

Light-Harvesting: The Never-Ending Lesson of Nature

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A new photoacclimation process identified in cryptophyte algae shed light on how natural systems can regulate photosynthesis.

Capturing solar light and transforming it into a more usable form of energy with high efficiency and in a controllable way is one of the biggest challenges of our century. Nature has been running this task, reaching, so far, unattainable performances within the photosynthesis process. Photosynthesis in cryptophyte algae begins with “light-harvesting” or the absorption of solar light by specialized antenna complexes. In this issue of *ACS Central Science*, Scholes and co-workers took an important step toward a more thorough understanding of the subtle mechanisms regulating the photosynthetic machinery by shedding light on a newly identified photoacclimation process in cryptophyte algae.¹

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Photoacclimation encompasses a set of diverse processes involving many cellular components and occurring over a broad range of time scales. These processes, covering many physiological, biochemical, biophysical, and biological changes, allow the optimization of cell activities, including photosynthesis, as a result of changes in light intensity or quality.² Among the various strategies put into play by different photosynthetic organisms, cyanobacteria and red algae can perform what is defined as “chromic acclimation”.

They are able to change the composition and the structure of their antennas, called phycobilisomes, to modify their absorption spectrum and compensate for the loss of light in specific wavelength regions. These algae live in deep ocean waters. To perform photosynthesis efficiently, they need to collect light across the entire solar spectrum, dynamically and promptly adapting their light-harvesting apparatuses to harvest more effectively the wavelengths not absorbed by all of the other organisms living above them. *Mater artium necessitas*.

For the readers used to the complexity of the photosynthetic apparatus, it should not come as a surprise that chromic acclimation in cyanobacteria and red algae is enabled by the peculiar architecture of phycobilisomes,³ complex superstructures made up of different types of phycobiliproteins arranged in sophisticated symmetries, whose number and pigment content can be modified as a response to a change of light quality.⁴ However, would this be possible with antennas having a much simpler structure? According to Scholes et al., the answer is yes. They focused their attention on cryptophytes, descendants of red algae no longer containing phycobilisomes, which perform light-harvesting through a single type of phycobiliprotein freely packed in the thylakoid lumen and not organized in any superstructure (Figure 1). They grew two different species of cryptophytes (*Proteomonas sulcata* and *Hemiselmis pacifica*) under full (white light) and restrictive (green light) light conditions. Using spectroscopic and biophysical measurements, not only could they demonstrate the activation of the chromic acclimation process, but they also



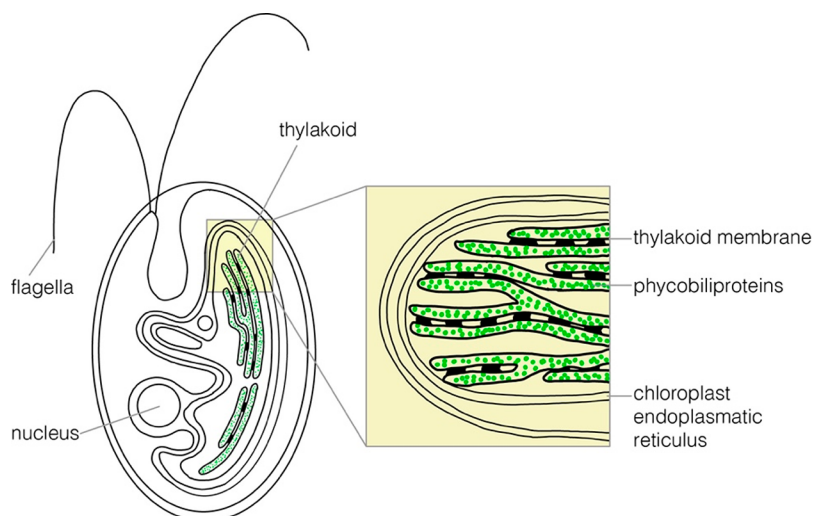


Figure 1. Pictorial representation of a cryptophyte alga with a zoomed in selection of the thylakoid region where photosynthesis occurs. The phycobiliproteins antennas are not organized into a phycobilisome superstructure like in cyanobacteria and red algae, but they are located in the thylakoid lumen.⁸

ascertained that the origin of the phenomenon is the incorporation of a different bilin pigment in a specific subunit of the phycobiliproteins. Any change related to the protein scaffold (amino-acid sequence, structural or conformational variations) or to pigment geometry was ruled out, confirming that the complex superstructure of phycobilisomes is not strictly necessary to put this adaptation strategy into practice. To survive under restricted light conditions, cryptophytes adapt the absorption spectrum of their phycobiliprotein antennas by replacing a bilin pigment with another one, capable of more efficiently harvesting the available wavelengths.

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However, there is more than that. Absorbing the wavelengths available in a limited spectral range more efficiently is just one of the necessary ingredients for efficient light-harvesting. A second crucial requirement is that the absorbed energy could be transported effectively among all of the photoactive molecules within the protein and then to reaction centers. For this to happen, the electronic levels of the pigments within the antenna must maintain a proper energy order to guarantee an adequate flow of energy across the protein. This might not necessarily be granted when a

pigment is replaced by a different one. Nonetheless, this happens in cryptophytes, where the overall kinetics of energy transportation is surprisingly not affected at all by the chromic acclimation. While the amount of absorbed energy can be optimized by exchanging a pigment, the efficiency of the ensuing energy transportation can be modulated by the interaction with the protein environment⁵ or, like in this case, remain unaffected if this environment does not change.

Although photosynthesis has been studied for decades, and several biomimicking approaches have already been put into practice,⁶ Nature keeps surprising us by deploying unexpected strategies to optimize, control, and fine-tune processes crucial for photosynthetic organisms' survival. These strategies are concretized with mechanisms of surprising complexity, ranging, for example, from the exploitation of quantum mechanical phenomena⁷ to the replacement of photoactive pigments, as described in this issue.¹ Many-body interactions between pigments and between pigments and the protein scaffold are finely modulated to direct and regulate the energy flow and to facilitate feedback and control. Every chemist who has ever tried to design and prepare a functional multichromophoric material in the same way is well aware of how difficult it is to precisely predict the outcome of a change, even minimal, in the structure, configuration, or geometry of the systems and to control its final functionalities. The photoacclimation of cryptophytes is an elegant example of how Nature performs this task effortlessly. Therefore, beyond having advanced the knowledge of cryptophytes' behavior, the article by Scholes and co-workers is helping us learn a new piece of the never-ending lesson of Nature.

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