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HOW DOES PHOTOSYNTHESIS TAKE PLACE IN OUR OCEANS?

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The food we eat ultimately comes from plants, either directly or indirectly. The importance of plants as the global kitchen can never be underestimated. Plants “eat” sunlight and carbon dioxide to produce their own food and food for the millions of other organisms dependent on them. A molecule, chlorophyll (Chl), is crucial for this process, since it absorbs sunlight. However, the way land plants produce their food is very different from the way plants in the oceans produce their food. Since it is difficult for light to reach underneath the water in the oceans, food production, scientifically called photosynthesis, becomes very slow. Phycobiliproteins are proteins that make this job easier, by absorbing the available light and passing it on to Chl. These phycobiliproteins are found in tiny, invisible organisms called cyanobacteria. Their “food-producing” reactions are critical for the survival of many living organisms like fish, birds, and other sea life. It is, therefore, very important for everyone to understand how cyanobacteria make their food, and what important roles the phycobiliproteins play in the process.

HOW DO LIVING THINGS OBTAIN THEIR FOOD?

When you think of food, do you usually come up with images of your favorite food? This is a natural process, since food is important for every living thing. To fulfill this basic need, all living things either make their own food or get it from some other source. Humans can eat both plants and animals. Some animals consume other animals, while some animals eat plants as their food. Ultimately, we see that everybody on this planet is dependent on plants for their food. But then, what do plants eat? Actually, plants "eat" sunlight and a gas called carbon dioxide, both of which are easily available right here on earth. The process by which land plants produce their own food using sunlight and carbon dioxide is known as **photosynthesis** (Figure 1). While carbon dioxide is absorbed by the leaves, the sunlight is captured by a chemical molecule in the plant, called **chlorophyll** (Chl). All photosynthetic organisms contain Chl.

However, the way land plants perform photosynthesis does not help the organisms living in the oceans, which cover nearly 70% of our earth. Plants in the oceans face problems with light availability. The blue and green portions of light penetrate into the water more than the yellow and red portions of light do (Figure 2). Luckily, ocean plants get help in producing food from such limited light and carbon dioxide, from tiny microscopic microbes called cyanobacteria (also known as blue-green algae). These microbes have adapted to dim light conditions, and they carry out photosynthesis both for themselves and for the benefit of other living things. Cyanobacteria are ancient microbes that have been living on our earth for billions of years. Cyanobacteria are said to be responsible for creating the oxygen-filled atmosphere we live in [1]. For carrying out photosynthesis in low light conditions, cyanobacteria have the help of proteins called **phycobiliproteins**, which are found buried in the cell membranes (the outer covering) of the cyanobacteria.

PHOTOSYNTHESIS

A process by which plants produce food for themselves and other organisms using sunlight and carbon dioxide gas

CHLOROPHYLL

A chemical molecule present in plants that absorbs the sunlight for photosynthesis.

PHYCOBILIPROTEINS

Colored pigments found in cyanobacteria and certain other organisms, which help in photosynthesis by absorbing certain colors of light which chlorophyll cannot absorb.

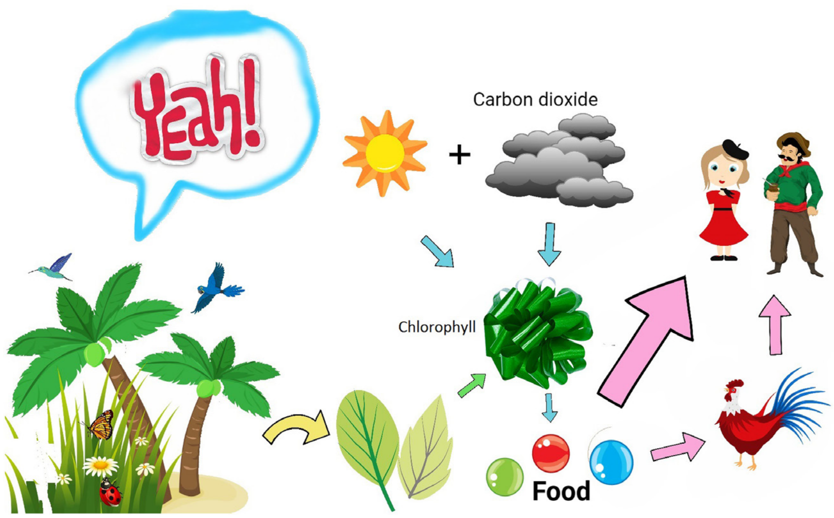

FIGURE 1

FIGURE 1

A simplified view of how plants produce food for us. The leaves of green plants contain chlorophyll, which absorbs sunlight for producing food. This food is then used by the plant itself as well as other animals, including humans.

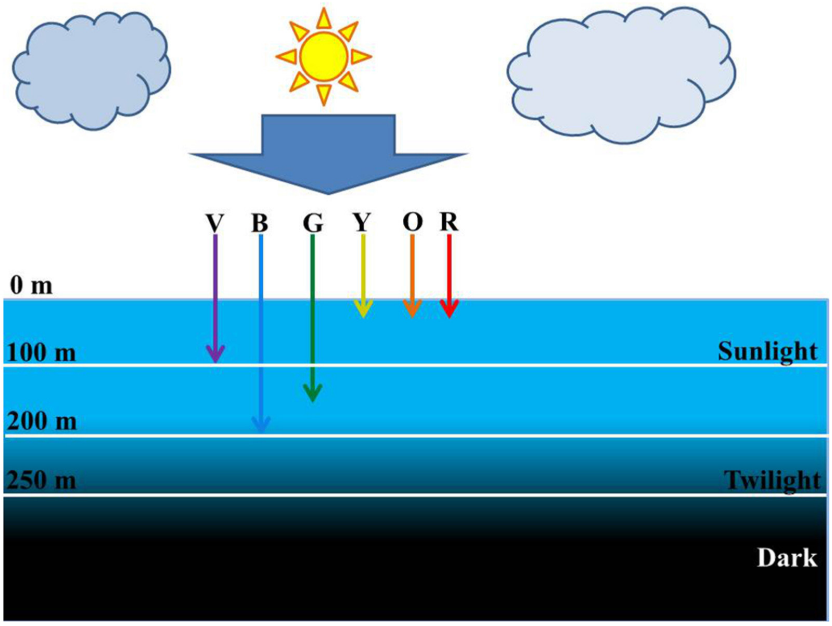

FIGURE 2

FIGURE 2

Penetration of sunlight in oceans. Sunlight is composed of different colors: V, violet; B, blue; G, green; Y, yellow; O, orange; and R, red. The blue and green colors reach up to 200 m inside water, while all the other colors including violet can reach only up to the first 100 m inside the oceans. The arrows represent the depth to which different colors of light reach the oceans.

WHAT ARE PHYCOBILIPROTEINS?

Phycobiliproteins play the role of assistants to Chl in aquatic (water) environments. Since light has a difficult time penetrating into the oceans, phycobiliproteins make this job easier by absorbing whatever light is available; they absorb the green portion of the light and turn it to red light, which is the color of light required by Chl [2]. However, changing the color of light is not as easy as it seems. The green light has to pass through different phycobiliprotein molecules, which absorb light of one color and give out light of another color. The color that is given out is then taken up by a second phycobiliprotein, which turns it into a third color. This process continues until the emitted light is red, which can finally be taken up by Chl. For this whole process to take place, we have three different kinds of phycobiliprotein molecules arranged as a sort of a hat over the Chl molecule, as you can see in Figure 3. These three kinds of phycobiliproteins are:

(a) C-phycoerythrin (CPE), pinkish-red in color and responsible for absorbing the green portion of sunlight.
(b) C-phycocyanin (CPC), deep blue in color and responsible for absorbing the orange-red portion of sunlight.
(c) Allophycocyanin (APC), light blue in color and responsible for absorbing the red portion of sunlight.

The reason phycobiliproteins absorb light of different colors is that they contain chemical molecules called bilins inside them, which give them their bright colors. These bilins are responsible for absorbing light of one color and emitting light of another color, thus causing a change in the color of light. Advanced instruments have let us analyze the arrangement of these molecules and

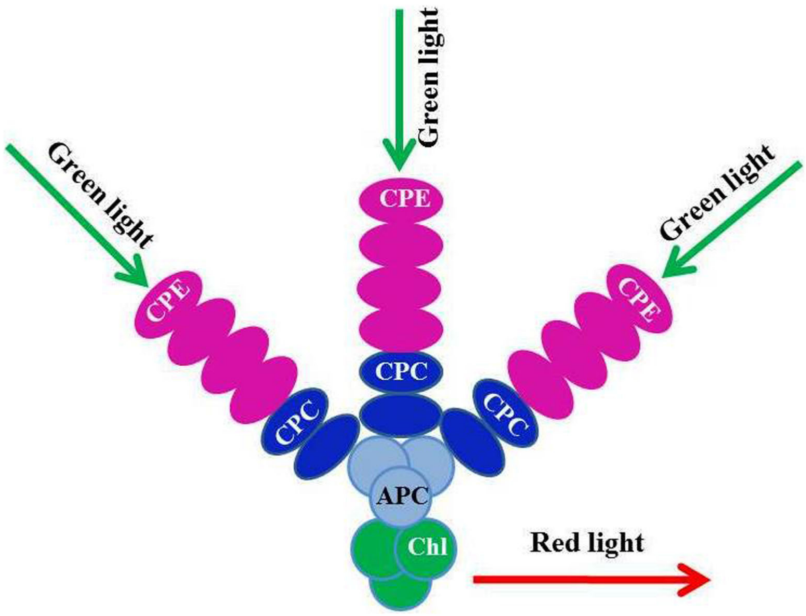

FIGURE 3

FIGURE 3

Hat-like arrangement of phycobiliproteins and chlorophyll (Chl) in cyanobacteria. The green light is first absorbed by C-phycoerythrin which passes it on to C-phycocyanin (CPC). CPC further passes the light energy to allophycocyanin (APC) which transfers it to Chl for photosynthesis, using the red light.

proteins in the cyanobacteria. We know that phycobiliproteins are shaped like disks [3], and the disks are stacked on top of each other to form the hat-like structure. One end of the stack is made of CPE, whereas the other end is made of CPC. This assembly joins to the core, made of APC. This entire structure is linked to Chl, which accepts the red light emitted by APC. The arrangement of the hat-like structure has been shown in Figure 3.

HOW DOES THE LIGHT ENERGY TRANSFER TAKE PLACE IN PHYCOBILIPROTEINS?

FLUORESCENCE

The property of certain compounds to absorb one color of light and to give off another color. Phycobiliproteins use this property to change the color of light they absorb so that the light can be used for photosynthesis.

The change in light color from green to red takes place through a process known as **fluorescence**. Let us see what fluorescence is. Imagine a transparent container filled with a pink-colored liquid that, when illuminated with a flashlight, shines a bright orange! That is exactly what CPE does (Figure 4). All phycobiliproteins possess this exciting property of giving off visible light of a color different from the color of light that is shone on them. After CPE changes green light to yellow-orange, CPC takes up the yellow-orange light and changes it to light red. APC takes up this light-red light and changes it to a deep red light for Chl. So, now we have the green light changed to red, which is the color of light that nature intended Chl to absorb. The entire process is a sort of a relay race, where each participant picks up where the previous one left off (Figure 5). These phycobiliproteins are an important part of the tiny microscopic organisms called cyanobacteria, which carry out photosynthesis in much the same way as land plants do. The only difference is that they use a different set of chemical molecules—cyanobacteria use phycobiliproteins while land plants use Chl.

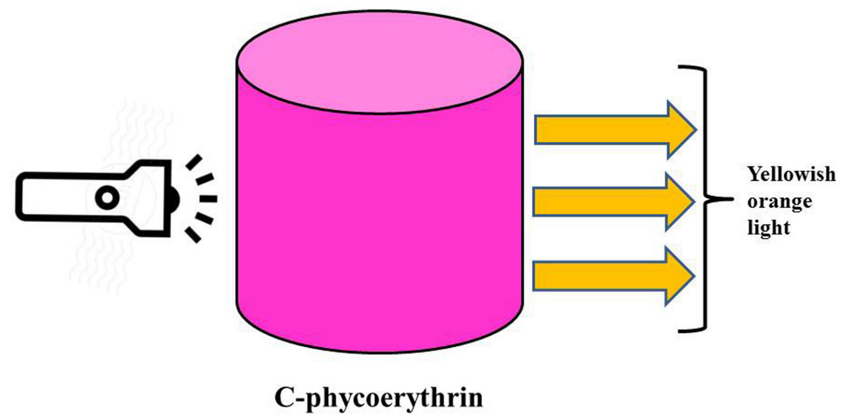

FIGURE 4

FIGURE 4

Fluorescence property of C-phycoerythrin (CPE). The white color of the light produced by the flashlight is changed to yellowish-orange light by CPE, to be taken up by C-phycocyanin.

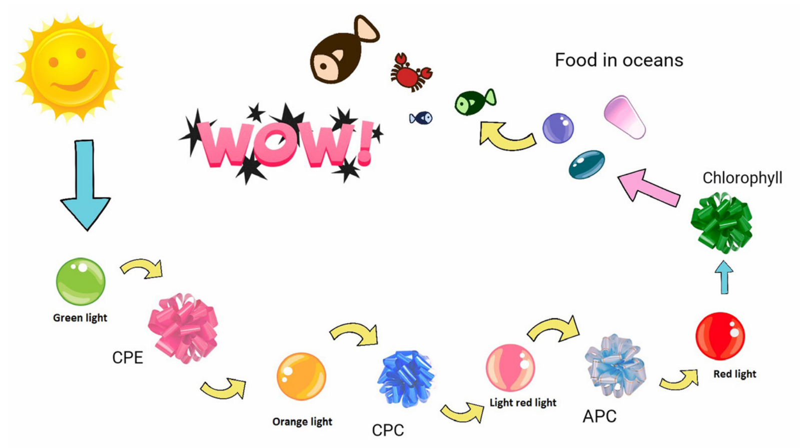

FIGURE 5

FIGURE 5

Phycobiliproteins change the color of light from green to red, so that it can be used for photosynthesis. The green-colored light is taken up by C-phycoerythrin (CPE), which changes the color of the light to yellowish orange. The orange light is taken up by C-phycocyanin (CPC), which further changes it to light red. The light red color is absorbed by allophycocyanin (APC), which changes it to red color. The red color is finally absorbed by chlorophyll, for producing food through photosynthesis.

WHAT DID WE LEARN?

So, we now know that photosynthesis is the process by which plants produce their food, using Chl. We also know that the reduced amount of light available in the oceans decreases this photosynthetic process. Nature has evolved some helper chemical molecules known as phycobiliproteins, which are able to absorb the colors of light available in the oceans and turn this light into a color that Chl molecules can use. These phycobiliproteins are found in tiny, invisible-to-the-naked-eye cyanobacteria, whose photosynthesis is responsible for providing food for the living organisms in the oceans and also for making the oxygen in our atmosphere that we breathe every second. Isn't it exciting that these tiny organisms can make such a difference to marine life? In the future, we hope to gain more understanding of the functions of phycobiliproteins and the roles that they may play for the benefit of mankind.

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CONFLICT OF INTEREST STATEMENT: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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MATILDE, 9 YEARS OLD

My name is Matilde. I am 9 years old and I enjoy playing chess and reading. My favorite subjects in school are math and science.

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My name is Emilia. I am 15 years old. I enjoy reading and writing. My favorite branch of science is astrophysics and general cosmology.

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TONMOY GHOSH

I was trained as a biotechnologist and have recently submitted my thesis. While waiting for my defense, I thought it would be wonderful if I could share my knowledge while working with the group of Dr. Sandhya Mishra from Central Salt and Marine Chemicals Research Institute, Gujarat, India. My research interests currently involve finding out new and exciting biological and chemistry applications for C-phycoerythrin, of which we have two or three different sources. In pursuit of my studies and goals, I thought it would be wonderful to share my experience in this field with our budding scientists and researchers the world over.

SANDHYA MISHRA

I completed my Ph.D. in bio-inorganic chemistry under Prof. M. M. Taqui Khan from Bhavnagar University in 1990. I have been working on phycobiliproteins and their applications for the past two decades and my research group currently focuses on phycobiliproteins and carotenoids from cyanobacteria. Since our state has a long coastline, we can always be found in some remote corner of Gujarat, and yes, we love beaches and the oceans! I have always tried to encourage and motivate my students to free their creativity with skill and back it up using scientific experiments. *smishra@csmcri.res.in