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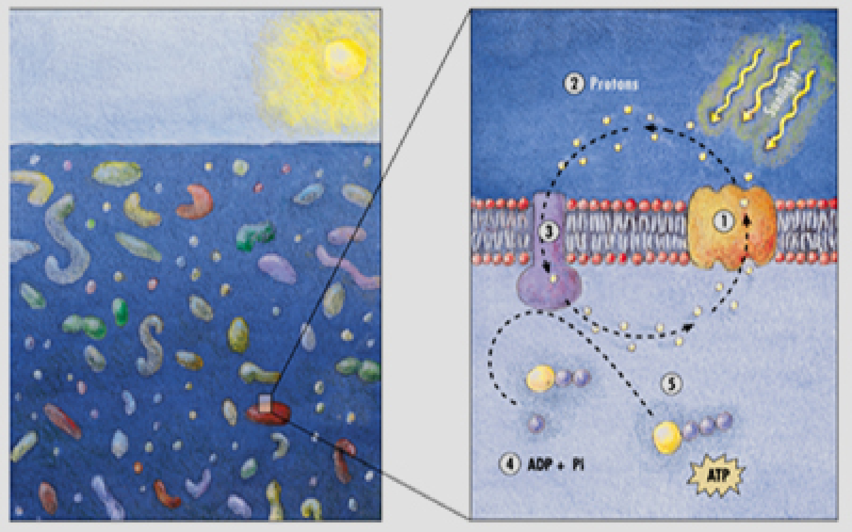
Vida de la Academia

Ensayos académicos

Enlightened by Microbial Rhodopsins

Iluminados por las rodopsinas bacterianas



Frontispiece: A cartoon of planktonic bacteria in the ocean water column (left) and a simple view of one potential proteorhodopsin energy circuit (right). Source. https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1000359

Keywords: rhodopsins, light capture, photosynthesis, ocean microbes, pigments.

The cold and dark northern winter days evoke nostalgia for the comfort and warmth of sunshine. We may take the sun for granted or even shun its scorching rays in hot weather, but we seldom think about the complex process of building life from solar energy, the foundation of our existence. And it is only a selected few photosynthetic microbes, plants and algae that are endowed with the capacity to convert light from the sun into chemical energy, transforming CO_2 and water into organic compounds that are then channeled through the food web to all other organisms on Earth.

Microbes are responsible for about 50% of this primary production. But what is fascinating about microbes is that in addition to the well-known chlorophyll-based systems involved in photosynthesis, some have a very different mechanism for harvesting light: microbial rhodopsins, proteins that were briefly introduced by Merry in an early STC post from 2007. Much has happened in this exciting field since then!

Microbial rhodopsins are proteins that capture light through the pigment retinal and not the chlorophyll pigments found in cyanobacteria, algae and plants. Rhodopsin proteins are found both in eukaryotes and prokaryotes, and even in viruses. These membrane proteins all bind retinal and have seven transmembrane domains, but they differ in their amino acid sequences and functions. Animal rhodopsins, for example, are used for sensing light, while microbial rhodopsins are involved in a broad array of functions like sensory

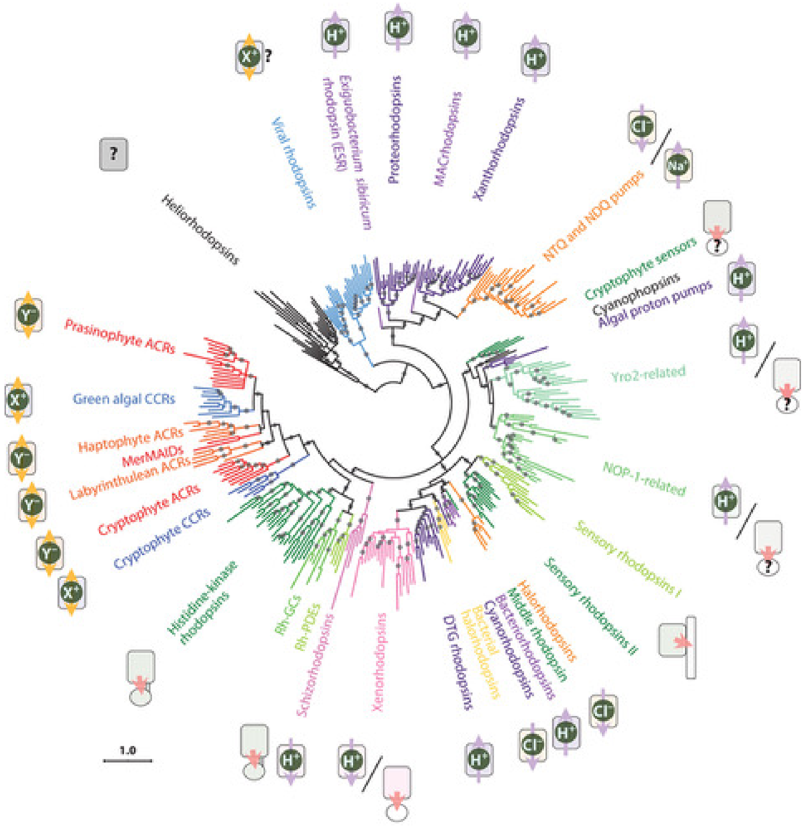


Figura 1. A phylogenetic tree of representatives of different families of microbial rhodopsins. Purple and orange arrows indicate active and passive transport of ions in pumps and channels, respectively. Pink arrows show the signal transduction from rhodopsins to either soluble or transmembrane transducer proteins. ACR, anion channelrhodopsin; CCR, cation channelrhodopsin; GC, guanylyl cyclase; MACrhodopsin, marine actinobacterial clade rhodopsin; MerMAID, metagenomically discovered, marine, anion-conducting, and intensely desensitizing channelrhodopsin; PDE, phosphodiesterase; Rh, rhodopsin. Source. https://www.annualreviews.org/doi/full/10.1146/annurev-micro-031721-020452

transduction and the use of ion pumps for cellular processes such as ATP synthesis and uptake of substrates (Fig. 1). The first microbial rhodopsin identified, bacteriorhodopsin, was found in the membrane of the halophilic archaeon *Halobacterium salinarum*, which also contains additional rhodopsins such as heliorhodopsin. Many years later, the analysis of metagenomic data uncovered the presence of proteorhodopsins in bacteria, a discovery that has upended our notions of energy capture and productivity on our planet.

The gene for proteorhodopsin, identified based on similarity to the already-known archaeal bacteriorhodopsin gene, was found in metagenomic data of uncultured marine gammaproteobacteria. This protein was then validated functionally in *Escherichia coli* as a light-dependent proton pump. This discovery – more than 20 years ago – of a novel photosystem capable of harnessing energy from the sun has since expanded our understanding of phototrophy. Microbial rhodopsins have been subsequently identified in various microbes from both marine and freshwater environments. Among these, proteorhodopsins are the most abundant. But what is their role and ecological relevance in ocean ecosystems?

To address this question, Gómez-Consarnau and colleagues looked at ocean water samples collected from locations with distinct characteristics: low-nutrient oligotrophic environments, sites close to the coast, and in the open ocean. They first quantitated rhodopsins, as well as the two other major pigments used in photosynthesis, chlorophyll-a and bacteriochlorophyll-a for oxygenic and anoxygenic photosynthesis, respectively. Proteorhodopsins were present only in the microbial fraction (0.2- to 3.0-µm), indicating

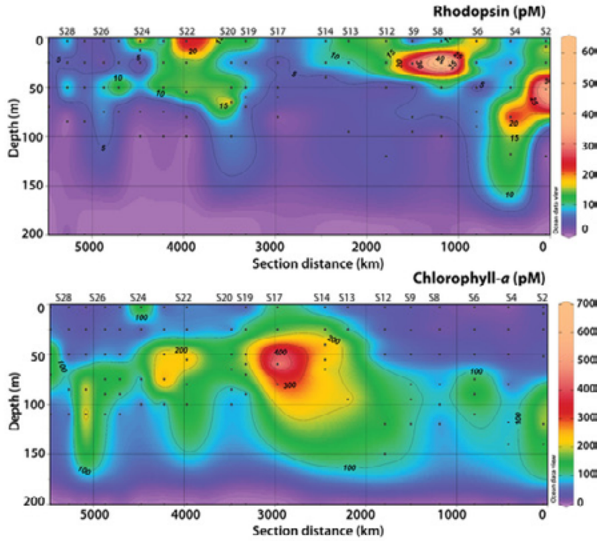


Figura 2. Sectional distributions of pigment concentrations measured along the Mediterranean Sea and in the Eastern Atlantic Ocean. Top, Distribution of retinal in rhodopsins. Bottom, Chlorophyll-a (Chl-a). The black circles indicate the depths of sampling. Source https://www.science.org/doi/10.1126/sciadv.aaw8855

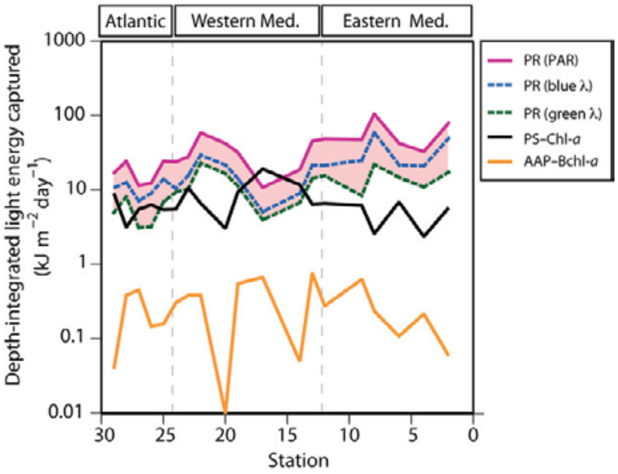


Figura 3. Geographical distribution of the depth-integrated light energy captured by proteorhodopsins (PR), Chlorophyll-a photosystem (PS–Chl-a), and aerobic anoxygenic phototrophy Bacteriochlorophyll-a (AAP–Bchl-a) at the different sampling regions of the Mediterranean. Solid lines denote estimates using all photosynthetically available radiant (PAR) energy (400 to 700 nm). Conservative energy calculations using specific wavelengths for blue-absorbing (490 nm) and green-absorbing (530 nm) PR are shown in dashed lines. Source https://www.science.org/doi/10.1126/sciadv.aaw8855

that they were more important in free-living rather than surface-attached microbes, and were found at depths situated above those where chlorophyll was more abundant (Fig. 2).

Both rhodopsin abundance and the number of rhodopsin molecules per cell were higher in low-nutrient regions, where chlorophyll-a was lowest. Based on estimated concentrations and the number of pigment clusters needed to form a "photosynthetic unit," – 300 molecules for chlorophyll-a and 34 for bacteriochlorophyll-a, versus 1 for rhodopsin – rhodopsins surpassed chlorophyll-based systems in their potential to absorb solar radiation due to the cumulative effect of these abundant and widespread photosystems (Fig. 3). Finally, and despite a low energy yield per cell, proteorhodopsins still seem to provide sufficient energy to sustain basal metabolism and promote survival, particularly in low-nutrient environments.

Proteorhodopsin light-harvesting systems have risen from obscurity to occupy prominence as important contributors to global solar energy capture and survival of microbes in oligotrophic ocean waters. But the interest in rhodopsins does not stop here. Microbial rhodopsins, which are encoded by a single gene, have proven more tractable than chlorophyll-based photosystems for technological applications in optogenetics, which aims to manipulate cell or animal behavior with light, and, more recently, the engineering of non-phototrophic organisms to harvest energy from light.

Equally amazing is the fact that these microbes, working tirelessly, are oblivious of their importance and indifferent to our concerns. Just as we are largely indifferent to them.

María Mercedes Zambrano

Fuente

Small Things Considered
A blog for sharing appreciation of the width and depth of microbes and microbial activities on this planet (https://schaechter.asmblog.org/schaechter/)

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