Fixing photosynthesis by engineering it to recycle a toxic mistake



Enlarge / A scientist transplants engineered tobacco for testing.

reader comments

244 with 115 posters participating

Share this story

The vast majority of life on Earth depends, either directly or indirectly, on photosynthesis for its energy. And photosynthesis depends on an enzyme called RuBisCO, which uses carbon dioxide from the atmosphere to build sugars. So, by extension, RuBisCO may be the most important catalyst on the planet.

Unfortunately, RuBisCO is, well, terrible at its job. It might not be obvious based on the plant growth around us, but the enzyme is not especially efficient at catalyzing the carbon dioxide reaction. And, worse still, it often uses oxygen instead. This produces a useless byproduct that, if allowed to build up, will eventually shut down photosynthesis entirely. It's estimated that crops such as wheat and rice lose anywhere from 20 to 50 percent of their growth potential due to this byproduct.

While plants have evolved ways of dealing with this byproduct, they're not especially efficient. So a group of researchers at the University of Illinois, Urbana decided to step in and engineer a better way. The result? In field tests, the engineered plants grew up to 40 percent more mass than ones that relied on the normal pathways.

Oops, wrong chemical

The key reaction catalyzed by RuBisCo can be simplified down to the following: it takes a five-carbon sugar and carbon dioxide, and it converts them to two three-carbon sugars. While this process doesn't sound very exciting, it is basically pulling carbon dioxide out of the air and converting it into a form that the cell's metabolism can work with. It's relatively simple, for example, to start with the three-carbon sugar and a two-carbon chemical that's present in all cells and then rebuild the five-carbon sugar that started the process. Other pathways branch off to make six-carbon sugars, amino acids, and the building blocks of DNA.

Life's phenomenal success indicates that RuBisCo works, but it could clearly do better. In terms of converting incoming light to usable energy, your average leaf is crushed by a solar panel. At least part of the problem is RuBisCo's tendency to use a molecule of oxygen rather than carbon dioxide, which results in the formation of a toxic two-carbon acid.

Plants can deal with this problematic byproduct by converting it into a related chemical that can be shunted into a different metabolic pathway. But their method of dealing with it involves *nine* catalytic steps, and the enzymes responsible for them are spread over three different compartments in the cell. This is not exactly a recipe for efficiency, and about a quarter of the carbon that goes through it ends up metabolized into carbon dioxide—the material the cell was trying to use in the first place.

Can we do better?

A number of researchers have come up with ideas for how to do better than the system that evolution left plants with. A variety of organisms metabolize these chemicals in different ways, and it's possible to mix and match enzymes to push the toxic chemical into a different pathway than the one plants normally use. The researchers tried two pathways that had been suggested by earlier research. One involved five genes taken from bacteria, while a second mixed and matched genes from pumpkin, *Arabidopsis* and *E. coli*.

The researchers also came up with a third simplified pathway of their own that involved two genes: one from the pumpkin and the second from a single-celled alga. Combined, the products of the two genes converted the toxic chemical into a compound called malate, which is used in a variety of biochemical pathways.

The simplified pathway avoided some of the problems with the two earlier efforts. Unlike the first pathway, both of the genes could be active in the chloroplast, the site where photosynthesis takes place. It also avoided the production of hydrogen peroxide, which is a byproduct of one of the reactions in the second pathway. To enhance things further, they also lowered the activity of a protein that normally transports the small, toxic byproduct out of the chloroplast,

where photosynthesis takes place. The reasoning here is that they would trap it in the same compartment as the enzymes that acted on it, and the efficiency would go up.

Field testing

All three of the pathways were engineered into tobacco plants, which are easy to work with and produce lots of seeds to scale up testing quickly. In the greenhouse, the second pathway ended up not having any effect. But the first boosted the plants' productivity by a bit over 10 percent, based on the dry mass of the plants compared to unengineered tobacco. But the pathway the researchers designed boosted productivity by 25 percent, with about 5 percent of that coming from knocking down the transporter gene. This productivity boost was associated with an increased rate of photosynthesis, as you'd expect.

That was enough to convince the researchers to take the engineered plants out of the greenhouse and into a field. The same general pattern held up. The two pathways that had been suggested earlier boosted productivity of the tobacco by about 10 to 15 percent. But the new pathway that had been devised caused biomass to increase by over 20 percent and, in some cases, over 40 percent.

Overall, the boost for individual leaves was pretty small, typically in the area of 5 to 8 percent. But the researchers liken the effect to compound interest: the small boosts in biomass allow the production of more leaves, which all operate with slightly increased efficiency, gradually leading to larger and larger effects.

Why so efficient?

If this is such a useful pathway and at least one of the genes was already around in pumpkins, why don't plants already have

this in place? Part of it could simply be the luck of history; for whatever reasons, chance never favored the right genes coming together for evolution to do its thing. But energetic considerations might play a role, as the researchers indicate the pathway currently used by these plants should burn through less of the ATP that cells use to power most basic functions. That may be a significant consideration on evolutionary time scales in a natural environment.

But our crops certainly don't operate in a natural environment. Rather than being selected in competition with plants and herbivores, our crops are simply selected for efficiently converting water and fertilizers into edible biomass.

The key part of that phrase is "edible." The product of tobacco is the plant itself, and we already grow far more of it than we should based on human health considerations. To be really useful, the biomass increase has to work in crops like rice and wheat, and at least some of that increase has to go into the seeds that we end up eating. So, obviously, we need to wait to see what happens when the same approach is tried on a food crop.

But if the new pathway has anywhere near the effect that it does in tobacco, then it's going to be a hugely useful innovation, and farmers would find resisting that sort of enhanced productivity difficult. Which, given the ongoing public mistrust of GMO foods, could put public tastes and societal needs on a collision course, with science stuck in the middle.

Science, 2019. DOI: 10.1126/science.aat9077 (About DOIs).

https://arstechnica.com/?p=1435811