Origin of photosynthesis: Is photosynthetic ability pressent in Actinobacteria?

The origin of photosynthesis, which sustains most life on earth, by converting light energy from the sun into chemical energy for plants, animals and other organism, remains an important unresolved problem in the history of life. Besides plants and algae, which are photosynthetic due to their acquisition of cyanobacteria via endosymbiosis, photosynthesis is only found in prokaryotes. Photosynthetic ability in prokaryotic organisms, where it originated, is presently found in seven phyla of bacteria: Chlorobi, Acidobacteria, Firmicutes, Cyanobacteria, Proteobacteria, Chloroflexi and Gemmatimonadetes (Fig. 1.). However, it is not known whether photosynthetic ability also exists in any other bacterial groups, nor is it clear in which group it has originated. Chlorophyll-bacteriochlorophyll (Bchl) is a key pigment required for photosynthesis, which is uniquely found in all photosynthetic organisms. Of the proteins involved in the biosynthesis of Bchl, three proteins, BchL, BchN and BchB (part of the protochlorophyllide oxidoreductase complex), are unique characteristics of all photosynthetic organisms. Due to their unique presence in all photosynthetic organisms, these proteins provide highly specific diagnostic tools to determine the presence of photosynthesis (or its remnants) in other bacterial lineages.

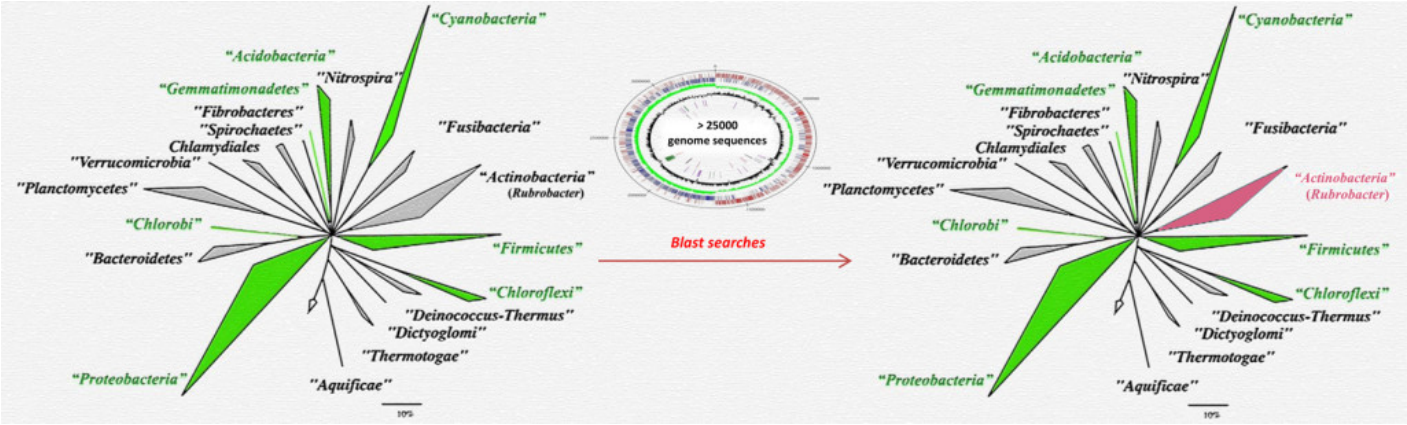

Fig. 1. (Left) The bacterial phyla which are known to possess Chlorophyll-bacteriochlorophyll (Bchl) based photosynthesis are shown in green. (Right) BLAST searches on genome sequences show that the key proteins involved in Bchl biosynthesis are also present in members of the genus Rubrobacter belonging to the phylum Actinobacteria (shown in purple), raising the possibility that photosynthesis either exists or was ancestrally present in this phylum.

In this study, sequence similarity searches were carried using the BLAST algorithm, with the sequences of BchL, BchN and BchB proteins on all available genomes. The results of these studies have revealed that in addition to the known photosynthetic organisms, homologs showing high degree of sequence similarity to the BchB and BchN proteins are also present in members of

the genus Rubrobacter, which is a part of the phylum Actinobacteria (Fig. 1.). The BchB and BchN homologs found in Rubrobacter show high degree of structural homology to the solved structures of BchB and BchN proteins from other photosynthetic bacteria (Fig. 2.). Additionally, phylogenetic analysis and sequence characteristics of the BchB and BchN proteins from Rubrobacter described in this study show that the Rubrobacter homologs are distinct from those found in all other photosynthetic groups and that they may represent the ancestral forms of these proteins.

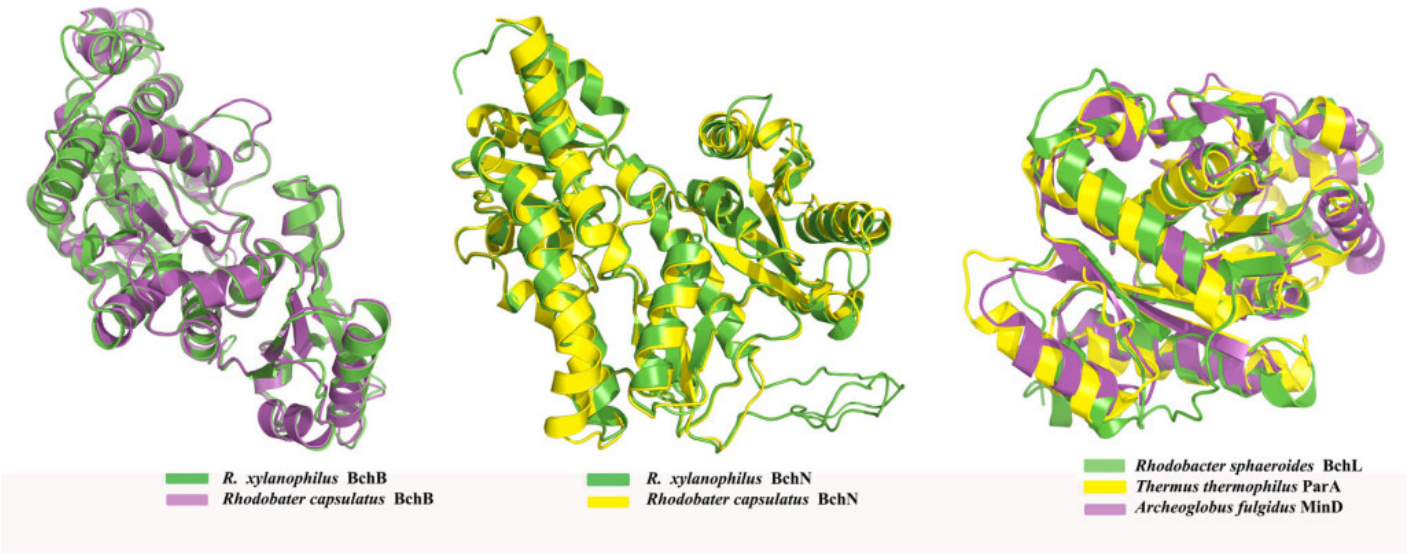

Fig. 2. (Left and centre): Structural comparisons of the BchB and BchN proteins from Rubrobacter with the solved structures of these proteins from Rhodobacter capsulatus. (Right): Structual comparison of the BchL protein of Rhodobacter sphaeroides with the solved structures of the chromosome partitioning protein (ParA) from Thermus thermophilus and cell division regulator MinD protein from Archaeoglobus fulgidus. Homologs showing high degree of sequence similarity to the latter proteins are present in Rubrobacter.

Although a homolog showing high degree of sequence similarity to the BchL protein was not detected in Rubrobacter, homologs of the ParA/MinD proteins found in Ruborbacter exhibit a high degree of structural similarity to BchL protein (Fig. 2, right diagram). Thus, it is possible that the role of the BchL protein in Rubrobacter was ancestrally performed by one of these proteins. In addition to the BchB/BchN homologs, Rubrobacter species also contain homologs exhibiting high degree of sequence similarity to a number of other core proteins required for Bchl biosynthesis (viz. BchD, BchH, BchI, BchP and BchG). These novel findings reported in this study provide the first evidence that some form of photosynthesis either exists or was anciently present in members of the genus Rubrobacter (phylum Actinobacteria), for which no prior evidence exists. Additionally, the characteristics of the photosynthesis-related proteins present in this deep branching lineage raises the questions regarding the nature of the earliest photosynthetic organism as well as the earliest form of photosynthesis. Further investigation of the photosynthesis related genes/proteins from

Rubrobacter should prove very helpful in understanding the origin and evolution of photosynthesis.

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Publication

Evidence for the presence of key chlorophyll-biosynthesis-related proteins in the genus Rubrobacter (Phylum Actinobacteria) and its implications for the evolution and origin of photosynthesis.
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