【Grant-in-Aid for Transformative Research Areas（A）】

Photosynthesis ubiquity: Supramolecular complexes and their regulations to enable photosynthesis all around the globe（Photosynthesis ubiquity）

Head Investigator	Osaka University, Institute for Protein Research, Professor KURISU Genji　　Researcher Number:90294131
Research Area Information	Number of Research Area : 23A305　Project Period (FY) : 2023-2027 Keywords : Photosynthesis, Plant Science, Structural Biology, Informatics

Purpose and Background of the Research

●Outline of the Research

Photosynthesis is one of the most important topics in plant science and the most important chemical reaction on earth, taking place under diverse light environments from tropical to polar regions. It is not too much to say that photosynthesis occurs everywhere, under not only high light and low light but also fluctuating light conditions. So, "How have photosynthetic organisms adapted to diverse light environments?" remains a big question (Figure 1).

Based on recent researches, it is suggested that photosynthetic organisms have kept the core apparatus but diversify their regulatory/accessory components to adapt to specific light conditions by forming various "supramolecules" of core and regulatory/accessory proteins. In other words, it is important to understand the environmental adaptation of photosynthesis based on the formation of various types of supramolecules. However, it has not yet been possible to link the dynamically formed supramolecules and the physiology of photosynthetic organisms. Therefore, researchers in structural biology and plant physiology/biochemistry, and informatics scientists in this research area tackle to elucidate the principles of how supramolecules accomplish diverse physiological functions on different time and spatial scales.

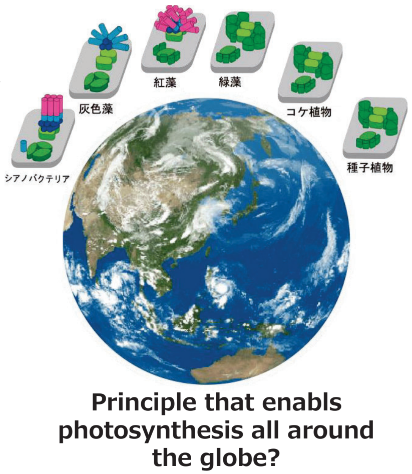

Figure 1. A conceptional drawing of the research on the principles of “photosynthesis everywhere”.

●Results/challenges from the previous project

The preceding JSPS project named ”New Photosynthesis” focused on the "accelerator" and "brake" of photosynthesis, and experimentally verified their networks from a system biological point of view. In addition, various types of supramolecular complex structures of photosynthesis apparatus were determined. However, our understanding of structure-function relationships was limited, and we have yet to understand the "principles" of structural diversity that reflects environmental adaptation (ex: Figure 2).

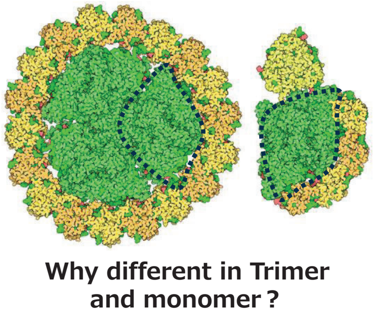

Figure 2. A reason why the different accessory antenna systems of Photosystem I were formed in cyanobacteria (left) and Maize (right) was not understood.

●Methods

Target spatial and time resolutions of supramolecules formation are from one millionth (angstrom) to one thousandth (sub-μm) of the thickness of a hair, and from picoseconds to minutes. To understand this multiscale system, we need to make full use of (1) visualization technology, including cryo-EM, AFM, and molecular calculations, (2) measurement technology that has been extended to non-model photosynthetic organisms, and (3) integrating these technologies by informatics covering the genome analysis and AI-based research represented by AlphaFold2 (Fig.3). We integrated all three “Visualization, Measurement, and Integration” methods to understand the ubiquitous photosynthesis, which we named "Photosynthesis Ubiquity” research.

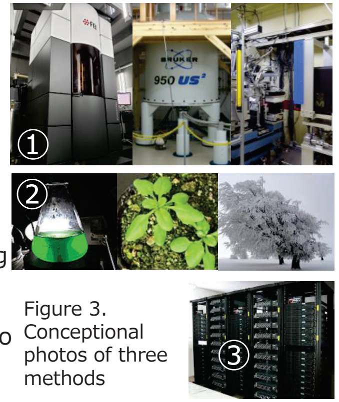

Figure 3. Conceptional photos of three methods

Expected Research Achievements

●Objectives as a research consortium

We will study the environmental adaptation of photosynthesis and its principles, which will answer how cyanobacteria, algae, and vacuolar plants have expanded from seawater/freshwater to land, and from the tropics to cold regions by integrating the multiscale researches in the field. This will also contribute to the future development of artificial design of photosynthesis.

In the ”Visualization” research, we will elucidate the principle of optimized arrangement of light-harvesting complexes around photosystems, including non-model organisms, and clarify the structural dynamics of the photosystem/antenna complexes under different light conditions. Molecular and structural studies will be carried out by molecular calculations and high-speed AFM as well as X-ray crystallography or cryo-EM to elucidate their dynamic behaviors.

In the "Measurement” research, we will analyze the formation of thylakoid membranes as scaffolds for photosynthetic supramolecules, characterize the structure and light-harvesting function of photosystem I and II supramolecules, and understand the diversity of light-harvesting structures and their energy transfer characteristics. We will elucidate how photosynthetic physiology or redox-based switching have contributed to the environmental adaptation of photosynthetic organisms.

In the ”Integrating" research, we will focus on the evolution of "regulatory systems" that control molecular devices that support environmental adaptation from comparative genomic analyses and AI-based prediction of key photosynthetic supramolecular complexes. This research will serve as a link between the functional and structural analysis and the principle of environmental adaptation.

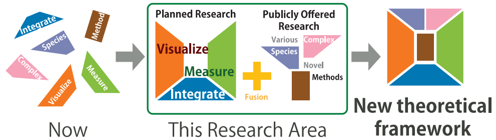

Figure 4. A conceptional drawing of “Photosynthesis Ubiquity” research by integration

Homepage Address, etc.	https://photosynthesis-ubiquity.jp/	https://twitter.com/Photosyn_ubiq