Impact Objectives

- Deepen understanding of molecular and cellular biology and physiology in plants
- Investigate the plastid signal arising from the chloroplasts
- Provide a better understanding of the role chloroplasts play in physiological responses

The inner communication of plants

***Professor Mitsumasa Hanaoka** explains why the communication between chloroplasts and the nucleus is vital to understanding plant growth and response to developmental and environmental changes*

Firstly, can you share a little about how you came to be involved in this research field?

I have been conducting research on molecular and cellular biology related to chloroplasts for most of my career. During my time in graduate school, I became interested in the regulation of the expression of genes encoded in the chloroplast genome. At this time, I focused on investigating the transcriptional regulation of photosynthesis genes by nuclear-encoded sigma factors. Since the expression of chloroplast genes is strongly controlled by the nucleus, I clarified the transcriptional control in various physiological responses, including: light responses; stress responses; control of the circadian clock; and plastid differentiation.

More recently I have been conducting a wide range of research with an interest in exploring the generality and specificity of plastid signal transduction. I am also interested in the endosymbiotic evolution that led to the origin of chloroplasts. I was keen to examine the environmental responses and signal transduction pathway to understand more about what kind of system was introduced into the chloroplast which enables it to evolve into the present plant cell. This has all led me to where I am now conducting research from the perspective of the origin and evolution of the plastid signals.

What is your interest in chloroplasts and what do you hope to reveal with these investigations?

Chloroplasts are important organelles directly linked to plant growth and productivity. However, since the genes required for chloroplast functions, like photosynthesis, are encoded separately in the nuclear genome and chloroplast genome, it is essential to coordinate gene expression of both genomes in response to developmental and environmental changes. During this coordination, bidirectional signal transduction between the nucleus and the chloroplast is considered to play an important role. This signal has been, until now, not very well understood.

We are conducting research on this plastid signal and the molecular function of GUN1, a protein which is thought to play a major role in signalling pathways. We are also looking at the candidate for the signal molecules, and the generality and specificity of downstream regulation of gene expression. With this we would like to elucidate the origin and evolution of the plastid signals and provide a better understanding of the role chloroplasts play in physiological responses, such as plant development, environmental adaptation, signal transduction and regulation of gene expression.

What is the ultimate impact of your research learnings?

This is basic research that seeks to clarify the entire picture of the signal transduction pathway between the nucleus and chloroplasts, and its elucidation itself has an academic impact. On the other hand, many photosynthetic and major metabolic functions are localised in chloroplasts, and thus they are essential organelles, not only for plant survival but also for productivity. Therefore, it is easy to see that signal transduction between the nucleus and chloroplast plays an important role in optimising the performance of photosynthesis and metabolic production. So, by understanding and improving this mechanism it is possible to contribute to stable food production, such as by producing stress-resistant plants. ▶

Decoding molecular messages within plant cells

In order to unravel the mysteries of plant responses to the environment, researchers are exploring how plants coordinate messages between the nucleus and chloroplasts responsible for optimised photosynthesis

Research into the process of photosynthesis could benefit a range of areas - from increasing output from agriculture and developing stress resistant crops, to the design of solar panels and solar energy harvesting technology.

In order to develop our understanding of this process, the study of photosynthesis needs to focus on the chloroplast - the cellular compartments where the magic of photosynthesis takes place. Professor Mitsumasa Hanaoka, from the Laboratory of Molecular and Cellular Functions in the Department of Applied Biological Chemistry, Graduate School of Horticulture at Chiba University, has been studying molecular and cellular biology since the beginning of his academic career and is an expert in this field.

'I wanted to explore the question about what kind of systems were introduced into the chloroplast that allowed it to evolve into the present plant cell'

Hanaoka explains that within the chloroplast the absorbed sunlight, in conjunction with water and carbon dioxide, is converted into energy in the form of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH). 'This energy drives plant growth and is also used to package nutrients into plant seeds so that seedlings have sufficient resources to get started once planted,' he clarifies. 'Interestingly, the chloroplast has its own genome, separate from the nuclear genome in plant cells.'

BI-DIRECTIONAL COMMUNICATION

Crucial for the functioning of a plant is the ability to respond to environments and regulate processes like photosynthesis. 'The expression of chloroplast genes is strongly controlled by the nucleus,' outlines Hanaoka. 'Early on in my career I was able to clarify the transcriptional control of various physiological responses, including light responses, stress responses, control of the circadian clock and plastid differentiation, from the perspective of signal transduction flowing from the nucleus to the chloroplast.' This is known as the anterograde signal. However, in recent years research on signalling in the opposite direction (chloroplast to nucleus) has advanced, which is known as the retrograde (or plastid) signal.

'Now under the working hypothesis that the bidirectional signals between the nucleus and chloroplast play an important role in coordinating gene expression in both genomes, a wide range of research is being carried out to explore the generality and specificity of plastid signal transduction,' says Hanaoka. Encompassed in this research programme is the study of how these systems evolved. 'I am also interested in the endosymbiotic evolution that led to the origin of chloroplasts, since chloroplasts are thought to have originated through the endosymbiosis of primitive cyanobacteria,' he confirms.

By looking at cyanobacteria, which are prokaryotic cells similar to the ones that existed before the endosymbiosis, and unicellular eukaryotic algal cells that are considered to be representative of the cells just after the establishment of the endosymbiosis, the evolution steps can be investigated. 'I wanted to explore the question about what kind of systems were introduced into the chloroplast that allowed it to evolve into the present plant cell by examining the environmental responses and signal transduction pathway,' explains Hanaoka. He is now conducting research from the perspective of origin and evolution of the plastid signals.

IDENTIFYING THE MESSENGERS

The activities at the Laboratory of Molecular and Cellular Functions are extensive and varied, all with the focus of learning more about the functions of organisms and the properties of cell organelles. For Hanaoka, one of the most important questions they are currently delving into is the clarification of what kind of signal molecule travels between the nucleus and the chloroplast.

For anterograde signalling, the main signal is proteins produced via transcription in the nucleus and translation in the cytosol, which is then transported to the chloroplast. 'On the other hand, retrograde signals or plastid signals going in the opposite direction, are unlikely to be a direct gene product from the chloroplast genome, released outside the chloroplast and travelling to the nucleus,' discusses Hanaoka. 'Instead the signal is thought to be transmitted to the nucleus via a number of processes, including: a metabolite or its intermediate molecule; a signal molecule; or a phosphorylation cascade.'

'The signal is thought to be transmitted to the nucleus via a number of processes'

Clarifying this has proved to be a big challenge. 'So far six genes that encode for factors involved in this plastid signal transduction have been identified, being GUN1 to GUN6,' Hanaoka highlights. 'Of these, GUN1 is supposed to play a major role in the signal transduction system, but exactly how this protein works to control on/off or intensity of signal transduction, or its molecular function, is not yet fully understood. For this reason, GUN1 is now the focus of most of our efforts.'

There is also a range of other research programmes and experiments underway by Hanaoka's team. For example, they have been working on how the circadian clock helps to regulate signalling and photosynthesis. 'We have clarified the mechanism by which time information generated in the nucleus is transferred to the chloroplast, and we revealed one part of the mechanism of regulation of photosynthetic function in the chloroplasts,' he confirms.

BUILDING BETTER PLANTS

The work of Hanaoka and his colleagues is essential basic research that contributes to our understanding of the evolution of photosynthetic organisms and the physiology of this complex cell system. Hanaoka is hoping this research will progress our understanding of plastid signalling and chloroplast evolution. He is working alongside students and collaborators with a range of expertise to build a more detailed picture of this, including in large-scale gene expression and data processing via bioinformatics. ●

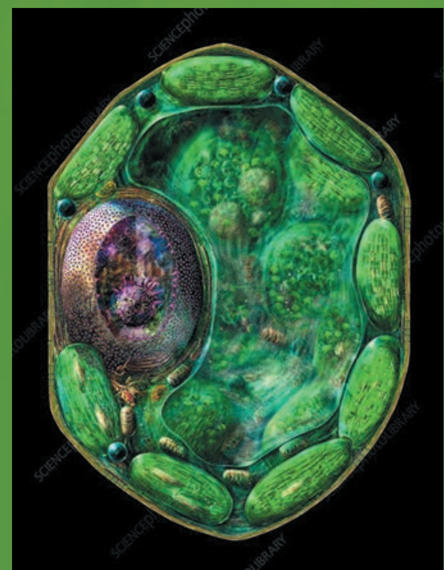

Image of the inside of a plant cell with the nucleus (purple, left) and the chloroplasts (green, surroundings), that are thought to communicate with each other by partly unidentified signals

Project Insights

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CONTACT

Professor Mitsumasa Hanaoka

T: +81 43 290 2970
E: mhanaoka@faculty.chiba-u.jp
W: http://www.h.chiba-u.jp/lab/molbio/

BIO

Professor Mitsumasa Hanaoka is the head of the Laboratory of Molecular and Cellular Functions in the Department of Applied Biological Chemistry, Graduate School of Horticulture, Chiba University. He has over 20 years' experience in research on regulation of chloroplast gene expression in response to environmental changes, signalling between the nucleus and the chloroplast, and the establishment of chloroplast systems through endosymbiotic evolution. Recently, he has also been conducting applied research on the development of highly functional plants as well as the bioproduction systems.