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Blue Green Algae As A Source of Biofertilizer for Sustainable Agriculture

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ABSTRACT: Biofertilizers like Blue Green Algae (Cyanobacteria) has a significant role in various aspect of agricultural field. It increases the fertility and aggregation of soil and makes atmospheric nitrogen available for plants which ultimately lead for the growth of the crops.

KEYWORDS-blue green algae, fertility, sustainable, agriculture, biofertilizer

I.INTRODUCTION

Cyanobacteria are the most abundant group of organisms on the earth. They are autotrophic and found in a diverse environment, especially in the marine and freshwater. Marine water is the richest source of nutrient for the cultivation of cyanobacteria [[1], [2], [3], [4]]. They are small and generally unicellular and often grow in large colonies. Cyanobacteria are composed of a broad range of bacteria with different shapes and sizes. They can cover 150 genera that have been identified so far. They have characteristics of the oldest fossils of about more than 3.5 billion years ago. They also have an evolutionary significance because they are responsible for present-day oxygenic environment.

Classification of cyanobacteria proposed in 1985, in which four orders of the bacteria have been identified as Chroococcales, Nostocales, Oscillatoriales and Stigonematales, and their phyla are Chroococcales, Gloeobacterales, and Pleurocapsales. Cyanobacteria are associated with the periods of origin of plants. The cyanobacteria are immensely important in determining the path of evolution and ecological changes all over the earth's history. In the late Proterozoic or the early Cambrian period, cyanobacteria began to take up residence within certain eukaryote cells, this event is called endosymbiosis, for the origin of the eukaryotes. They have the potential to fix atmospheric nitrogen, so that could be used as a biofertilizer for the cultivation of economically important crops such as rice and beans. Outer most layers of cyanobacteria are made up of distinct three types of layers such as a mucilaginous layer, cell wall, and innermost plasma membrane. The cytoplasm contains pigmented lamellae which are not organized into plastid. The pigments include chlorophylls, carotenes, xanthophylls, c-phycoerythrin and c-phycoyanin, and the last two pigments are found in blue-green algae [[5], [6], [7]].

Cyanobacteria consist of numerous organic inclusion bodies that can carry out different specialized functions. These inclusion bodies include the light-harvesting antennae, the phycobilisomes [8,9], polyphosphate bodies [10], cyanophycin granules [11], polyhydroxyalkanoate (PHA) granules [5,12,13], carboxysomes/polyhedral bodies [14], lipid bodies [11,15], thylakoid centers [16], DNA-containing regions [17] and ribosomes [18,19]. Cyanophycin granules acquire large polypeptides containing approximately the same number of the amino acids such as arginine and aspartic acid. These granules are visible large under the light microscope and store more nitrogen. Carboxysomes are also found in nitrifying bacteria and thiobacilli. Carboxysomes are polyhedral in shape about 100 nm in diameter. It is the reserve of ribulose-1,5-bisphosphate carboxylase (RuBisCo) in a paracrystalline arrangement site of CO₂ fixation. Halobacterium and Thiobacillus are purple and green photosynthetic bacteria; contain organic inclusion bodies such as gas vacuoles which provide buoyancy to the cyanobacteria to float over the surface. The nucleoplasm or the DNA enclosing region is present in the center of the cell and shows a fibrillar structure. There is unorganized nucleus is found in cyanobacteria and DNA is clumped without nuclear boundary and nucleolus. During the cell division, the nucleoplasmic materials dispersed throughout the cytoplasm without the participation of the spindle apparatus. Cyanobacteria consist of two important cells: (i) Heterocysts (responsible for nitrogen fixation for ammonia synthesis), and (ii) Vegetative cells (exhibit normal photosynthesis and reproductive growth).

Emerging roles of cyanobacteria as functional foods

Functional foods provide the necessary amounts of important nutritional compounds, such as proteins, carbohydrates, vitamins, fats, and minerals [9]. They may consist of bioactive compounds which are natural chemicals derived from plants, animals or micro-organisms and useful for human health. Cyanobacteria may be used as potential food

supplements and provide nutritional, therapeutic and beneficial values. There are several characteristics which make cyanobacteria as an attractive substitute for sustainable food production: global distributions, high nutrient content, require small volumes of water for growth and development (saltwater can also be used), need lesser amounts of land which may be infertile and unsuitable for other crops, easily digestible, product constancy over an extensive pH and temperature range, etc. [[20], [21], [22]]. In the present time, cyanobacteria are available as food supplements in the market in various forms like instance capsules, tablets and liquids [23,24]. They are considered to increase the nutritive values of snack foods, pasta, candy bars or gums and beverages, and also act as a source of natural food colorants [[25], [26], [27], [28], [29], [30]].

In recent time, the most frequent cyanobacterial strain used for human nutrition value is *Spirulina* (*Arthrospira*), due to its immense protein contents and significant nutritive values [27,31,32]. According to certain statistical analysis, 1 Kg of *Spirulina* may substitute of 1000 Kg of diversified fruits and vegetables in terms of nutritive value. Some cyanobacterial members (for example *Spirulina*, *Anabaena*, and *Nostoc*) are consumed as food supplements in several countries comprising Mexico, Chile, Peru and the Philippines. *Spirulina platensis* is grown on a huge scale using either aqueduct ponds or sophisticated photobioreactors and promoted as flakes, powder and tablets or capsules. It comprises more than 60% proteins, broad spectrum of prophylactic and therapeutic nutrients containing beta-carotene, thiamine, riboflavin, B-complex vitamins, minerals, trace elements and many surprising bioactive compounds [[33], [34], [35], [36]].

In the current scenario, it has been realized that existing requirement for wide research on functional food from cyanobacteria; several companies have introduced large scale production of cyanobacteria. The crucial steps involved for large scale productions are; culturing, harvesting, processing (drying) and packaging. At present time, more than 70 countries have commercialized products of nutritional importance which is obtained from cyanobacteria [37]. There are several commercial companies involved in the production of cyanobacteria as functional food products. The demand for wide-scale production of cyanobacterial products is enhancing, but there are restrictions related to their production which essential to be determined (Fig. 1). Therefore, advancement of proficient technologies is needed to decrease the production cost along with maintenance and upgrading of product quality. Furthermore, selection of potential cyanobacterial strain should be intensive and research oriented for the collection of the valuable germplasm [[40], [41], [42]]. Moreover, limitation in relations of water constraint should be considered for possible substitutes like wastewater or seawater [40,43,44]. There are some examples of cyanobacteria such as *Oscillatoria limnetica*, *Phormidium abronema*, *Oscillatoria tenuis*, *Lyngbya cryptovaginata*, *Tolypothrix tenuis* [45], *Spirulina platensis* [46], *Calothrix fusca* and *Gloeocapsa livida* [47], *Lyngbya limnetica*, *Scytonema bohnneri*, *Oscillatoria acuminata*, *Oscillatoria calcuttensis*, *Oscillatoria foreaui*, *Spirulina pacifica* and *Spirulina platensis* [48], which are the good source of carbohydrates and proteins. Lipids of *Spirulina* are cholesterol-free, which is useful for reducing blood cholesterol level, treatment of obesity, atherosclerosis, and diabetes [[49], [50], [51]]. Cyanobacteria are the source of minerals and vitamins which are good for bones, teeth, and blood. They contain vitamin A, B1, B2, B3, B6, E, H, folacin, pantothenic acid, inositol and abundant in vitamin B12 [49]. They also produce secondary metabolites which are the source of bioactive molecules including cytotoxic (41%), antitumor (13%), antiviral (4%), and antimicrobial (12%), and other compounds (18%) such as antimalarials, antimycotics, multidrug resistance reversers, herbicides, insecticides, algacides, and immunosuppressive agents [52,53]. All the above important characteristics make cyanobacteria as an emerging and attractive alternative source for sustainable food production.[1,2,3]

II.DISCUSSION

Present day's population is continuously increasing, and it will be reached to ~9.7 billion within 30 years. The major proportion of the population would be contributed by India (DESA UN, 2015). Increment in population has directly and indirectly dependent on the demand for contamination-free healthy food. World Health Organization has increased 50% of global food production by 2029. "Green Revolution" practices are also working for the increases in productivity of agriculture and reduce the risk of chemical-based fertilizers on human health as well as the environment. Thus, 'green technology' has been used by researchers for making eco-friendly environment by the exploitation of microbes. Green technology discusses several aspects of the use of cyanobacteria to improve crop productivity and soil fertility. Cyanobacteria can degrade a wide range of pollutants and perform different roles in the soil ecosystem to sustain soil fertility [54].

Cyanobacteria are emerging microorganism for sustainable agricultural development [24,55,56]. Fig. 2 displays a theoretical representation that exhibits the potential functions of cyanobacteria in sustainable agriculture and the environment. Diazotrophes are cyanobacteria useful for the generation of eco-friendly biofertilizers which are easily

available and less costly. They can control the nitrogen deficiency in plants, improve the aeration of soil, water holding capacity and add vitamin B12 [[57], [58], [59], [60]]. The most efficient nitrogen-fixing cyanobacteria are *Nostoc linkia*, *Anabaena variabilis*, *Aulosira fertilissima*, *Calothrix* sp., *Tolypothrix* sp., and *Scytonema* sp. are present in the rice crop cultivation area [61]. *Anabaena* and *Nostoc* are surviving on the surface of soil and rocks, and fix up to 20–25 kg/ha atmospheric nitrogen. *Anabaena* can fix 60 kg/ha/season of nitrogen and also enriches soils with organic matter [62]. Cyanobacteria do not require a host for their growth, development, and production of valuable organic products. *Azolla-Anabaena* association is an example of symbiosis for nitrogen fixation and nutrient enrichment in the rice paddy field. They exhibit lysis of lignin of cell wall and released phenolic compounds which induced profuse sporulation of the organism [63]. Applications of these biofertilizers have been reported in barley, oats, tomato, radish, cotton, sugarcane, maize, chilli and lettuce [4,5,6]

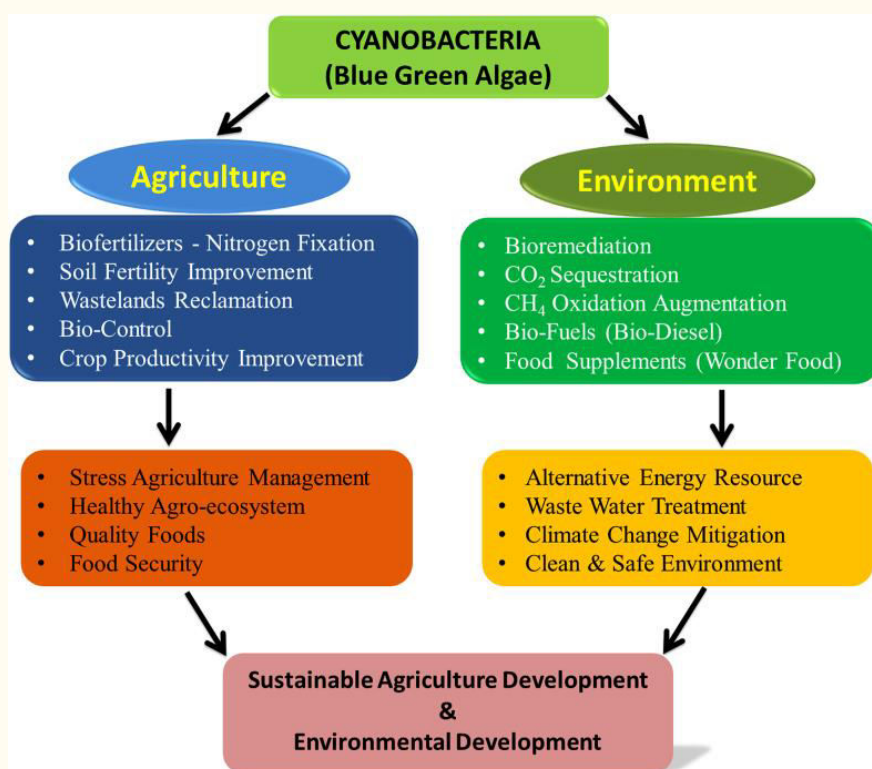


Fig. 2

A theoretical representation exhibits the potential functions of cyanobacteria in sustainable agriculture and the environment.

Song et al. [60] stated that cyanobacteria play a chief role in the maintenance and build-up of soil fertility, consequently yield as a natural biofertilizer (Development of sustainable agricultural practices by utilization of beneficial outcomes of cyanobacterial growth). The major actions of blue-green algae include; (a) Make porous soil and produce adhesive substances. (b) Excretion of phytohormones (auxin, gibberellins, etc.), vitamins, amino acids [65,66]. (c) Improve the water holding capacity of soil through their characteristic jelly structure [65]. (d) Increase in biomass of soil after their death and decomposition [67]. (e) Decrease in soil salinity [67]. (f) Controls weeds growth [67]. (g) Availability of soil phosphate by excretion of organic acids [68]. (h) Efficient absorption of heavy metals on the microbial surface (bioremediation) [69].

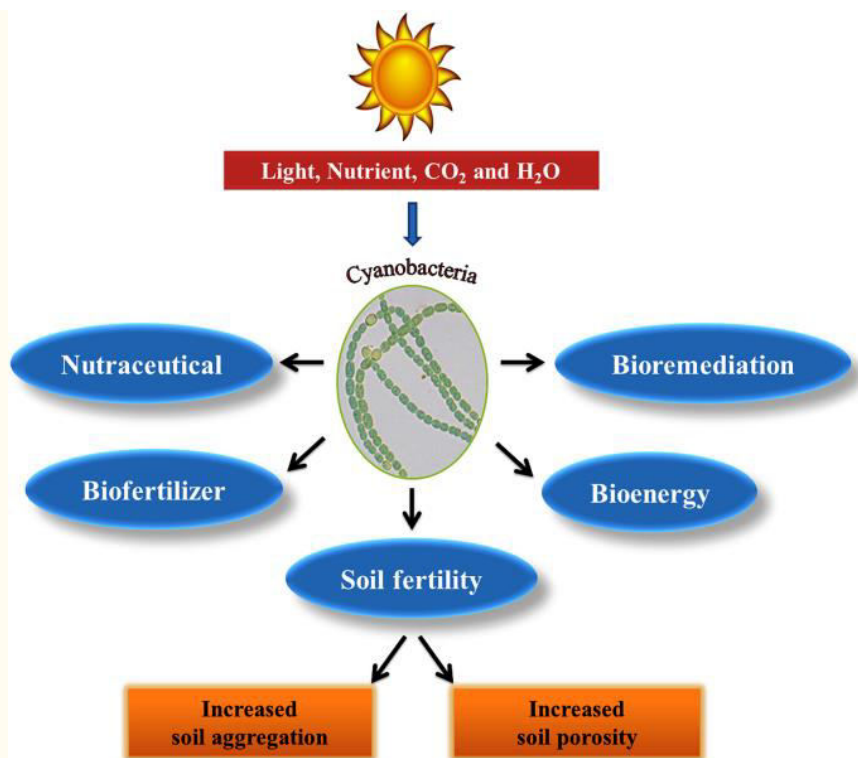


Fig. 3

Development of sustainable agricultural practices by utilization of beneficial outcomes of cyanobacterial growth.

III.RESULTS

Continuous increase in global human population and depletion of natural resources of energy posing threat to environment needs, sustainable supply of food and energy. The most ecofriendly approach 'green technology' has been exploited for biofertilizer preparation. Cyanobacteria are the most successful and sustained prokaryotic organism during the course of evolution. They are considered as one of the primitive life forms found on our planet. Cyanobacteria are emerging candidates for efficiently conversion of radiant energy into chemical energy. This biological system produces oxygen as a by-product. Cyanobacterial biomass can also be used for the large scale production of food, energy, biofertilizers, secondary metabolites, cosmetics and medicines. Therefore, cyanobacteria are used in ecofriendly sustainable agricultural practice for production of biomass of very high value and decreasing the level of CO₂. Bio-fertilization is a sustainable agricultural practice that includes using bio-fertilizers to increase soil nutrient content resulting in higher productivity. Soil micro-flora has been exposed to improve soil fertility and increase biomass productivity and identified as a correct environmentally friendly bio-based fertilizer for pollution-free agricultural applies. The majority of cyanobacteria can fix nitrogen from the atmosphere and several species including *Anabaena* sp., *Nostoc* sp., and *Oscillatoria angustissima* is known to be effective cyanobacterial based bio fertilizers. *Acutodesmus dimorphus*, *Spirulina platensis* *Chlorella vulgaris*, *Scenedesmus dimorphus*, *Anabaena azolla*, and *Nostoc* sp. are some of the green microalgae and cyanobacteria species that have been successfully used as bio fertilizers to boost crop growth. Also, *Chlorella vulgaris* is one of the most commonly used [7,8,9]microalgae in bio fertilizer studies. The addition of seaweed species that are *Sargassum* sp. and *Gracilaria verrucosa* leads to chemical changes as a soil fertility indicator on clay and sandy soils, and the addition of seaweed conditioner to soil can improve its organic content, return pH to normal, and reduce C/N ratio in both sandy and clay soil. This review provides an effective approach to increase soil fertility via environmentally friendly bio-based fertilizer using micro and macro algae. Instead of the usage of inorganic and organic fertilizers that have polluted impacts to soil as aggregation of heavy metals, in addition to there their human carcinogenic effects.

Soil microflora has been found to promote biomass productivity and improve soil fertility. However, algal microflora has also been found as a true bio-based fertilizer for agricultural techniques that are both environmentally favorable and pollution-free. Although photosynthetic, these algae are adapted to extremes of environments and have been observed

to thrive under extreme light settings with limited nutrients such as C and N levels and a low water need. They are extremely independent of alerts in terrestrial N pools that generate primary necessary amino acids, growth promoters, and hormones that are required for good crop growth in cropping systems because they are excellent N-fixing agents. The agricultural production in the industrialized world is largely determined by nature and the kind of soil, as most farmers in the lower sections of society cannot afford synthetic agricultural fertilizer unless it is subsidized (Mahapatra et al. 2018). Using improved crop varieties and efficient nutrient management strategies, the lost fertility of agricultural soils can be restored. This essentially advises that plentiful natural bio resources be used to improve crop nutrient status and allow for additional potential biological nutrient transfer mechanisms. Bio-fertilizers are important components of the regulated mineralization and [10,11,12] fertilization process in these situations. This can replace or supplement the currently utilized cost and energy-intensive chemical fertilizers because it is cost-effective, environmentally friendly, and renewable. Live and/or dead cells containing beneficial microbes are applied to plant and soil systems. They invade the rhizosphere quickly, promoting plant growth and development by converting inaccessible mineral forms into needed nutrients through mechanisms such as nitrogen fixation, mineralization, and rock phosphate solubility (Priya et al. 2014).

For the generation or cultivation of algal biomass, open Pond and closed photo-bioreactor (PBR) technologies have been developed. The production of open ponds is divided into two systems 1. Natural waters (ponds, lakes, and lagoons) and 2. Artificial ponds (circular and raceway). The open pond is a less expensive method of producing large-scale algal biomass than the PBR; but, the PBR provides a superior and controlled closed culture system for growing, which prevents contamination from molds, bacteria, protozoa, and competition from other microalgae. It's frequently set up outside to take use of the free energy that sunshine provides (Ozcan Konur 2015).

4.2. Harvesting

Biomass aggregation (flocculation and ultrasonic), flotation, centrifugation, and filtration are four ways for separating algal biomass from the growth media or harvesting it. In some circumstances, a combination of two or more strategies is utilized to boost effectiveness. Algae are chosen depending on a number of factors, including density, size, and desired end products. With the addition of flocculants to the media, such as multivalent cations and cationic polymers, algal cells are aggregated together to form a bigger particle known as a floc in this approach, which helps neutralize the cells' surface charge. Flotation is a technology that uses a micro-air bubble disperser to float algal cells on the water's surface without the use of chemicals; it is cost-effective due to its cheap operational expenses, simple operating procedure, and high biomass yield. Using a centrifuge and gravitational force, centrifugation is a method of extracting algal biomass from culture media. This technology is quick, easy, and effective, but because to the large energy input and maintenance requirements, the cost can soon climb. Another problem of this method is that it damages interior cells, resulting in the loss of delicate nutrients, whereas filtration is a way of extracting alga biomass from the liquid culture media by utilizing a porous membrane with a range of particle sizes. There are three types of filtration: ordinary, microfiltration, and ultrafiltration (isolation of metabolites) (Barros et al. 2015).

4.3. Biomass dehydration

Algae biomass is quickly processed to the next stage after being isolated from the growth medium to prevent spoiling or extend its shelf life. The three most popular types of drying or dehydration procedures are sun drying, spray drying, and freeze drying. The method used is largely influenced by the intended end results; when compared to the other two; sun-drying is the least expensive option. Because this method relies only on solar energy, it is limited by weather conditions, long drying durations, and the size of the drying area required. [13,14,15]Overheating, as well as changes in texture, color, and taste of the microalgae, may occur as a result of the unregulated process of drying with sunlight. Spray-drying is a method for making a dry powder from a thin spray of suspension droplets in a big vessel that is constantly in touch with heated air. This method has many advantages, including the ability to operate continuously, the fine powder produced, and the rapid drying ability to maintain a high-quality product because of its efficiency. However, some algae components, such as pigments, can deteriorate significantly, and the operation cost is high. Because large-scale production is prohibitively expensive, freeze-drying, also known as lyophilisation, is frequently employed in laboratories to dry microalgae. Freeze-drying is a dehydration method that uses the sublimation mechanism to dehydrate frozen items. The microalgae are frozen before freeze-drying to solidify the material at low temperatures. As the moisture content of the microalgae declines, the product's solid structure and quality are preserved (Balasubramaniam et al. 2021).

Go to:

Microalgae as bio-fertilizers 5.

Eukaryotic green algae and prokaryotic blue algae are examples of photosynthetic organisms known as microalgae. They have a lot of promise as biological resources in fields including medicine, health care, feed, and fuel. Because of their potential to increase soil nutrients, these intriguing organisms can also be utilized in modern agriculture. They might be unicellular, multicellular, filamentous, or saponaceous in nature. They are also the world's largest primary producers, with over 200,000 species. [16,17,18,19]

IV.CONCLUSION

Microalgae production entails mass cultivation, biomass recovery, and downstream operations to ensure a consistent yield for food, chemicals, feed, biofuel, and bio fertilizers (Balasubramaniam et al. 2021). In addition to enhancing soil fertility and quality, microalgae can create plant growth hormones, polysaccharides, antibacterial chemicals, and other metabolites (e.g., *Spirulina* sp., *Chlorella* sp., *Cyanobacteria* (blue-green algae) (Ronga et al. 2019). Because they participate directly in the assimilation of atmospheric carbon dioxide into organic algal biomass via photosynthesis, cyanobacteria and green microalgae are major organic matter sources in the agro-ecosystem (Guo et al. 2020a). Algae are responsible for half of all photosynthesis on the globe. Algae may greatly enhance soil organic carbon content by assimilating carbon dioxide. Heterocyst cells in cyanobacteria may fix atmospheric nitrogen and thereby meet the needs of soil micro and macrofauna, flora, and plants. Crops injected with cyanobacteria or cyanobacteria consortia boosted soil nitrogen concentration significantly, according to several studies. Cyanobacteria inoculation can economize 25–40% of chemical nitrogen fertilizer in the soil. Various microalgae and cyanobacteria that can be used as bio fertilizers [20]

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