Mechanism for photosynthesis already existed in primeval microbe: additional details

Background

Photosynthesis is a process that creates glucose and other carbohydrates, the energy sources that supports life, from sunlight, CO_2 and water. It is a biological function that sustains most living things on earth, but scientists have been unable to determine how the photosynthetic process began or became established, or its evolutionary origins. Previous research revealed that while *Bacillus subtilis* such as *Bacillus natto* (fermented beans) which do not engage in photosynthesis have genes that resemble those of RuBisCO – an enzyme used by most photosynthetic organisms for CO_2 fixation[1] – the enzyme that resembles RuBisCO[2] does not carry out CO_2 fixation, but functions in a metabolic pathway with no relation to photosynthesis. It catalyzes the only partial reaction of CO_2 fixation catalyzed by photosynthetic RuBisCO and therefore both have evolved from the same ancestral protein. This finding was published in 2003 by Associate Professor Ashida in the journal Science.

These findings pioneered research into the genetic evolution of photosynthesis as far back as the organisms who existed on earth before the appearance of the photosynthetic system, but they did not go as far as explaining the source of the RuBisCO-like genes in *Bacillus subtilis*, or the origins of the photosynthetic Calvin-Benson cycle[3] in which RuBisCO functions to synthesize glucose from CO_2 on a molecular level.

Research contents

RuBisCO and phosphoribulokinase (PRK)[4] are enzymes unique to the Calvin-Benson cycle. Through bioinformatics analysis of their genome database, Associate Professor Ashida's research team discovered that the genes for these enzymes existed in an extremophile species thought to have appeared in the very early stages of life on Earth, a species of methanogenic archaea (methanospirillum hungatei)[5]. This demonstrated that the non-photosynthetic methanogenic archaea possessed genes that are specific to photosynthetic organisms. Additionally, the enzymes synthesized using these genes in the methanogenic bacteria possessed properties that enabled them to function in the Calvin-Benson cycle. Using genetic analysis of these methanogenic bacteria, detailed biochemical analyses, and metabolome analysis[6] using labeled-CO_2, the team discovered that within methanogenic archaea these two enzymes were creating an as yet unknown reductive CO_2 fixation path, and this path used the same reaction steps as part of the already known Calvin-Benson cycle (see Figure 1). Considering the evolutionary position of this organism, the CO_2 fixation path in *Methanospirillum hungatei* that resembles the Calvin-Benson cycle could be an evolutionary model for the photosynthetic Calvin-Benson cycle.

Future developments

The discovery of the existence of a primitive reductive CO_2 fixation path that could be the source of photosynthesis may be able to shed light on how the photosynthetic system formed during the process of evolution. The early organisms that appeared on Earth around 4 billion years ago only had 500-1000 genes, but over the 4 billion year process of evolution, this small number of genes, through alterations such as replication, variation, and sequence insertion, became the 25,000-35,000 genes in higher animals and higher plants, enabling organisms to adapt to many different environments. However, it is not clear what molecular changes caused the genes of early organisms to evolve. These findings are a step forward in research into genetic molecular evolution, having succeeding in linking RuBisCO and PRK with the evolutionary process dating back 4 billion years. In future studies, by clarifying the functions of genetic evolution 4 billion years ago, researchers could potentially discover the evolutionary functions of all organisms, and even the essence of survival strategies among animals today. This research direction also has potential applications for refining and using the photosynthetic functions of plants and algae in order to solve global environmental problems such as global warming, food supply and energy issues. Since RuBisCO and the Calvin-Benson cycle are responsible for regulating the photosynthesis efficiency in various aspects, they are the main targets in order to improve photosynthetic functions in plants and algae. By continuing research into this newly discovered evolutionary model for RuBisCO and the Calvin-Benson cycle, this could enhance photosynthetic functions, and contribute to solving global issues.

(1) CO_2 fixation: when plants and some microorganisms convert carbon dioxide that they have ingested into an organic compound.
(2) RuBisCO: an enzyme that functions at the CO_2 fixation stage in the Calvin-Benson cycle. The quality of this function dictates the photosynthesis efficiency in several aspects
(3) Calvin-Benson cycle: the metabolic pathway for synthesizing glucose from ingested CO_2 in photosynthesis. The name of this pathway originates from the scientists responsible for its discovery. Melvin Calvin was awarded the 1961 Nobel Prize in Chemistry for this work.
(4) Phosphoribulokinase (PRK): an enzyme which synthesizes ribulose bisphosphate, which is used to receive CO_2 molecules when RuBisCO carries out CO_2 fixation in the Calvin-Benson cycle
(5) Methanogenic archaea: found in the digestive organs of animals, swamps, submarine sediment, near sea-floor hydrothermal deposits, and beneath the earth's crust, these organisms produce the majority of methane gas on Earth. They obtain the energy necessary to live through the process of producing methane.
(6) Metabolome analysis: an method that comprehensively detects and quantifies metabolic pathways inside organisms. By utilizing carbon-13, a stable isotope of carbon-12, this can also be used to identify the carbon metabolic pathway.