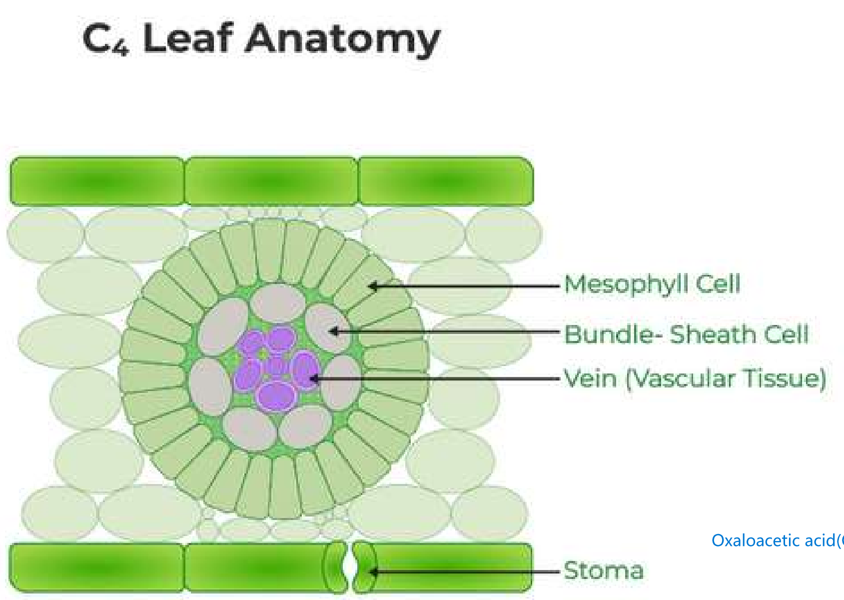
Photorespiration is not energy demanding, but leads to a net loss of CO_2. Plants have developed different ways to cope with this problem of photorespiration. C4 photosynthesis is one of the successful ways evolved by plants to reduce photorespiration. C4 plants use PEP carboxylase to capture CO_2 in the mesophyll cells. Instead of using CO_2 in mesophyll cells, PEP carboxylase utilizes bicarbonate.

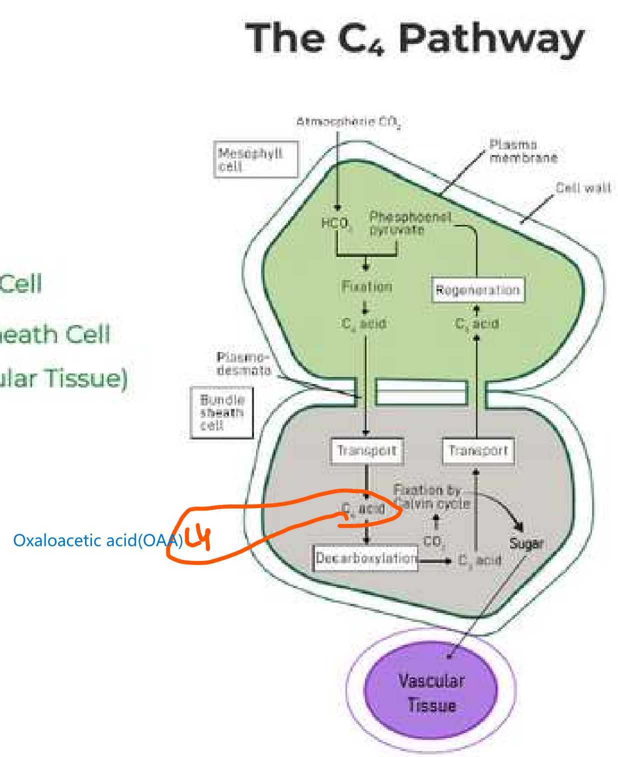
In Mesophyll Cell

- The CO_2 entering the mesophyll cells from the atmosphere will be converted to bicarbonate by hydrating CO_2 using carbonic anhydrase. This bicarbonate will bind with **Phosphoenol Pyruvate** (PEP) in presence of PEP carboxylase to form oxaloacetate.
- Oxaloacetate is the first stable compound having four carbons, so the pathway is C4 pathway. Then OAA is reduced to malate or aspartate which are four carbon compounds.

In Bundle Sheath Cell

- The malate/**aspartate** enters bundle sheath cells and releases CO_2 inside bundle sheath through decarboxylation.
- The released CO_2 is immediately fixed by RuBisCO which will be followed by a normal Calvin cycle.
- The remaining 3 carbon compounds Pyruvate formed after decarboxylation of malate will return to the mesophyll cell for next C4 cycle using energy in the form of ATP.
- Photorespiration is a major problem for plants in hot climates as it consumes O_2 and releases CO_2. During hot conditions, the plants close the **stomata** to conserve water but this leads to a drop in the CO_2 concentration within the leaf, favoring photorespiration.

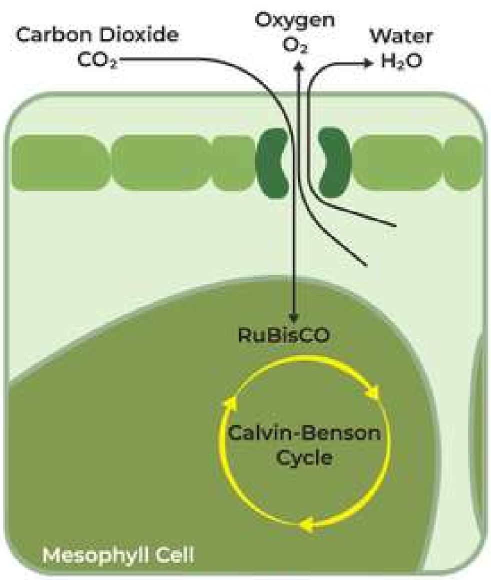




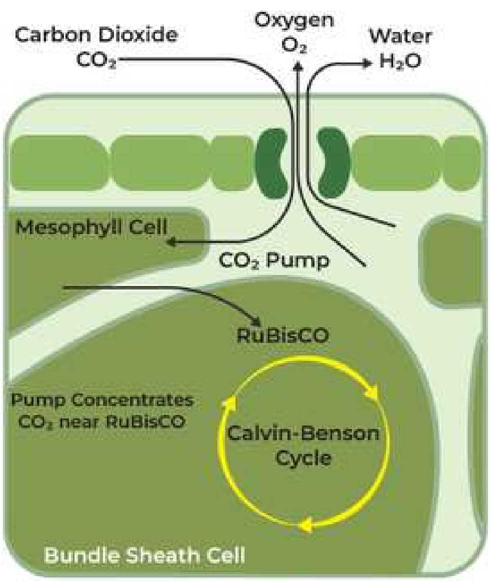
Difference Between C3 and C4 Pathway

The differences between C3 and C4 Pathways are stated below:

C3 Pathway	C4 Pathway
Found in all the plants containing three- carbon compound their first stable compound.	Found in only C4 plants with four-carbon compound as their first stable compound.
Primary carbon dioxide acceptor is a five carbon compound i.e. Ribulose bisphosphate	Primary carbon dioxide acceptor is a three carbon compound i.e. phosphoenol pyruvic acid.
Single carbon fixation occurs.	Double carbon fixation occurs.
Require 3 ATP and 2 NADH	Require 5 ATP and 3 NADH
Carried out by mesophyll cells	Carried out by mesophyll cells and bundle sheath cells.
Oats, Rice, Wheat, sugar beets and spinach are some examples of C3 Pathways.	Sugarcane, sorghum and maize are some examples of C4 pathways.



C_3 Plant
Example: Elm



C_4 Plant
Example: Corn

Conclusion - C3 and C4 Pathways

Most of the plants show the C3 mechanism for carbon fixation during photosynthesis. However, one of the important enzymes involved in carbon fixation **RuBisCO** has both carboxylase and oxygenase activity. And during certain conditions, instead of acting as carboxylase, RuBisCO acts as oxygenase leading to photorespirations that will result in loss of huge energy. To avoid additional loss of energy through photorespiration, plants have evolved a C4 mechanism which will avoid the losses during photosynthesis. Although C3 plants are more common in nature than C4 plants, C4 plants are found to have more photosynthetic activity due to more efficient use of CO2 and light. Understanding the mechanisms of C3 and C4 mechanisms will help in the increase in productivity of plants.