Robust Photosynthesis in Dynamic Environments

Plants rely on sunlight to meet their biochemical needs for cell maintenance, growth, and defense, through photosynthesis, the process that powers life on our planet.

Decades of research have given us a detailed view of the core cell components of photosynthesis. These components have been studied the most thoroughly under highly controlled laboratory conditions.

Now, scientists want to increase the efficiency of photosynthesis and improve crop productivity around the world, so we can tackle the problems of feeding billions of people and producing biofuels with cleaner environmental footprints.

Yet, a major challenge in plant biology is understanding how photosynthetic reactions are managed and tuned in the real world.

The challenge: studying photosynthesis in dynamic environments

Natural environments, unlike the lab, are highly unpredictable: light conditions can change in fractions of a second, while rapid changes in other environmental factors, such as temperature or moisture, can affect how well the photosynthetic machinery can operate.

This is particularly dangerous for plants, because any imbalance between the light absorbed and the energy used can lead to the formation of destructive by-products (Reactive Oxygen Species: ROS) and photodamage.

In response, the plant photosynthetic machinery has accordingly evolved to anticipate unexpected changes, through support functions that adjust the system for short term changes (fluctuating light due to a passing cloud) and for long term events (heat waves or droughts).

Despite the importance of these support functions to plants growth and stability in the real world, the nature of their components and how they integrate with the core photosynthetic machinery is relatively unexplored.

Part of the difficulty in studying these components is the lack of good tools to approach the problem systematically.

Our approach: "Bringing the field to the lab"

We are tackling this research through a combination of strategies and new technologies:

* **Developing** **new scientific instruments** that allow us to test plants under a wide range of realistic conditions and to identify undiscovered processes that tune photosynthesis;
* **Collaborating** with researchers across Michigan State University with expertise in established methods of studying photosynthesis;
* Taking advantage of **large on-campus collections of plants** with distinct ecotypes and mutants;
* Developing**automated big data processing streams and bioinformatic pipelines**.

**Our current studies focus on**:

1. **New approaches to high-throughput, non-invasive measurements** of the rapid responses of photosynthesis (*Jeffrey Cruz, Kramer and Sharkey labs*);
2. The **dynamic organization of photosynthetic complexes**, including how they safely assemble and repair themselves (*Ben Lucker, Kramer and Benning labs*);
3. The **ATP synthase**, a protein complex in the chloroplast, as the “safety brake” of photosynthesis (*Atsuko Kanazawa, John Froehlich, Kramer and Sharkey labs*);
4. The **dangers of “overcharging” photosynthesis**, and how that might lead to photodamage, by identifying relevant genes and biophysical processes (*Kramer lab* *and Geoffry Davis*);
5. The **mechanisms of metabolic sink demand** and their effect on the light reactions of cyanobacterial photosynthesis (*Ducat and Kramer labs*);
6. The role of **thylakoid lipids** in photosynthesis, in dynamic environments (*Benning and Kramer labs, Ben Lucker*);
7. The **evolution of photosynthetic responses**, in algae, field crops, and plants (*Kramer, Benning, Howe, Hu, Sharkey labs, with Jeffrey Cruz, Atsuko Kanazawa, Ben Lucker, and others*).

Ultimately, we want to bridge the gaps between the field and the lab.

For example, our growth chambers allow a researcher to program in fluctuating, yet reproducible conditions. It is possible to gather environmental data from a natural site – say light and temperature readings from an Autumn day in a Michigan park – and then replay these conditions faithfully within the chamber.

On-board detectors monitor the growth and health of the plant lines and can determine how efficiently their photosynthesis proceeds, without destroying the plants, by using spectroscopic and fluorescence sensors.

Furthermore, we have developed the capability to gather plant data from across the globe, in collaboration with researchers, educators, farmers, and citizen scientists, allowing for crowdsourced analysis of plant performance.

In this way, we are uncovering the functions of previously unknown genes that are essential to protect photosynthesis against environmental fluctuations and stresses. This will help us breed or create more resilient and productive plants.

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