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A Review of General Properties of Blue-Green Algae (Cyanobacteria)

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A R T I C L E I N F O

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A B S T R A C T

Cyanobacteria are a photosynthetic Gram-negative bacteria that found in all habitat and usually in water. About two-thirds of the species studied are able to fix nitrogen, and thus participate in the nitrogen cycle. Cyanobacteria contain three pigments, green, blue and red. The green pigment is chlorophyll and helps it in photosynthesis. The blue dye is what gives it the blue colour, and the reason for that is due to the abundance of blue dye inside it. As for the red pigment, it is beta-carotene, so we infer its presence from the flamingo bird. When the flamingo drinks water, cyanobacteria enter its body, and the pink colour appears on some parts of its body. Cyanobacteria are currently considered a group of germs, so they are also called cyanobacteria. It has been completely shown that they are not closely related to plants, as they are not related to plants in any way (contrary to what was expected), nor to fungi or animals. Cyanobacteria are a variety of Gram-positive bacteria present in a range of different environmental locations such as soil, vegetables, sewage, skin and skin blotches. Some such as *Corynebacterium diphtheriae* are pathogens while others such as *Corynebacterium glutamicum* are of enormous industrial importance. *C. glutamicum* is a biotechnologically important bacterium with an annual production of more than two tons of the amino acids Polycomb group and lysine.

1. Introduction

Cyanobacteria also known as Cyanophyta, are a phylum of Gram-negative bacteria (Sinha & Häder, 2008) that obtain energy via photosynthesis. The name cyanobacteria refers to their color (from Ancient Greek κυανός (kuanós) 'blue' which similarly forms the basis of cyanobacteria's common name, blue-green algae (Allaby, 1992) although they are not usually scientifically classified as algae. They appear to have originated in a freshwater or terrestrial environment (Stal, 2016). Sericytochromatia, the proposed name of the paraphyletic and most basal group, is the ancestor of both the non-photosynthetic group Melainabacteria and the photosynthetic cyanobacteria, also called Oxyphotobacteria (Monchamp, et al, 2019).

Cyanobacteria use photosynthetic pigments, such as carotenoids, phycobilins, and various forms of chlorophyll, which absorb energy from light. Unlike heterotrophic prokaryotes, cyanobacteria have internal membranes. These are flattened sacs called thylakoids where photosynthesis is performed (Monchamp, et al, 2019). Phototrophic eukaryotes such as green plants perform photosynthesis in plastids that are thought to have their ancestry in cyanobacteria, acquired long ago via a process called endosymbiosis. These endosymbiotic cyanobacteria in eukaryotes then evolved and differentiated into specialized organelles such as chloroplasts, chromoplasts, etioplasts, and leucoplasts, collectively known as plastids.

Cyanobacteria are the first organisms known to have produced oxygen by producing and releasing oxygen as a biproduct of photosynthesis, cyanobacteria are thought to have converted the early oxygen-poor, reducing atmosphere into an oxidizing one, causing the great oxidation event and the "rusting of the Earth", (Liberton & Pakrasi, 2008). It

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dramatically changed the composition of the Earth's life forms (Pathak, et al., 2018).

2. Materials and Methods

The cyanobacteria *Synechocystis spp* and Cyanothece are important model organisms with potential applications in biotechnology for bioethanol production, food colorings, as a source of human and animal food, dietary supplements and raw materials. Cyanobacteria produce a range of toxins known as cyanotoxins that can pose a danger to humans and animals.

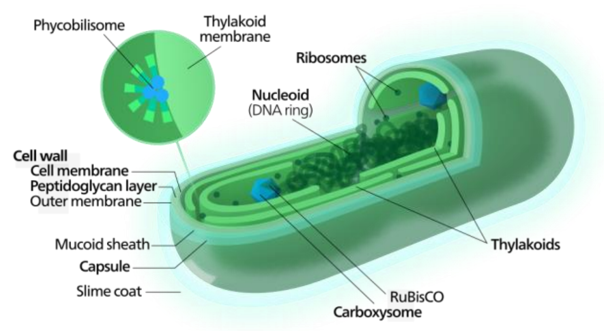

Fig. 1. Diagram of a typical cyanobacterial cell (Long et al, 2007)

Morphology

Cyanobacteria are variable in morphology, ranging from unicellular and filamentous to colonial forms. Filamentous forms exhibit functional cell differentiation such as heterocysts (for nitrogen fixation), akinetes (resting stage cells), and hormogonia (reproductive, motile filaments). These, together with the intercellular connections they possess, are considered the first signs of multicellularity (Claessen et al, 2014; Nürnberg et al., 2014).

Each individual cell (each single cyanobacterium) typically has a thick, gelatinous cell wall. They lack flagella, but hormogonia of some species can move about by gliding along surfaces. Many of the multicellular filamentous forms of Oscillatoria are capable of a waving motion; the filament oscillates back and forth. In water columns, some cyanobacteria float by forming gas vesicles, as in archaea. These vesicles are not organelles as such. They are not bounded by lipid membranes, but by a protein sheath (Singh, 2014).

Many cyanobacteria form motile filaments of cells, called hormogonia, that travel away from the main biomass to bud and form new colonies elsewhere (Risser et al, 2014; Khayatan et al, 2017). The cells in a hormogonium are often thinner than in the vegetative state, and the cells on either end of the motile chain may be tapered. To break away from the parent colony, a hormogonium often must tear apart a weaker cell in a filament, called a necridium (Risser et al, 2014).

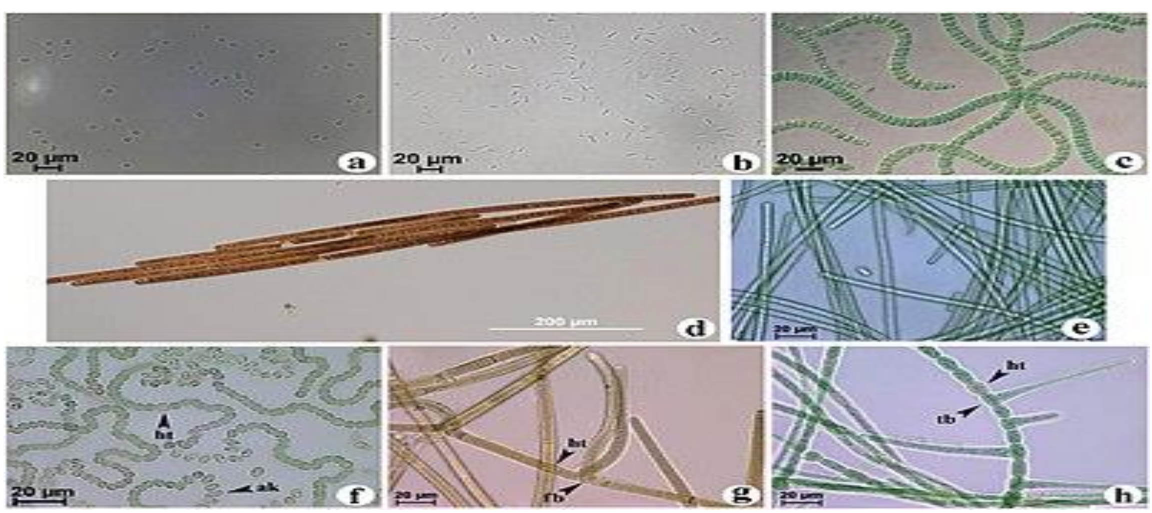

Fig. 2. Morphological variations of some cyanobacteria

Morphological variations (Esteves-Ferreira et al, 2017)

- Unicellular: (a) *Synechocystis and (b) Synechococcus elongates*
- Non-heterocytous: (c) *Arthrospira maxima*, (d) *Trichodesmium* and (e) *Phormidium*
- False- or non-branching heterocytous: (f) *Nostoc* and (g) *Brasilonema octagenarum*
- True-branching heterocytous: (h) *Stigonema* (ak) Akinetes (fb) false branching (tb) true branching

Some filamentous species can differentiate into several different cell types:

- Vegetative cells – the normal, photosynthetic cells that are formed under favorable growing conditions

- Akinetes – climate-resistant spores that may form when environmental conditions become harsh

- Thick-walled heterocysts – which contain the enzyme nitrogenase vital for nitrogen fixation (Meeks et al, 2001; Golden & Yoon, 1998; Fay, 1992) in an anaerobic environment due to its sensitivity to oxygen.

Each individual cell (unicellular cyanobacterium) typically has a thick, gelatinous cell wall. They lack flagella, but hormogonia of some species can move about by gliding along surfaces (Walsby, 1994). Many of the multicellular filamentous forms of *Oscillatoria* are capable of movement. In water columns. some cyanobacteria float by forming gas vesicles, as in archaea. These vesicles are not organelles as such. They are not bounded by lipid membranes, but by a protein sheath.

Nitrogen Fixation

Nitrogen-Fixing Cyanobacteria

Some cyanobacteria can fix atmospheric nitrogen in anaerobic conditions by means of specialized cells called heterocysts. Heterocysts may also form under the appropriate environmental conditions (anoxic) when fixed nitrogen is scarce. Heterocyst-forming species are specialized for nitrogen fixation and are able to fix nitrogen into ammonia (NH_3), nitrites (NO_2 (or nitrates (NO_3) (Esteves-Ferreira et al, 2017).

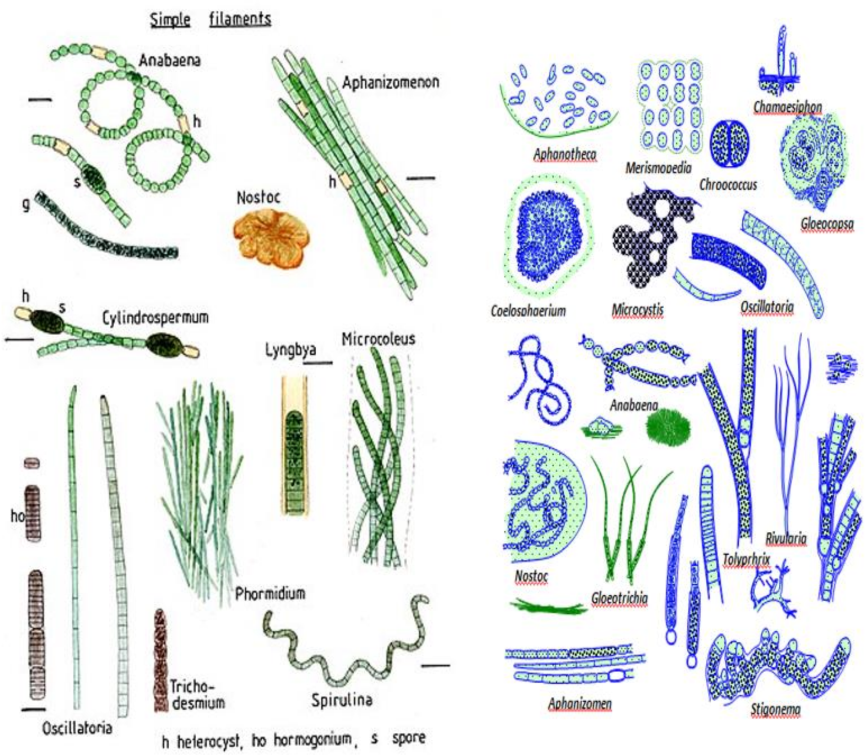

Fig. 3. Nitrogen-fixing cyanobacteria (Bocchi, 2010)

3. Result and Discussion

Photosynthesis

Carbon Fixation

Cyanobacteria use the energy of sunlight to drive photosynthesis, a process where the energy of light is used to synthesize organic compounds from carbon dioxide. They typically employ several strategies which are collectively known as a "CO_2 concentrating mechanism" to aid in the acquisition of inorganic carbon (CO_2 or bicarbonate). Among the more specific strategies is the widespread prevalence of the bacterial micro compartments known as carboxysomes (Kerfeld et al, 2010) which co-operate with active transporters of CO_2 and bicarbonate, in order to accumulate bicarbonate into the cytoplasm of the cell (Rae et al, 2013).

Carboxysomes are icosahedral structures composed of hexameric shell proteins that assemble into cage-like structures that can be several hundreds of nanometres in diameter. It is believed that these structures tether the CO_2-fixing enzyme, RuBisCO, to the interior of the shell, as well as the enzyme carbonic anhydrase, using metabolic channeling to enhance the local CO_2 concentrations and thus increase the efficiency of the RuBisCO enzyme (Long et al, 2007).

Electron Transport

In contrast to purple bacteria and other bacteria performing anoxygenic photosynthesis, thylakoid membranes of cyanobacteria are not continuous with the plasma membrane but are separate compartments (Vothknecht & Westhoff, 2001). The photosynthetic machinery is embedded in the thylakoid membranes, with phycobilisomes acting as light-harvesting antennae attached to the membrane, giving the green pigmentation observed (with wavelengths from 450 nm to 660 nm) in most cyanobacteria (Sobiechowska-Sasim et al, 2014).

While most of the high-energy electrons derived from water are used by the cyanobacterial cells for their own needs, a fraction of these electrons may be donated to the external environment via electrogenic activity

Respiration

Respiration in cyanobacteria can occur in the thylakoid membrane alongside photosynthesis, (Vermaas, 2001) with their photosynthetic electron transport sharing the same compartment as the components of respiratory electron transport. While the goal of photosynthesis is to store energy by building carbohydrates from CO2, respiration is the reverse of this, with carbohydrates turned back into CO2 accompanying energy release.

Cyanobacteria appear to separate these two processes with their plasma membrane containing only components of the respiratory chain, while the thylakoid membrane hosts an interlinked respiratory and photosynthetic electron transport chain. Cyanobacteria use electrons from succinate dehydrogenase rather than from NADPH for respiration (Vermaas, 2001).

Electron Transport Chain

Many cyanobacteria are able to reduce nitrogen and carbon dioxide under aerobic conditions, a fact that may be responsible for their evolutionary and ecological success. The water-oxidizing photosynthesis is accomplished by coupling the activity of photosystem (PS) II and I (Z-scheme). In contrast to green sulfur bacteria which only use one photosystem, the use of water as an electron donor is energetically demanding, requiring two photosystems (Klatt et al, 2016).

Attached to the thylakoid membrane, phycobilisomes act as light-harvesting antennae for the photosystems (Grossman et al, 1993). The phycobilisome components (phycobiliproteins) are responsible for the blue-green pigmentation of most cyanobacteria. The variations on this theme are due mainly to carotenoids and phycoerythrins that give the cells their red-brownish coloration. In some cyanobacteria, the color of light influences the composition of the phycobilisomes (Garcia-Pichel, 2009; Kehoe, 2010). In green light, the cells accumulate more phycoerythrin, which absorbs green light, whereas in red light they produce more phycocyanin which absorbs red. Thus, these bacteria can change from brick-red to bright blue-green depending on whether they are exposed to green light or to red light (Kehoe & Gutu, 2006).This process of "complementary chromatic adaptation" is a way for the cells to maximize the use of available light for photosynthesis (Kehoe & Gutu, 2006).

A few genera lack phycobilisomes and have chlorophyll b instead (*Prochloron, Prochlorococcus* and *Prochlorothrix*). These were originally grouped together as the *prochlorophytes or chloroxybacteria*, but appear to have developed in several different lines of cyanobacteria. For this reason, they are now considered as part of the cyanobacterial group (Palenik & Haselkorn, 1992).

Movement

It has long been known that filamentous cyanobacteria perform surface motions, and that these movements result from type V pili (Wilde et al, 2015). Additionally, *Synechococcus*, a marine cyanobacteria, is known to swim at a speed of 25 µm/s by a mechanism different to that of bacterial flagella (Waterbury et al, 1985). The formation of waves on the cyanobacteria surface is thought to push surrounding water backwards (Ehlers et al, 2012). Cells are known to be motile by a gliding method and a novel uncharacterized, nonphototactic swimming method that does not involve flagellar motion (Waterbury et al, 1985).

Many species of cyanobacteria are capable of gliding. Gliding is a form of cell movement that differs from crawling or swimming in that it does not rely on any obvious external organ or change in cell shape and it occurs only in the presence of a substrate (McBride, 2001). Gliding in filamentous cyanobacteria appears to be powered by a "slime jet" mechanism, in which the cells extrude a gel that expands quickly as it hydrates providing a propulsion force (Hoiczyk et al, 1998), although some unicellular cyanobacteria use type IV pili for gliding (McBride, 2001).

Cyanobacteria have strict light requirements. Too little light can result in insufficient energy production, and in some species may cause the cells to resort to heterotrophic respiration (Hoiczyk et al, 1998).Too much light can inhibit the cells, decrease photosynthesis efficiency and cause damage by bleaching. UV radiation is especially deadly for cyanobacteria, with normal solar levels being significantly detrimental for these microorganisms in some cases.

Filamentous cyanobacteria that live in microbial mats often migrate vertically and horizontally within the mat in order to find an optimal niche that balances their light requirements for photosynthesis against their sensitivity to photodamage. For example, the filamentous cyanobacteria *Oscillatoria sp.* and *Spirulina subsalsa* found in the hypersaline benthic mats of Guerrero Negro, Mexico migrate downwards into the lower layers during the day in order to escape the intense sunlight and then rise to the surface at dusk (Baumgartner, et al., 2019). In contrast, the population of *Microcoleus chthonoplastes* found in hypersaline mats in Camargue, France migrate to the upper layer of the mat during the day and are spread homogenously through the mat at night. An in vitro experiment using *Phormidium uncinatum* also demonstrated this species' tendency to migrate in order to avoid damaging radiation. These migrations are usually the result of some sort of photomovement, although other forms of taxis can also play a role (Corsetti et al, 2003).

Photomovement – the modulation of cell movement as a function of the incident light – is employed by the cyanoabacteria as a means to find optimal light conditions in their environment. There are three types of photomovement: photokinesis, phototaxis and photophobic responses (Baumgartner, et al., 2019).

Photokinetic microorganisms modulate their gliding speed according to the incident light intensity. For example, the speed with which *Phormidium autumnale* glides increases linearly with the incident light intensity (Corsetti et al, 2003). Phototactic microorganisms move according to the direction of the light within the environment, such that positively phototactic species will tend to move roughly parallel to the light and towards the light source. Species such as *Phormidium uncinatum* cannot steer directly towards the light, but rely on random collisions to orient themselves in the right direction, after which they tend to move more towards the light source. Others, such as Anabaena variabilis, can steer by bending the trichome (Baumgartner, et al., 2019).

Finally, photophobic microorganisms respond to spatial and temporal light gradients. A step-up photophobic reaction occurs when an organism enters a brighter area field from a darker one and then reverses direction, thus avoiding the bright light. The opposite reaction, called a step-down reaction, occurs when an organism enters a dark area from a bright area and then reverses direction, thus remaining in the light (Corsetti et al, 2003).

4. Conclusion

Cyanophyta is a type of plankton or algae with a dominant green pigment so it is often referred as blue green algae. Cyanophyta is also referred to as Cyanobacteria. The term Cyanobacteria is an organism with properties between bacteria and algae, which is capable of photosynthesis, but has a cell structure like bacteria. Cyanophyta is the oldest living thing that plays a major role in the biogeochemical cycles and is the only group of organisms capable of binding nitrogen from the air through heterocysts.
Cyanophyta is easily found in various environments because it can live in high-salinity seas, lakes, and freshwater rivers and also in extreme environmental conditions such as high acidity and high temperatures. These algae is very easy to grow in waters with high organic matter, especially those rich in nitrogen and phosphate. The ability to bind nitrogen from the air causes Cyanophyta able to survive in a nutrient-poor environment, so it is known as a pioneering microorganism.

Blooming Cyanophyta gives a blue green color (bottle green / dark green) in fresh water and red in seawater, depending on the dominant species. Cyanophyta which develops predominantly in a waters need to be monitored because they cause adverse. Some Cyanophyta species existence need to be aware of their, because they actively produce toxins into the waters.

Competing Interests

The authors have declared that no competing interests exist.

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