C_4 photosynthesis —evolution or design?

Don Batten

Life depends on photosynthesis, where plants take carbon dioxide from the atmosphere and 'fix' it into high-energy sugars using light as the energy source. Two basic forms of photosynthesis have been discovered. In one, the first compound made from CO_2 is a three-carbon compound, so this is called C_3 photosynthesis. In the other, the first compound is a four-carbon compound, so it is called C_4 photosynthesis.[1] Most plants are C_3; about 15% of species have the C_4 system. Examples of C_3 plants include wheat, rice, potatoes and cabbage. C_4 plants include maize, sugar cane, sorghum and succulents—mainly tropical/arid environment species.

C_4 and C_3 plants differ in their leaf anatomy and where photosynthesis occurs. C_3 plants have chloroplasts throughout the internal ('mesophyll') leaf cells, and there are air spaces around the cells to allow ready diffusion of CO_2 into them. In C_4 plants, the photosynthetic cells cluster around the vascular bundles (leaf veins) and there are no air spaces around the photosynthetic cells. The photosynthetic cells are called *bundle sheath cells* because they form a tight sheath around the vascular bundles.

C_3 and C_4 plants share the same light-harvesting systems, as well as the same enzyme cycle for incorporating the carbon into sugars—the Calvin-Benson cycle. The first enzyme in this cycle, nicknamed 'Rubisco', makes up 25% of the protein in leaves, which makes it the most abundant protein on Earth. Rubisco takes CO_2 and adds it to a 5-carbon sugar, making two 3-carbon sugar molecules.

C_4 plants have extra enzymes operating in the leaf. These incorporate the CO_2 (actually bicarbonate, HCO_3^-) into a 4-carbon compound (usually malate), which the mesophyll cells transport into the bundle sheath cells via many tiny tubes called plasmodesmata. Here another enzyme releases the CO_2 for Rubisco to fix into sugars in the same manner as in C_3 plants. The bundle sheath cells have specialized thickened cell walls and they have no air spaces around them, so the CO_2 cannot escape and it becomes concentrated to at least 10 times that of normal outside air. This accounts for one of the major differences between C_3 and C_4 plants: in the short term, C_3 plants increase their rate of photosynthesis in response to increased atmospheric levels of CO_2, but C_4 plants don't.

C_3 and C_4 plants also differ in that C_3 plants exhibit 'photorespiration', where they lose some of the CO_2 fixed into 3-carbon sugar, whereas C_4 plants don't. This happens because O_2 competes for the active site on Rubisco to which CO_2 binds. While Rubisco has a much greater affinity for CO_2, the partial pressure of O_2 in air is 700 times greater than that of CO_2. Oxygen drives the release of CO_2 with the production of the energy-depleted forms of energy-carrier molecules (ADP and NADP).
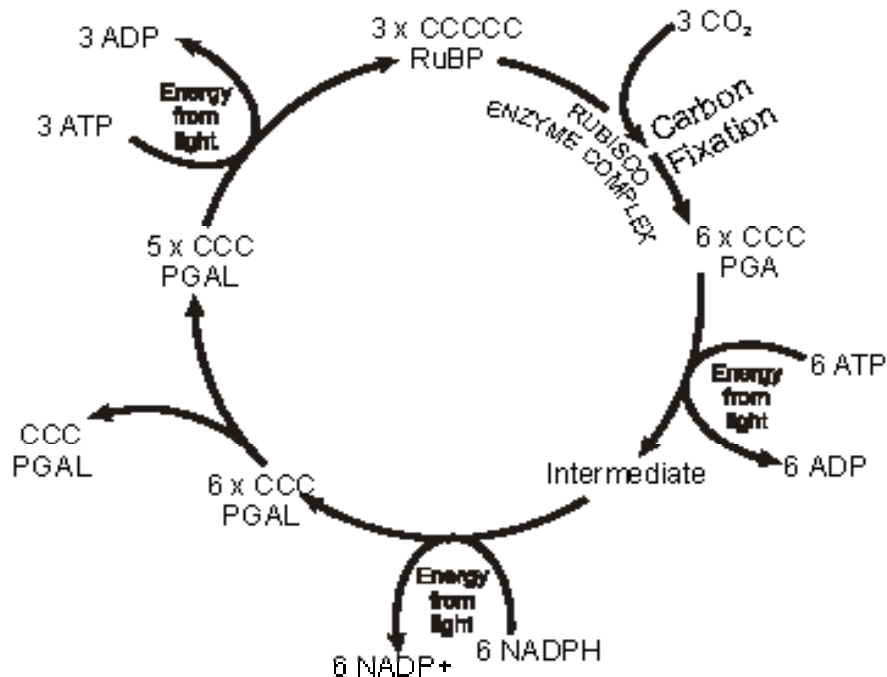
This seems to be a safety mechanism to avoid damage to the photosynthesis system at low CO_2 levels. If there is inadequate CO_2 to fix the energy harvested by the chlorophyll system, then oxygen radicals form and these damage the light harvesting system. Photorespiration maintains a supply of ADP and NADP to accept the energy generated by the light-harvesting system.
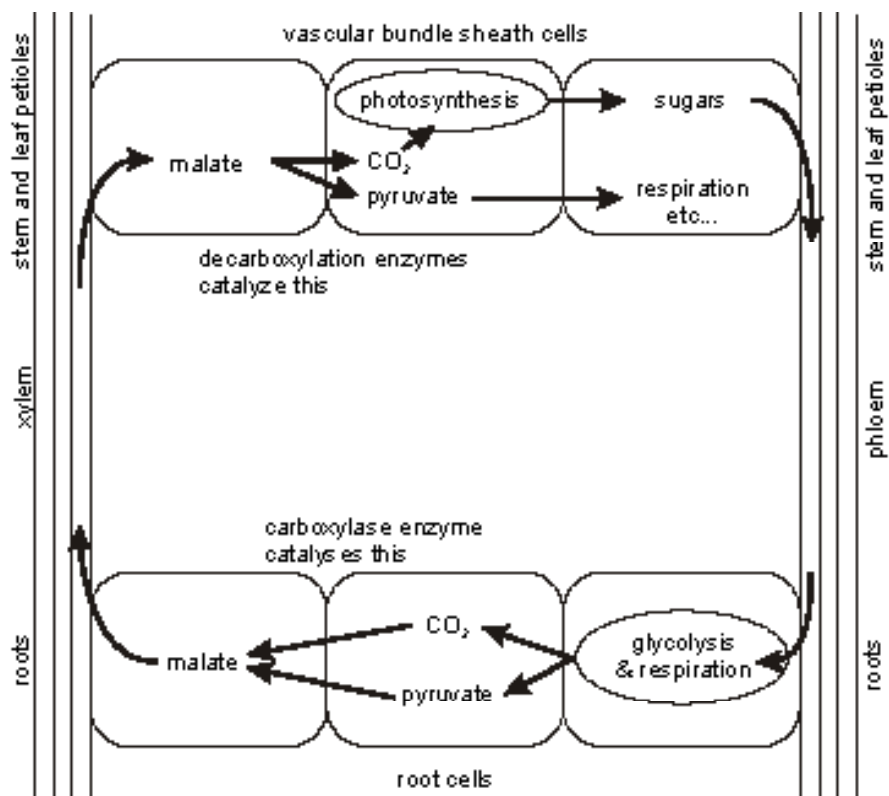
C_4 plants concentrate their CO_2, thus suppressing photorespiration. Also, since the supply of CO_2 is maintained, even at low concentrations, there is always a sink for the energy from the light harvesting, and damage to the photosystems is avoided. So there is no need for photorespiration.

Why two methods of fixing CO_2?

Why do C_3 plants tend to be temperate in their adaptation and C_4 plants tropical/arid? The rate of photorespiration rises rapidly with temperature, so it becomes a much more serious problem, in terms of its 'inefficiency' (loss of fixed carbon), in the tropics. On the other hand, the C_4 system has energy costs: each CO_2 fixed into ma-

The Calvin-Benson Cycle of photosynthesis. Each turn of the cycle produces a molecule of phosphoglyceraldehyde 'PGAL', (containing 3 carbon atoms). This is transported from the chloroplast to make glucose and fructose, which in turn condense to form sucrose.

Diagrammatic representation of the Hatch-Slack system of CO_2 capture and fixation that operates in the roots and stems of C_3 plants, which were thought to lack this capacity entirely. (Xylem and phloem are actually in vascular bundles together; not separated as in the diagram.)

late needs one NADPH and one ATP for the complete cycle. So the relative advantages seem to be due to the trade-off between photorespiration in C_3 plants and the extra costs of carbon fixation in C_4 plants. With increasing temperatures, the cost of photorespiration becomes greater than the extra cost of the C_4 system, which is met by the increased sunlight energy anyway, and so the latter prevails.

C_4 plants also do well in arid environments. In this situation the plant closes its stomata (leaf pores) to conserve water. This also reduces the amount of CO_2 entering the leaf and raises the leaf temperature. The enzyme that fixes CO_2 in C_4 plants has a much greater affinity for CO_2 than Rubisco, which does the job alone in C_3 plants. So C_4 plants are still able to supply plenty of CO_2 to the Rubisco in the photosynthetic cells, whereas a C_3 plant would have trouble.[2]

The origins of the C_4 system

Some 8,000 to 10,000 species of plants in 18 families, including both monocots (which includes grasses) and dicots (roughly, 'broad-leaved' plants), have the C_4 system. C_4 metabolism has even been found in a single-celled marine diatom.[3]

Many flowering plant families have both C_3 and C_4 species. Some species are intermediate, showing both C_3 and C_4 characteristics. In the *Atriplex* genus, some species are C_3, while others are C_4, and C_3 and C_4 species have been hybridized.[4] Wood and Cavanaugh have reviewed the genus *Flaveria*, which has species of C_3, C_4 and intermediate type, many of which hybridize.[5]

The distribution of C_4 species does not form any pattern that could relate to any reasonable evolutionary phylogeny. Consequently, evolutionists have proposed that C_4 photosynthesis has arisen independently at least 30

times—a classic case of 'polyphyletic evolution'.

However, C_4 chemistry involves several complex enzyme systems, and the chemistry is remarkably consistent across the spectrum (there are three types of enzyme used to release the CO_2 from the organic acid that transports the CO_2, otherwise the chemistry is similar).

To believe that C_4 chemistry arose once by natural processes would require super 'faith' for the evolutionist. But to propose that such a system with its new complex coded genetic information arose separately some 30 times by mutations and natural selection, and that these processes arrived at essentially the same solution, stretches credulity to breaking point. This would be an extreme example of 'convergent evolution'—even more than the supposed polyphyletic origin of the eye in general, and the compound eye in particular.[6]

Some species that exhibit both C_3 and C_4 forms are even able to switch from one to the other during development. This suggests that maybe the C_4 chemistry is latent in C_3 plants, or is suppressed by some means. In the marine diatom mentioned above, C_4 metabolism seems to be facultative.[3]

Wood and Cavanaugh[5] concluded from their baraminological study of *Flaveria* that the C_4 photosynthetic pathway arose from plants that were originally C_3, and this probably happened post-Flood. These authors propose that the genetic information for C_4-mode photosynthesis was present in the original created kinds, but has become activated since.

Surprise: C_3 plants have the C_4 system!

Now Hibberd and Quick have shown that tobacco and celery, two classical C_3 plants, contain virtually all the C_4 characteristics, not in their leaves, but in their roots, stems and petioles.[7] They showed that CO_2 respired in the roots is fixed into malate by the same enzyme that fixes CO_2 in the leaves of C_4 plants. The malate

moves in the xylem stream up the plant where it transfers into bundle sheath cells surrounding the vascular bundles in the stems and petioles. Here all three decarboxylation (CO_2-releasing) enzymes identified in the three sub-types of the C_4 system are present in elevated levels. They release the CO_2 so that Rubisco can use it in the Calvin cycle. The chemistry is apparently identical to the C_4 system. These plants differ from C_4 plants only in the site of synthesis of the malate (roots in C_3 plants versus leaf mesophyll cells in C_4 plants) and its transfer to the bundle sheath cells. Even the anatomy of the bundle sheath cells in the stems and petioles is similar.

This makes for a very efficient system for retrieving respired carbon from the roots. Indeed, CO_2 may even enter the roots from the soil, where the level of CO_2 is usually quite high due to the activity of heterotrophic micro-organisms. This would reduce the CO_2 concentration in the soil, which would be beneficial to the aerobic organisms living there. What wonderful design for an efficient ecology!

Hibberd and Quick point out that since so much of the C_4 system is already present in the C_3 plants, 'fewer modifications are needed for C_4 photosynthesis to evolve'. Indeed, are we talking about the origin of *new* complex, coded genetic information at all, or are we looking at adaptation based on *existing* genetic information—as proposed by the creationists Wood and Cavanaugh?

It now seems that the genes for C_4 enzymes and anatomy are selectively expressed in the roots, stems and petioles of C_3 plants, but are suppressed in the leaves. C_4 plants differ in having these genes expressed in the leaves as well. If the suppression in the leaves of C_3 plants were due to the synthesis of proteins that interact with promoter sequences, for example, it may even be possible to see mutations in the genes for these proteins that result in the expression of C_3–C_4 or C_4 photosynthesis. Or there might be some designed means of switching on this adaptation genetically so that it is inherited once switched on—something like Wood's Altruistic Genetic Elements (AGEs)?[5]

These developments underline just how cleverly the original plants were created—with built-in latent capacity for adaptation to a wide range of environments. It will be interesting to see the details fleshed out.

References

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2. A variation on the C_4 theme is seen in CAM (crassulacean acid metabolism) plants. Typically succulent desert plants, they open their stomata at night to fix CO_2, storing the fixed form in vacuoles (reservoirs within cells), and then releasing the CO_2 for photosynthesis during the day when the stomata shut. In this manner they conserve water very efficiently.

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5. Wood, T.C. and Cavanaugh, D.P., A baraminological analysis of subtribe Flaverinae (Asteraceae: Helenieae) and the origin of biological complexity, *Origins (GRI)* **52**:7–27, 2001.

6. Oakley, T.H. and Cunningham, C.W., Molecular phylogenetic evidence for the independent evolutionary origin of an arthropod compound eye, *Proc. Nat. Acad. Sci. USA* **99**(3):1426–1430, 2002. Their abstract says, 'These results illustrate exactly why arthropod compound eye evolution has remained controversial, because one of two seemingly very unlikely evolutionary histories must be true. Either compound eyes with detailed similarities evolved multiple times in different arthropod groups or compound eyes have been lost in a seemingly inordinate number of arthropod lineages.'

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The short-period comets 'problem' (for evolutionists): Have recent 'Kuiper Belt' discoveries solved the evolutionary/long-age dilemma?

Robert Newton

Recently, astronomers have discovered that several KBOs ('Kuiper Belt Objects') are binary—they consist of two co-orbiting masses. What are the implications for Creation?

Comets—icy masses that orbit the sun in elliptical paths—are one of many evidences that the solar system is much younger than billions of years. Every time a comet passes near the sun, it loses some of its icy material to evaporation. This stream of lost material is what gives rise to the characteristic comet tail. A comet can only survive a certain number of orbits before it runs out of material completely.[1] If the solar system were billions of years old, there should be no comets left.[2]

Evolutionary astronomers, who assume the solar system is billions of years old, must propose a 'source' that will supply new comets as old ones are destroyed. The Kuiper Belt[3] is one such proposed source. It was invented to explain the existence of short-period comets (comets that take less than 200 years to orbit the sun). Whereas an 'Oort Cloud' (which has been previously addressed in *TJ*[4]) was proposed to explain the existence of the long-period comets.[5] The Kuiper belt is a hypothetical massive flattened disc of billions of icy planetesimals supposedly left over from the formation of the solar system.

These planetesimals are assumed to exist in (roughly) circular orbits in the outer regions of the solar system—beyond Neptune (extending from 30 AU[6] out to around 100 AU).