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Unlocking the Structure and Function of Light-harvesting Complexes in Algae

By YAN Fusheng (Staff Reporter)

Oxygenic photosynthetic organisms harness solar energy to convert carbon dioxide and water into carbohydrates and molecular oxygen, which are essential to nearly all living things on the planet.

In higher plants and algae, the photosynthetic machinery locates in the membrane of chloroplasts and consists of two major pigment-protein complexes, photosystem II (PSII) and photosystem I (PSI). Photosystem II (PSII) converted the light energy absorbed by its bound light-harvesting complex for splitting water into oxygen, protons and electrons. The protons and electrons are later used for the synthesis of ATP and NADPH by chloroplastic ATP synthase and PSI complex.

To make full use of light energy, photosynthetic organisms have developed light-harvesting complexes (LHCs) to gather light energy and transfer it to photosynthetic reaction centers (PSII and PSI). Many LHCII subunits are associated with a core PSII, forming PSII-LHCII supercomplexes.

To adapt to different light environments, LHCs are capable of using different spectral regions of sunlight and dissipating excess energy to protect the organisms, a process also known as photoprotection. The LHC proteins vary across lineages of photosynthetic organisms.

Diatoms, as one of the main groups in the red lineage, use light-harvesting complex called fucoxanthin (Fx) chlorophyll (Chl) a/c-binding proteins (FCPs) for light harvest and dissipation. In fact, the centric role of diatoms in global primary productivity (accounting up to ~20%) and carbon cycling, is largely attributed to its powerful light-harvesting antenna. Therefore, diatoms represent as valuable research subjects in elucidating the structural basis for photosynthetic reactions.

Early 2019, a research team led by Prof. SHEN Jianren and CAS member KUANG Tingyun at the CAS Institute of Botany elucidated a fine structure of an FCP from the marine diatom *Phaeodactylum tricornutum*, which reveals the binding of seven Chls a, two Chls c, seven Fxs, and probably one diadinoxanthin within the FCP protein scaffold (Wang *et al*., 2019). They also revealed that efficient energy transfer pathways exist between Chl a and c, and each Fx is surrounded by Chls, enabling the energy transfer and quenching via Fx highly efficient, which partly explains the strong adaptiveness of diatoms to underwater environments.

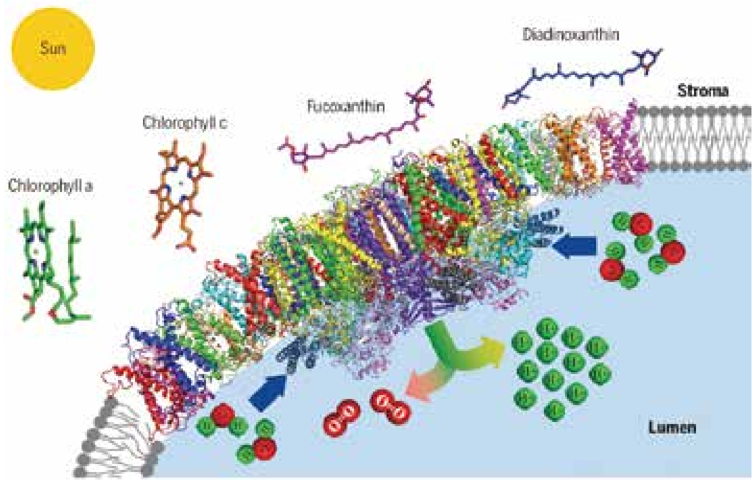
Many FCPs subunits of diatoms associate with the PSII core to form the PSII-FCPII supercomplex. However, the exact composition and organization of FCPs associated with the PSII core remains elusive.

Seeking to tackle this mystery, scientists from the same research team then worked together with Prof. SUI Senfang at the Tsinghua University and successfully elucidated a fine structure of the PSII-FCPII supercomplex from the diatom *Chaetoceros gracilis* at a resolution of 3.0 Å (Pi *et al*., 2019), which was published in Science as a Research Article on August 2, 2019.

They found that the supercomplex comprises two protomers, each with two tetrameric and three monomeric FCPIIs around a PSII core that contains five extrinsic oxygen-evolving proteins at the lumenal surface. They also revealed the arrangement of a huge pigment network that contributes to efficient light energy harvesting, transfer, and dissipation processes in the diatoms.

All these findings in diatoms will provide a structural basis for a precise understanding of how light energy is collected and converted. The elucidated PSII-FCPII structure also lays a good foundation for other investigations that would bring out more details of the reactions occurring in the thylakoid membrane where photosynthesis occurs.

The researchers also extended their investigations to green algae, which have an extremely large LHCI that captures and transfers energy to the PSI core. Using single-particle cryo-electron microscopy, they obtained the fine structure of PSI-LHCI supercomplex from the green alga *Bryopsis corticulans* at 3.49-Å resolution (Qin *et al*., 2019). They also elucidated the structure of a complete, $C_2S_2M_2N_2$-type PSII-LHCII supercomplex from the green alga *C.°reinhardtii* at 3.37-Å resolution (Shen *et al*., 2019). In order to harvest energy efficiently under water, this green alga contains more antenna subunits and pigments than the dominant PSII-LHCII supercomplex of plants. The fine structures of PSI-LHCI and PSII-LHCII supercomplexes provide a solid basis for elucidating mechanisms of how light is harvested, converted and also quenched in green algae, and also provide important clues for revealing the changes that have occurred during their evolutions.



Model of a diatom PSII-FCPII supercomplex embedded in the thylakoid membrane where photosynthesis takes place. The PSII-FCPII complex contains 35 protein subunits and a number of pigments and cofactors. It catalyzes light-induced electron transfer and water-splitting reactions. The latter occur on the lumen side of the membrane, leading to the generation of protons and molecular oxygen. Light is absorbed by the light-harvesting antenna pigments, among which Chl c and Fx enable absorption of blue-green light available under water. In addition, diadinoxanthin associated with FCPII plays important roles in photoprotection. (Credit: *Science*)

All these findings made by this research team are of great significance not only to providing a solid structural basis for revealing how the light is collected and converted in nature, but also to providing insights to design new crops with exceptional light-harvesting ability and even create an artificial photosynthetic system that allow us to convert sunlight into electricity or whatever of commercial values in the future.

References

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