Photorespiration

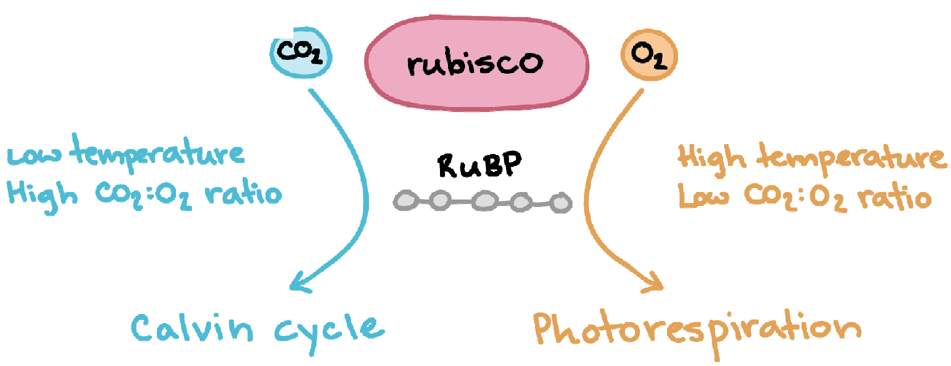
Photorespiration is a wasteful pathway that competes with the Calvin cycle. It begins when rubisco acts on oxygen instead of carbon dioxide.

RuBP oxygenase-carboxylase (**rubisco**), a key enzyme in photosynthesis. In the process of **carbon fixation**, rubisco incorporates carbon dioxide into an organic molecule during the first stage of the Calvin cycle. Rubisco is so important to plants that it makes upto 30% percent or more of the soluble protein in a typical plant leaf. But rubisco also has a major flaw: instead of always using CO_2 as a substrate, it sometimes picks up O_2 instead.

This side reaction initiates a pathway called **photorespiration**, which, rather than fixing carbon, actually leads to the loss of already-fixed carbon as CO_2. Photorespiration wastes energy and decreases sugar synthesis, so when rubisco initiates this pathway, it's committing a serious molecular mess.

Rubisco binds to either CO_2 or O_2

As we know, the enzyme rubisco can use either CO_2 or O_2 as a substrate. Rubisco adds whichever molecule it binds to a five-carbon compound called ribulose-1,5-bisphosphate (RuBP). The reaction that uses CO_2 is the first step of the Calvin cycle and leads to the production of sugar. The reaction that uses O_2 is the first step of the photorespiration pathway, which wastes energy and "undoes" the work of the Calvin cycle.



When a plant has its stomata, or leaf pores, open CO_2 diffuses in, O_2 and water vapor diffuse out, and photorespiration is minimized. However, when a plant closes its stomata—for instance, to reduce water loss by evaporation O_2 from photosynthesis builds up inside the leaf. Under these conditions, photorespiration increases due to the higher ratio of O_2 to CO_2.

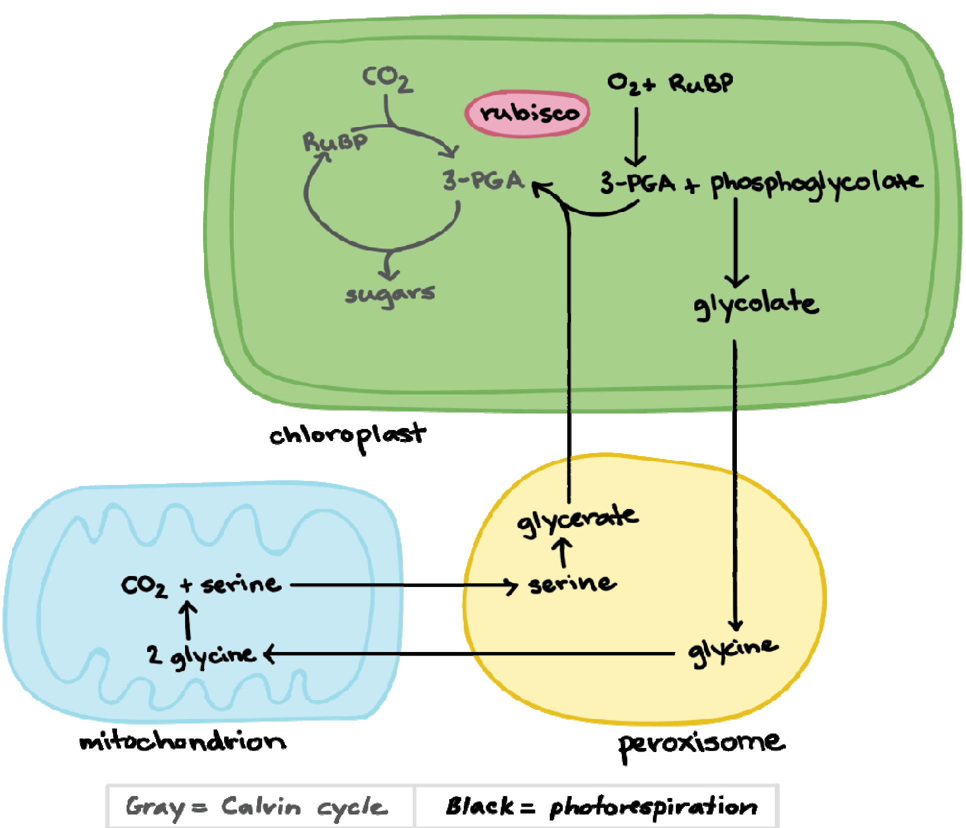
In addition, Rubisco has a higher affinity for O_2 when temperatures increase. At mild temperatures, rubisco's affinity for (tendency to bind to) CO_2 is about 80 times higher than its affinity for O_2. At high temperatures, however, rubisco is less able to tell the molecules apart and grabs oxygen more often.

The bottom line is that hot, dry conditions tend to cause more photorespiration—unless plants have special features to minimize the problem as in C4 plants and CAM plants.

Photorespiration wastes energy and steals carbon

Photorespiration begins in the chloroplast, when rubisco attaches O_2 to RuBP in its oxygenase reaction. Two molecules are produced: a three-carbon compound, 3-PGA, and a two-carbon compound, phosphoglycolate. 3-PGA is a normal intermediate of the Calvin cycle, but phosphoglycolate cannot enter the cycle, so its two carbons are removed, or "stolen," from the cycle.

To recover some of the lost carbon, plants put phosphoglycolate through a series of reactions that involve transport between various organelles. Three-fourths of the carbon that enters this pathway as phosphoglycolate is recovered, while one-fourth is lost as CO_2.

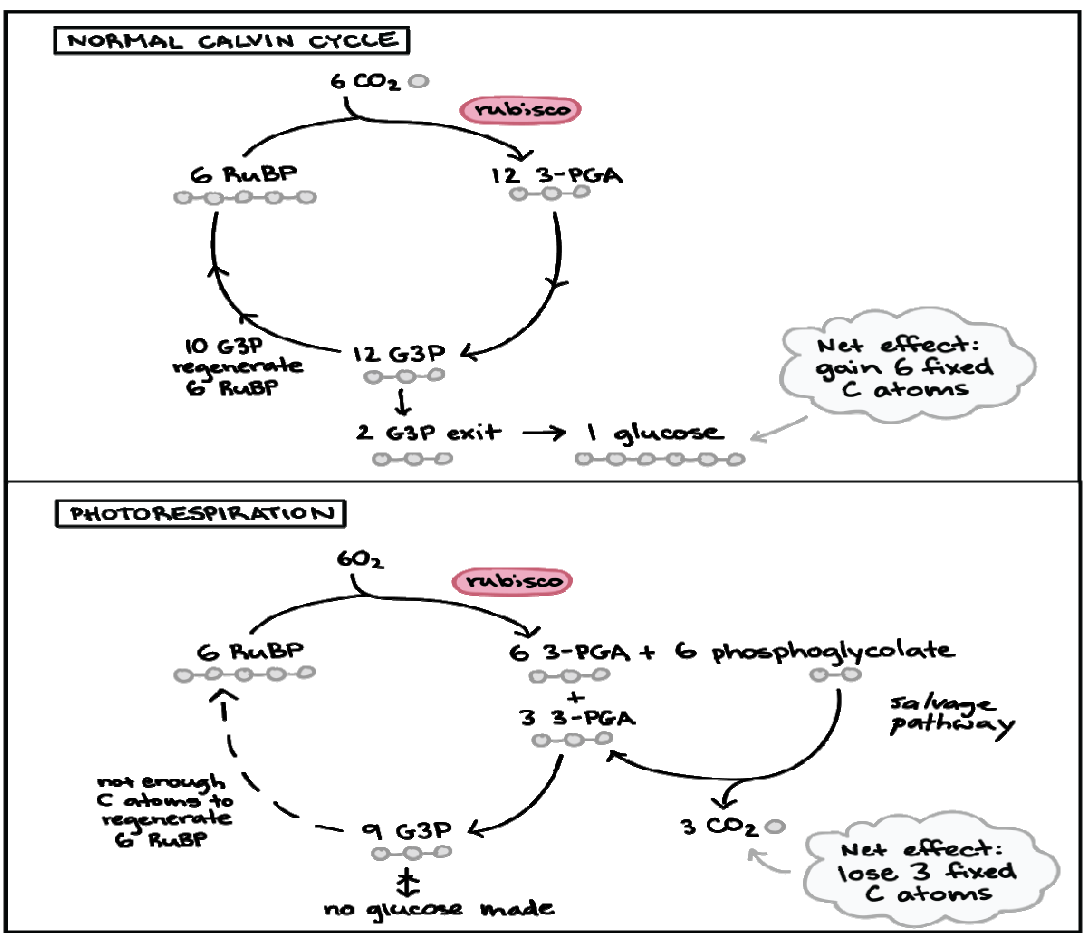


How does the photorespiration pathway actually work?

To answer this question, let's follow the path of phosphoglycolate, starting when it's just been made in the chloroplast via rubisco's oxygenase reaction.

- Phosphoglycolate is first converted to glycolate inside of the chloroplast. Glycolate then travels to the peroxisome, where it's converted to the amino acid glycine.
- Glycine travels from the peroxisome to a mitochondrion. There, two glycine molecules (e.g., from two iterations of the pathway) are converted to serine, a three-carbon amino acid. This releases one CO_2 molecule.
- Serine returns to the peroxisome, where it's converted to glycerate. In the chloroplast, glycerate is turned into 3-PGA and can thus enter the Calvin cycle.

In the diagram below, you can see a comparison between photorespiration and the normal Calvin cycle, showing how many fixed carbons are gained or lost when either 6 CO_2 or 6 O_2 molecules are captured by rubisco. Photorespiration results in a loss of 3 fixed carbon atoms under these conditions, while the Calvin cycle results in a gain of 6 fixed carbon atoms.



Conclusion

Photorespiration is definitely not a win from a carbon fixation standpoint. However, it may have other benefits for plants. There's some evidence that photorespiration can have photoprotective effects (preventing light-induced damage to the molecules involved in photosynthesis), help maintain redox balance in cells, and support plant immune defenses.