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Cyanobacteria (BGA), A Boom Of Multiple Resources

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Abstract

The ongoing rise in human population resulted in the depletion of energy resources which pose a threat to the environment's demands, food security, global warming as well as to the sustainable production of food and energy. The prokaryotic creature that has evolved and persisted the longest is the Cyanobacterium, often called as blue green algae. They are regarded as one of the earliest living organisms on Earth. They effectively convert radiative energy into chemical energy. As a by-product, this biological system creates oxygen. BGA are able to fix molecular nitrogen in to assimiable forms of nitrogen. These forms can be easily then absorbed by the plants for their growth and development. Thus BGA makes the soil more fertile. So they are used as biofertilizer. For the manufacturing of biofertilizer, "green technology," the most environmentally friendly method, has been used. Cyanobacteria also have the potential to be employed in a number of industries, including bioenergy, biotechnology, natural products, medicine, agriculture, and the environment, due to their remarkable pace of development. We have outlined the prospective uses of cyanobacteria in this review's several scientific and technological fields, with a focus on how they might be used to create biofuels and other useful by products.

Key words: BGA, green technology, biofuel, biotechnology, antibacterial, biofertilizer

1. Introduction:

Cyanobacteria are an ancient class of algae. Cyan, which refers to the colour "turquoise blue," is how cyanobacteria got their name. They are also known to be blue green algae. Prokaryotic life forms include cyanobacteria. They are autotrophic, especially found in marine and fresh water. They prefer diverse environment to grow. Marine water is found to be richest source of nutrients for the cultivation of blue green algae [1-4]. BGA typically grow in vast colonies and are filamentous, unicellular, and tiny in size. Up to this point, 150 genera of BGA have been recognized. As they contribute to the current oxygen-rich atmosphere on the surface of the earth, they also have evolutionary significance. Their earliest fossil evidence is thought to be about 3.5 billion years ago. In 1985, a classification of BGA was presented, with three phyla—Chroococcales, Gloeobaterales, and Pleurocapsales—and four orders: Chroococcales, Nostocales, Oscillatoriales, and Stigonematales**.** They have a significant potential for fixing nitrogen in the atmosphere. For the production of commercially significant agricultural plants like rice and beans, they could therefore be utilized as biofertilizer.

One of the main groups that contribute to the biomass in paddy fields that fixes nitrogen is BGA. BGA's ability to fix nitrogen is closely tied to its agricultural significance in rice farming. Fertilizers are used to compensate for nitrogen deficiency, which is the second element that limits plant development in many regions. [5]. The overuse of chemical fertilizers contributes to a number of environmental issues, including the greenhouse effect, ozone layer thinning, soil and water salinity, and changes in other physico-chemical aspects of soil. Such problems can be minimizes by biofertilizers [6]. Biofertilizers are natural in origin. So they are beneficial. They provide nutrients and maintain soil texture and structure [7]. BGA play an important role in maintenance and buildup of soil fertility increasing rice cultivation [8].

BGA are composed of three different types of layers, including an inner plasma membrane, a cell wall, and an outermost mucilaginous sheath. The color-rich lamellae occupies the position in the cytoplasm which are not organized into plastid. Chlorophylls, carotenes, xanthophylls, c-phycoerythrin and c-phycocyanin pigments are present in BGA. [9-10].

2. Role of organic inclusion bodies associated with BGA

BGA consists of many organic inclusion bodies which have different specific functions. These bodies include the phycobilisomes [11-12] which act as light harvesting antennae, polyphosphate bodies [13], cyanophycean granules [14] store more nitrogen in the form of polypeptides, polyhydroxyalkanoate (PHA)granules [9,15,16], carboxysomes [17]which acts as reserve of RuBisCo (Ribulose 1-5 bisphosphate carboxylase) , lipid bodies [14,18], thylakoid centers [19], DNA containing regions [20] present in the center of the cell showing fibrillar structure ,ribosomes [21,22] and gas vacuoles which help BGA to float over the surface. In BGA, the nucleus is disorganized. BGA is made up of two crucial cells: a heterocyst that fixes nitrogen and a vegetative cell that performs photosynthesis and reproduction.

3. BGA as a tool for biological nitrogen fixation in paddy/rice fields.

The world's population is more than 50% dependent on rice. About 75% of land under rice cultivation, are wetlands. The traditional wetland rice cultivation is found to be extremely successful. Stable yield at moderate level has been maintained for thousands of years without causing any harmful effects to the soil [23]. This is due to wetland conditions which establish an environment suitable to maintain soil nitrogen. So that all the nitrogen fixing microorganisms' can able to flourish well in wetland rice fields.

India is a populous country with a strong agricultural economy. A growing population calls for more food to be available. Given their financial situation, the majority of Indian farmers find it challenging to employ expensive chemical fertilizers that are also naturally problematic. There is only one solution to the problem of rising food demand: improving crop output at low production costs. This is made feasible by employing biofertilizers in the form of BGA. BGA serve as biofertilizer because of their capacity to fix nitrogen. By fixing 20–30 kg N/ha, BGA can boost crop output by 10%–15%.

Biological nitrogen fixation in rice fields and its uses have been reviewed by Watanabe and Roger [24] and Roger and Watanabe [25]. Specific reviews associated with BGA [26], biological nitrogen fixation associated with Straw [27], rice genotypic differences in stimulating biological nitrogen fixation [28], *Azolla* [29] and leguminous green manures [30]. BGA are directly related with their ability to fix atmospheric nitrogen and improve soil fertility, consequently increasing rice growth and yield as natural biofertilizer [31].

The BGA also converts CO_2 to O_2 and thus contribute in minimizing environmental pollution. BGA enhance the soil aeration resulting in considerable increase in amount of O_2 rhizosphere. BGA excrete growth promoting substances such as Auxins, gibberellins, vitamins and amino acids [32].BGA increase water holding capacity of soil due to their jelly structure and also increase soil biomass after their death and decomposition. BGA reduce soil salinity and prevent weed growth. They increase soil phosphate by excreting organic acids [33]. Thus BGA ensure ecofriendly environment to agriculture, increasing soil fertility, decreasing chemical fertilizer's utilization and also production cost.

4. Role of BGA as functional food

The food which supplies necessary amount of essential nutrients in the form of carbohydrates, proteins, fats, vitamins and minerals, is called functional food [34]. The food may contain bioactive compounds, which are organic substances that are good for human health and come from plants, animals, and even microorganisms. There are many characters associated with BGA which make them to use as functional food viz. they are globally distributed, high nutrient contents, ability to grow in small water contents, require small area for cultivation ,food is easily digestible [35,36]. Now a days, BGA are available as food supplements in the market in various forms such as capsules, tablets and liquids [37, 38]. They are said to boost the nutritional content of drinks, pasta, candies, and snack items. They may be also used as food colorants [39-44].The most frequently used BGA strain for the human food supplement is *Spirulina* (*Arthrospira*) as it contains large amount of proteins and has significant nutritive value [45,46,47]. One kilograms of *Spirulina* can replace 1,000 kilograms of various fruits and vegetables, according to some statistical statistics. In a number of nations, including Mexico, Chile, Peru, and the Philippines, some BGA are eaten as food. Commercially grown *Spirulina* plantensis is offered as powder, pills, flakes and capsules in the market. It has a protein content of about 60%, along with minerals, vitamin B-complex, thiamine, riboflavin, and alpha-carotene [47, 48, 49]. *Spirulina's* lipids are cholesterol-free and helpful in lowering blood cholesterol, obesity, and diabetes. Vitamins and minerals that are excellent for bones, teeth, and blood can be found in plenty in BGA.

They also produce secondary metabolites which act as source of bioactive molecules including anti-tumor, anti-viral, anti-bacterial, cytotoxic, anti-malarial, anti-mycotic agents [50-51]. There are some examples of BGA like *Oscillatoria tenuis*, *Lyngbya cryptovaginata*, *Tolipothrix tenuis* [51], *Spirulina platensis* [52], *Calothrix fusca and Gloeocapsa livida* [53], *Lyngbya limnetica*, *Scytonema bohneri*, *Oscillatoria acuminate*, *Oscillatoria calcuttensis*, *Oscillatoria foreaui*, *Spirulina pacifica* [54], are good source of carbohydrates and proteins. At present time, there are 70 countries in the world which commercialized the products of nutritive value obtained from the BGA. The critical phases in producing nutritious items produced from BGA include cultivation, harvesting, processing (drying), and packaging. The table 1 lists a number of commercial businesses that produce BGA as functional food supplements. The need for large-scale cyanobacterial product manufacturing is growing, yet there are production challenges that need to be addressed (Figure 1.).

Companies	Country
Earthrise Farms, Cyanotech Corporation, Bio Earth Spirulina, Kalmath Valley Botanicals LLC	USA
Hainan DIC Microalgae, Nan Pao Resins, Fuqing King Dnarmsa Spirulina Co. Ltd, Hainan Simai Pharmacy Co. Ltd, Jiangsu Cibainian Nutrition Food Co. Ltd, Jiangxi Boyuan Spirulina Co. Ltd, Nanjing General Spirulina Developing Corporation, Blue bio Bio-Pharmaceutical Co. Ltd	China
Green Valley Spirulina, Blue Biotech, Sanatur Spirulina	Germany
Myanmar Microalgae Biotechnology Project, Myanmar Spirulina Factory	Myanmar
Bio Earth Spirulina	Italy
Ballarpur Industries, EID Parry, Zydus Cadila, Ahmedabad; Mapra Laboratories Pvt. Ltd, Mumbai; Cosmic Nutracos Solutions Pvt. Ltd, New Delhi; Hash Biotech Limited, Chandigarh; Sanat Products Ltd, New Delhi; Parry Neutraceuticals, Oonaiyur; Hydrolina Biotech Pvt Ltd, Chennai; Ecotech Technologies India Pvt Ltd, Mumbai; Essar Biotech, Hindupur; Miraculous Mushroom, Pune; Admark, Vijayawada; Care	India
Neotech Food, Siam Algae, Boonsom Spirulina Farm	Thailand
All Seasons Health	UK
Nan Pao Resins, Far East Bio-Tec Co. Ltd; Far East Microalgae Ind Co. Ltd	Taiwan
Natésis Spirulina	France
NaturKraftWerke Spirulina	Switzerland
Marcus Rohrer Spirulina	Netherlands
EXsymol S.A.M	Monacco
Solarium Biotechnology	Chile
Spirulina Mexicana	Mexico
Panmol	Australia
Inner Mongolia Biomedical Engineering	Mongolia
GeniX	Cuba

Ocean Nutrition	Canada
Koor Foods	Israel

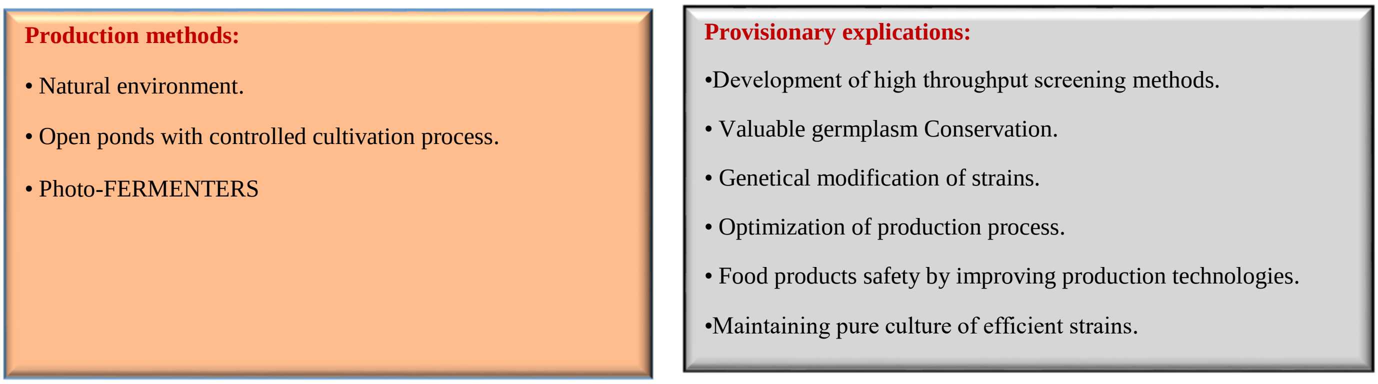
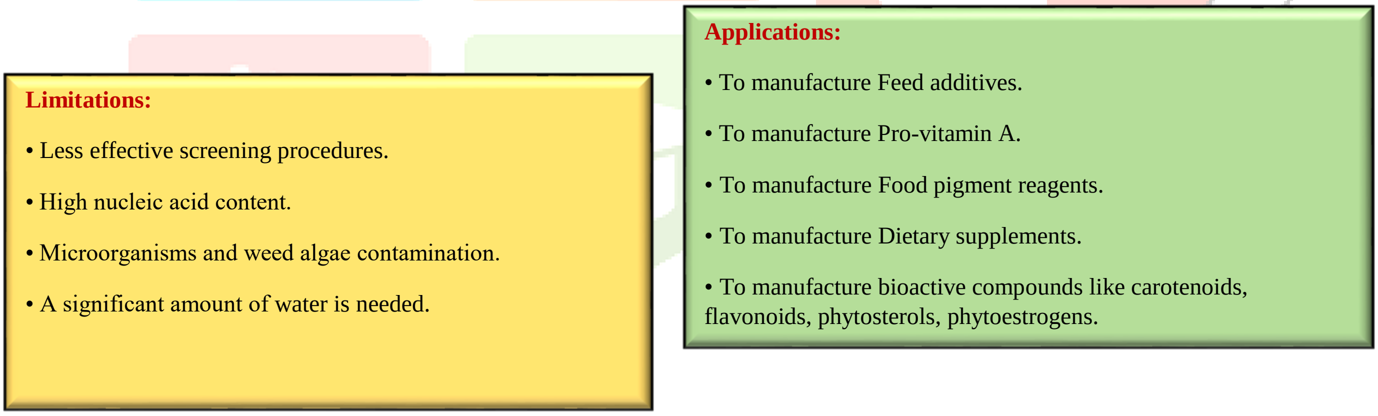


Fig 1: shows a diagrammatic representation of the production processes, uses, restrictions, and provisional explanations connected to the manufacture of cyanobacterial food items.

In India, to fulfil the nutritive demand of ever increasing population, BGA may have wide scope as an alternative source for sustainable food production.



5. BGA as a Resource for Biofuel Production

The word "biofuel" refers to the type of energy that is converted into chemical energy in the molecules that autotrophic organisms at the base of the food chain create through photosynthesis.

A variety of fuels known as "biofuels" are made in some way using biomass. Since the majority of the world's existing fuel supply is made up of fossil fuels, we urgently need new energy fuel sources. Although the idea of using micro algal biomass as a potential source of biofuel is not new, it is now being seriously considered in light of the rising cost of oil and, more significantly, the growing concern over climate change and global warming, which are more strongly linked to the burning of fossil fuels [55, 56, 57]. About 85% of all energy demand is met by these fossil fuels [58]. There is a significant demand to meet energy needs because fossil fuels are used so extensively. The necessity to investigate alternative energy sources has grown [59]. The most difficult challenges are finding clean, sustainable energy sources for future supplies. In the end, it is related to a higher level of living, economic prosperity, and stability. BGA have been designed to create a variety of various molecules linked to biofuels. Because of their genetic tractability, quick growth, and capacity to repair carbon dioxide. Synechococcus elongatus sp. strain PCC 7942 (S. elongatus), which was successfully designed to create ethanol with the addition of a pyruvate decarboxylase and an alcohol dehydrogenase, redirecting carbon from pyruvate, is one of the first examples of biofuel production in cyanobacteria [60]. Since then, the ability to produce ethanol from BGA has substantially increased [61]. But because of its hygroscopicity and low energy density, ethanol makes a pretty poor alternative for gasoline. These factors have led to a shift in focus on fuels with longer carbon chains. S. elongatus effectively synthesised isobutyraldehyde, a crucial chemical feedstock for hydrocarbons typically sourced from petroleum. Chemical conversion makes it simple to create isobutyraldehyde, a viable substitute for gasoline. Direct biological production of Isobutanol from *S. elongatus* was achieved with the addition of an alcohol dehydrogenase reaching 450 mg/L in 6 days [62]. There are three heterologous enzymes, acetolactate synthase, 2-acetolactate decarboxylase, and a secondary alcohol dehydrogenase, introduced into *S. elongatus* which catalysed the conversion of carbon flux from pyruvate to the production of the 2,3-butanediol reaching 2.4 g/L in 21 days [63]. Other chemicals produced with heterologous biosynthetic pathways from cyanobacteria include 1-butanol (29.9 mg/L) [64], 2-methyl-1-butanol (200 mg/L) [65], ethylene (~171 mg/L·day) [66, 67], isoprene (0.05 mg/g dry cell day) [68], and fatty acids (197 mg/L) [69]. BGA also possess significant potential for lipid production, which can be used as biofuel feedstock [70].

As a result, BGA can produce biofuel in a more efficient, sustainable, and safe manner for the environment. They might replace the majority of the use of fossil fuels.

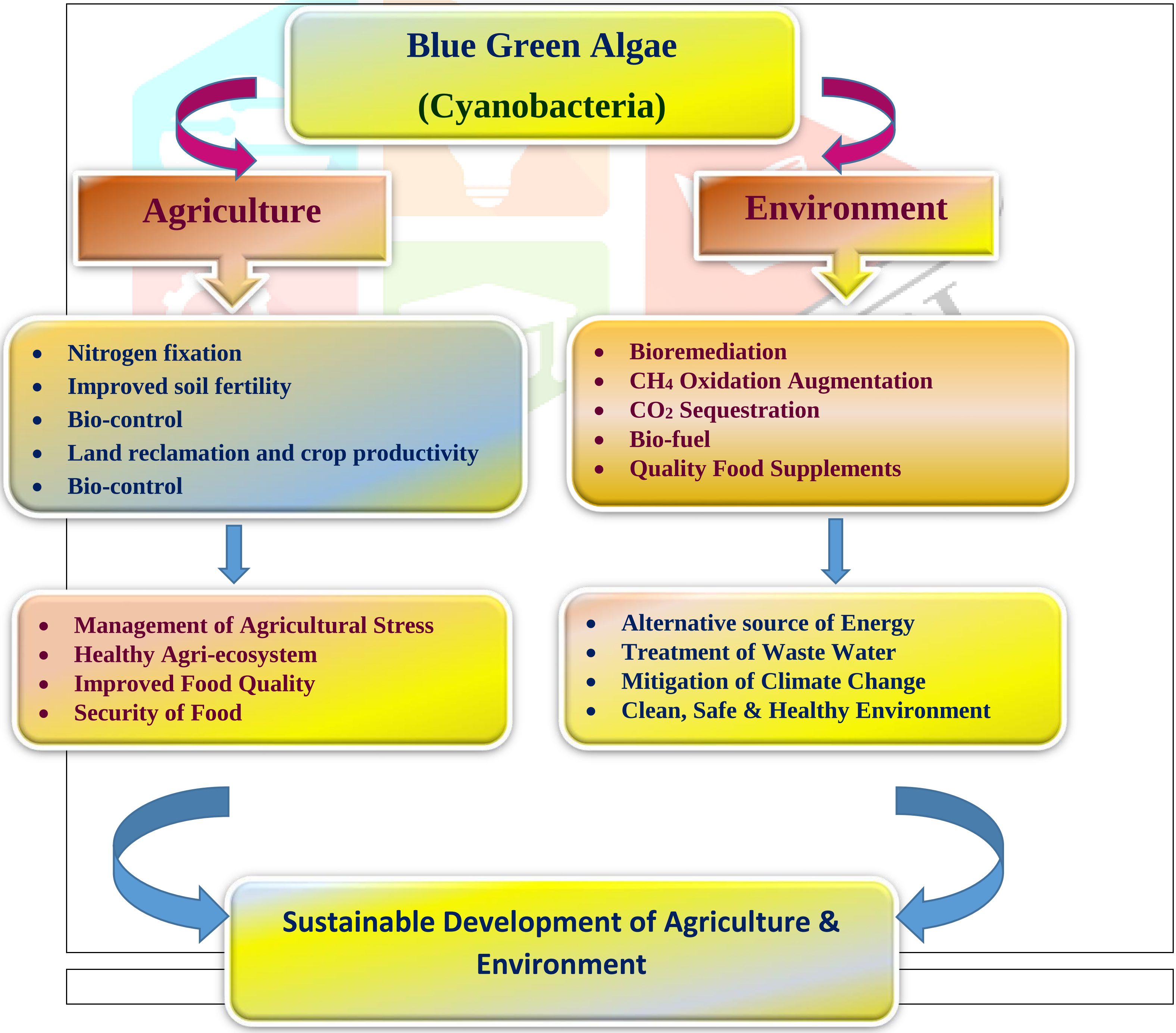


Figure 2: A fictitious example of how cyanobacteria might be used in environmentally friendly and sustainable agriculture.

6. Environmental management of blooms of BGA

BGA develop very quickly and produce large blooms on the water's surface when given enough phosphorus (P) and nitrogen (N), as well as water, air, sunlight, and other nutrients.

These BGA blooms have the potential to release toxins into the water and reduce its oxygen content. The development of other aquatic species can be adversely affected. The growth and reproduction of BGA depend heavily on phosphorus. Some cyanobacteria species are also capable of producing toxins or poisons. When exposed in excessive doses, these poisons can harm the liver or nerves in both humans and animals. When large amounts of the toxins are ingested, it can kill animals. Thus these BGA blooms act as a major agent of water quality deterioration and water pollution [71-72]. A few experimental studies on manipulating BBGA have been conducted. For the effective long-term control and management of damaging BGA blooms, the dual N and P input reductions are typically necessary [71, 73].The prevention of BGA blooms has been the subject of some experimental experiments. It has been discovered that balancing the amounts of nitrogen and phosphate in water can help control BGA blooms. In general, nitrogen was thought to be the main ingredient that restricted the growth of phytoplankton biomass. [74, 75, 76].

There are two methods i.e. 1. Reducing the inputs of Nitrogen and Phosphorus. 2. Reducing the input of Phosphorus. So that the ratio of N and P differ greatly from the equilibrium **[77-**78]. The deficiency of 'P' can affect cell division which in turn reduce the growth. BGA require a high concentration of "N," which can't be supplied exclusively through nitrogen fixation. Therefore, the ban on importing nitrogen can still be utilised to limit BGA growth.

The growth rate of the BGA population can be slowed down and BGA blooms can be prevented if two environmental elements, P and N, are managed to some extent. As a result, it may be a method of reducing water quality pollution.

7. Cyanobacteria: A Potential Source of Bioactive compounds of pharmaceutical importance

The marine BGA are rich source of secondary metabolites [78]. Secondary metabolites of BGA contain various bioactive molecules which include 41% cytotoxic, 13% antitumor, 4% antiviral, 12% antimicrobial, and 18% other compounds including antimalarial, antimycotics, multidrug resistance reversers, herbicides, insecticides, algaecides, and immuno- suppressive agents [79]. Both medications and prototypes for the creation of new drugs are made from these natural substances. Therefore, BGA metabolites continue to be explored for their application in many biological areas and can be an exceptional source of compounds for drug discovery [80, 81, 82].

Anticancer activity

Moore (Oregon State University) and Gerwick (University of Hawaii) started screening cyanobacterial extracts for novel anticancer chemicals in the 1990s. Numerous cyanobacterial bioactive chemicals target tubulin or actin filaments in eukaryotic cells, making them an effective source of anticancer medicines [83]. Dolastatin 10 and 12 are two tiny anticancer peptides that were isolated from Symploca species and Leptolyngbya species, respectively. [84, 85]. Curacin A showed antiproliferative property that has been isolated from *Lyngbya majuscula* [86]. Curacin A was also artificially synthesized because of its pharmacological importance [87].

Antibacterial Activity

Scientists are testing cyanobacterial extracts for their antibacterial activity in an effort to create novel antibiotics [88 89 90] and have discovered that they may be active against a variety of bacteria. Noscomin from *Nostoc commune* exhibited antibacterial activity against *Bacillus cereus, Staphylococcus epidermidis, and Escherichia coli* [91].

Nostocarboline from *Nostoc* was found to inhibit the growth of other cyanobacteria and green alga [92]. Nostocine A isolated from *Nostoc spongiaeforme* inhibited the growth of green algae more strongly than cyanobacteria [93]. Hapalindole (alkaloids) from *Nostoc* CCC537 and *Fischerella* sp. showed antimicrobial activity *against Mycobacterium tuberculosis H37Rv, Staphylococcus aureus ATCC25923, Salmonella typhi MTCC3216, Pseudomonas aeruginosa ATCC27853, E. coli ATCC25992,* and *Enterobacter aerogenes MTCC2822* [94]. Cyanobacteria will be potentially viable candidates because of the urgent need to find novel active compounds with antibacterial activity due to the rise in bacterial resistance to antibiotics.

Antiviral Activity

HIV, AIDS, dengue, and avian influenza (H5N1 virus) are lethal viral diseases spread all over the world and has had serious consequences. The anti-HIV highly active antiretroviral therapy (HAART) is found to be effective in controlling the development of HIV infections but it is toxic [95]. Therefore, new medications are required to combat these deadly diseases. By preventing viral absorption or penetration and slowing the multiplication phases of progeny viruses after penetration into host cells, antiviral substances derived from cyanobacteria shown bioactivity against these viruses. Protection of human lymphoblastoid T-cells from the cytopathic effect of HIV infection was reported with an extract of *Lyngbya lagerheimeii* and *Phormidium tenue* [96]. Sulfonic acids, a new class of HIV inhibitors that contain glycolipid and were derived from an extract of cyanobacteria, were discovered to have anti-HIV activity. Cyanovirin-N (CVN), a peptide isolated from cyanobacteria, inactivates strains of HIV virus and inhibits cell-to-cell and virus-to-cell fusion [97].

Antiprotozoal Activity

As per the data given by WHO, more than 1 billion people throughout the world are suffering from tropical diseases caused by *Plasmodium*, *Trypanosoma*, *Leishmania*, *Schistosoma*, and others [98]. Failures in the treatment of these diseases, especially in cases of malaria [99] and leishmaniasis [100], are due to development of resistance by these protozoa. On the other hand, progress in the advancement of drug discovery programs against these diseases is very slow [101]. To advance the creation of efficient and affordable medicines for a variety of ailments, the Panamanian International Cooperative Biodiversity Group is evaluating extracts from terrestrial and marine sources. In addition, the protease inhibitor nostocarboline [102], an alkaloid isolated from Nostoc sp., was found to be active against *Trypanosoma brucei*, *Trypanosoma cruzi*, *Leishmania donovani*, and *Plasmodium falciparum*. Aerucyclamide [103] isolated from *Microcystis aeruginosa* PCC 7806 was also found to be active against *T. brucei*, and the already known aerucyclamide B against *Plasmodium falciparum.* There are six new acyl proline derivatives tumonoic acids D–I, isolated from the marine cyanobacterium, *Blennothrix cantharidosmum*, among which tumonoic acid I displayed moderate activity in an antimalarial assay [104]. Microorganisms used for the production of nanoparticles and they are in use for food preservation [105] and showing antiprotozoal activity.

Conclusion

BGA have a great potential as biofertilizer. BGA turn solar energy into biomass by using CO2, water, and nutrients. The thorough study found that BGA can be used in a variety of ways to improve human health, including enhancing food quality, balancing soil physicochemical properties, preventing soil-borne illnesses, amending the soil with organic matter, releasing phytohormones crucial for crop growth, solubilizing insoluble phosphates, and their use as nutraceuticals. BGA serve as a promising resource in pharmaceuticals. Well-structured applications of BGA in agriculture have been found to be minimize global warming as they utilize the atmospheric CO_2. Algal biofuels appear to be the only current renewable energy source that could meet the global demand for transport fuels. Thus BGA are economical and eco-friendly natural resources. Role of BGA in all these fields needs to be further explored.

Author's contribution

SPP came up with the concept for the manuscript, contributed the overall idea and inputs for each individual section, and partially wrote the manuscript. The review was written by VVC and MRN after they read the literature. The manuscript was edited, put together, and finalized by authors SPP and VVC. After reading and approving it for publishing, all authors signed off.

Declaration of competing interest

The authors affirm that there were no business or financial ties that might be seen as a potential conflict of interest when the work was done.

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