Key Molecule in Plant Photo-Protection Identified

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Another important piece to the photosynthesis puzzle is now in place. Researchers with the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and the University of California at Berkeley have identified one of the key molecules that help protect plants from oxidation damage as the result of absorbing too much light. The researchers determined that when chlorophyll molecules in green plants take in more solar energy than they are able to immediately use, molecules of zeaxanthin, a member of the carotenoid family of pigment molecules, carry away the excess energy.

This study was led by Graham Fleming, director of Berkeley Lab's Physical Biosciences Division and a chemistry professor with UC Berkeley, and Kris Niyogi, who also holds joint appointments with Berkeley Lab and UC Berkeley. Its results are reported in the January 21, 2005 issue of the journal Science. Co-authoring the paper with Fleming and Niyogi were Nancy Holt, plus Donatas Zigmantas, Leonas Valkunas and Xiao-Ping Li.

Through photosynthesis, green plants are able to harvest energy from sunlight and convert it to chemical energy at an energy transfer efficiency rate of approximately 97 percent. If scientists can create artificial versions of photosynthesis, the dream of solar power as a clean, efficient and sustainable source of energy for humanity could be realized.

A potential pitfall for any sunlight-harvesting system is that if the system becomes overloaded with absorbed energy, it will likely suffer some form of damage. Plants solve this problem on a daily basis with a photo-protective mechanism called feedback de-excitation quenching. Excess energy, detected by changes in pH levels (the feedback mechanism), is safely dissipated from one molecular system to another, where it can then be routed down relatively harmless chemical reaction pathways.

Said Fleming, “This defense mechanism is so sensitive to changing light conditions, it will even respond to the passing of clouds overhead. It is one of Nature’s supreme examples of nanoscale engineering.”

The light harvesting system of plants consists of two protein complexes, Photosystem I and Photosystem II. Each complex features antennae made up of chlorophyll and carotenoid molecules that gain extra “excitation” energy when they capture photons. This excitation energy is funneled through a series of molecules into a reaction center where it is converted to chemical energy. Scientists have long suspected that the photo-protective mechanism involved carotenoids in Photosystem II, but, until now, the details were unknown.

Said Holt, “While it takes from 10 to 15 minutes for a plant’s feedback de-excitation quenching mechanism to maximize, the individual steps in the quenching process occur on picosecond and even femtosecond time-scales (a femtosecond is one millionth of a billionth of a second). To identify these steps, we needed the ultrafast spectroscopic capabilities that have only recently become available.”

The Berkeley researchers used femtosecond spectroscopic techniques to follow the movement of absorbed excitation energy in the thylakoid membranes of spinach leaves, which are large and proficient at quenching excess solar energy. They found that intense exposure to light triggers the formation of zeaxanthin molecules which are able to interact with the excited chlorophyll molecules. During this interaction, energy is dissipated via a charge exchange mechanism in which the zeaxanthin gives up an electron to the chlorophyll. The charge exchange brings the chlorophyll's energy back down to its ground state and turns the zeaxanthin into a radical cation which, unlike an excited chlorophyll molecule, is a non-oxidizing agent.

To confirm that zeaxanthin was indeed the key player in the energy quenching, and not some other intermediate, the Berkeley researchers conducted similar tests on special mutant strains of Arabidopsis thaliana, a weed that serves as a model organism for plant studies. These mutant strains were genetically engineered to either over express or not express at all the gene, psbS, which codes for an eponymous protein that is essential for the quenching process (most likely by binding zeaxanthin to chlorophyll).

"Our work with the mutant strains of Arabidopsis thaliana clearly showed that formation of zeaxanthin and its charge exchange with chlorophyll were responsible for the energy quenching we measured," said Niyogi. "We were surprised to find that the mechanism behind this energy quenching was a charge exchange, as earlier studies had indicated the mechanism was an energy transfer."

Fleming credits calculations performed on the supercomputers at the National Energy Research Scientific Computing Center (NERSC), under the leadership of Martin Head-Gordon, as an important factor in his group's determination that the mechanism behind energy quenching was an electron charge exchange. NERSC is a U.S. Department of Energy national user facility hosted by Berkeley Lab. Head-Gordon is a UC Berkeley faculty chemist with Berkeley Lab's Chemical Sciences Division.

"The success of this project depended on several different areas of science, from the greenhouse to the supercomputer," Fleming said. "It demonstrates that to understand extremely complex chemical systems, like photosynthesis, it is essential to combine state-of-the-art expertise in multiple scientific disciplines."

There are still many pieces of the photosynthesis puzzle that have yet to be placed for scientists to have a clear picture of the process. Fleming likens the on-going research effort to the popular board game, Clue.

"You have to figure out something like it was Colonel Mustard in the library with the lead pipe," he says. "When we began this project, we didn't know who did it, how they did it, or where they did it. Now we know who did it and how, but we don't know where. That's next!"

Source: Berkeley Lab

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