USDA

A Missouri farmer with rice plants. More CO_2 would increase rice productivity.

C4 vs. C3 Photosynthesis: A Response to Low CO_2 Levels

by Christine Craig

About 90 percent of land plants, including both monocots and dicots, are equipped to photosynthesize only through the C3 photosynthetic pathway. Chloroplasts of only one type of plant cell, the mesophyll cell, are primarily involved in photosynthetic light capture and CO_2 assimilation into 3-carbon carbohydrates, which are then used to manufacture plant structural and functional elements.

The problem with this situation, as far as human food production is concerned, is that, "under current atmospheric conditions (0.036% CO_2, 21% O_2), up to 50% of the fixed carbon is lost by photorespiration"[1] in such plants.

Why? The enzyme which catalyzes the primary CO_2 fixation reaction in mesophyll chloroplasts, Rubisco, is sensitive to CO_2 concentration. Under low CO_2 conditions, it will bind with oxygen instead, essentially, breaking down carbohydrate and releasing CO_2, in a process known as photorespiration. This is considered very wasteful to plant productivity.

C4-type photosynthesis apparently evolved at various times, in various plant groups, as a mechanism of concentrating CO_2 in the cells where CO_2 fixation is occurring. In monocots such as maize and sorghum, this is accomplished by a division of labor between two cell types: CO_2 is brought into mesophyll cells, chemically joined to a three-carbon molecule to make a four-carbon molecule, and shunted to the bundle sheath cell, where it is cleaved off and made available to the Rubisco-catalyzed C3 photosynthetic cycle.

The 3-carbon molecule resulting from the CO_2 removal in the bundle sheath cell is shunted back to the mesophyll cell for reuse, and two ATP are used up in the process. Therefore, C4 photosynthetic pathways are reactions in addition to C3 pathways, with a division of labor set up between bundle sheath cells, where photosynthetic carbon assimilation occurs, and mesophyll cells, which house the mechanisms for bringing CO_2 into the cell and temporarily adding it to a 3-carbon molecule for later use by Rubisco. So, both enzymatic and anatomical changes are part of the evolutionary developments which have allowed plants like maize to get around the problem of photorespiration under low CO_2 conditions.

Higher CO_2 Would Boost Rice

C4 plants function well in high-light, high-heat conditions as in the tropics, whereas C3 plants do best in lower light, more temperate conditions. The problem for crop scientists is, that one of the main food crops in tropical climates is rice, a C3 monocot. Under present atmospheric conditions, rice is not nearly as productive as it would be under higher CO_2 concentrations. Until—or unless—that situation occurs, scientists are in a bind

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(2) that mathematics cannot be separated from a general understanding of nature,

(3) that political action is coexistent with all the rest. . . .

It's not easy for a scientist to crawl against the current. Even if modern science is full of so-called accepted "paradoxes," it's not a good basis for reflection.

It's necessary, as you do, to return to older conflicts, an idea out-of-fashion, except perhaps recently. (As I must go frequently to an university hospital, I went to the library there, only to find that all books older than 10 years are thrown away!)

We must not accept "technical" truth, reread critically even Cauchy, and accept that morals may be a key of mathematics!

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Brussels, Belgium

Correction

A box titled "Thorium Converter Reactor Ready for Development," on p. 49 of the Fall 2005 *21st Century* erroneously states that Tak Pui Lou, Ph.D., of Lawrence Berkeley National Laboratory, is a co-owner of the company Thorenco LLC. He is not, and we regret the error.

C_4 vs. C_3 Photosyhthesis

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as far as boosting rice productivity to keep pace with population growth and land loss to non-agricultural uses.

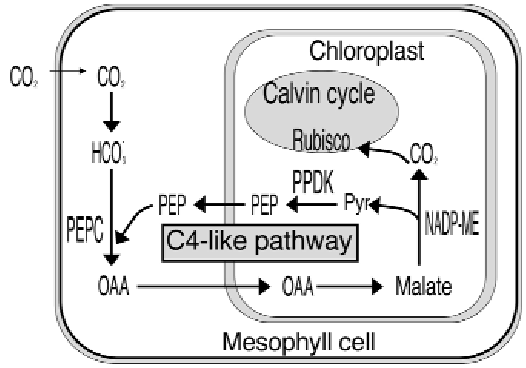
One of the most promising approaches to give a large boost to productivity of rice, would be the successful incorporation of CO_2-concentrating C4 photosynthetic pathways into the rice plants by genetic engineering techniques.

Many scientists are looking at ways to do this, and some progress has occurred with the overexpression of C4 enzymes in C3 plants, but the ultimate goal—significantly boosting photosynthetic efficiency—has not yet been reached. The main problem lies in the anatomical arrangement of C4 plants.

As mentioned earlier, almost all C4 plants break up photosynthetic activity into two cell types, with CO_2 concentration occurring in a different cell than CO_2 uptake. A few C4 plants with just one cell type have elongated cells with one end facing outward and the other to the center of the plant, allowing another sort of separation in space. C3 plants as a rule do not have those qualities of structural complexity.

Whether C4 genes in C3 rice will successfully boost productivity remains to be seen. Perhaps the easier route would be to tinker with the Rubisco protein to shift its affinity for CO_2 vs. O_2 so the CO_2 assimilation reaction drives forward more efficiently under present levels of CO_2, but that also has proved hard to achieve so far.

A MODEL FOR INCREASING THE CO_2 AVAILABLE FOR C3 RICE



Scientists at the National Institute of Agrobiological Sciences (NIAS) of Japan are inserting genes that code for C4 photosynthetic enzymes (PEPC, PPDK, and NADP-ME) into rice, in an attempt to create a functional C4-like pathway to move CO_2 into the mesophyll cell, and incorporate it into the three-carbon molecule phosphoenolpyruvate (PEP) to make the four-carbon oxaloacetate. That would then be shuttled into the chloroplast, where it would be transformed and ultimately cleaved back into PEP by way of pyruvate, releasing CO_2 to be utilized by Rubisco in the C3 photosynthetic cycle, the Calvin cycle. This diagram is adapted from a NIAS schematic.

Notes

1. Mitsue Miyao, 2003. *Journal of Experimental Botany*, Vol. 54, No. 381, pp. 179-189.