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Rishi Raj
Junior Research Fellow, Department of Entomology, MBAC, Agwanpur, Saharsa, Bihar, India

Mrinalini Kumari
Assistant Professor cum Junior Scientist Zoology, Department of Entomology, MBAC, Agwanpur, Saharsa, Bihar, India

Corresponding Author:
Mrinalini Kumari
Assistant Professor cum Junior Scientist Zoology, Department of Entomology, MBAC, Agwanpur, Saharsa, Bihar, India

Blue green algae (BGA) and its application

Rishi Raj and Mrinalini Kumari

Abstract

Cyanobacteria are known from a long evolutionary history and its unique traits, for example, oxygenic photosynthesis, high biomass yield, growth on water sources mainly contaminated and polluted waters), generation of useful by-products and bio-fuels, in agriculture as biofertilizer, wastewater treatment, enhancing the soil fertility, reclamation of saline soil, and in nutrition as food supplements and reducing greenhouse gas emissions, have collectively offered these bio-agents as the precious bio-resource to harness the maximum benefit of cyanobacteria. Furthermore, Cyanobacteria also produce an ample variety of chemicals (secondary metabolites) that are not needed for their normal growth of cyanobacteria which show powerful biological activities such as strong antiviral, antibacterial, antifungal, antimalarial, antitumoral and anti-inflammatory activities useful for therapeutic purposes. Since cyanobacteria grow in simple growth needs, therefore it is cost-effective to make full use of cyanobacteria for the production of recombinant compounds of medicinal and commercial purposes. Recently cyanobacteria have opened new ways to explore in screening, culture, and genetic engineering techniques without many side effects. In this review examines cyanobacteria uses and its application that can be used to deal with current problems and scarcity such as food, energy, and environmental deterioration.

Keywords: Cyanobacteria, agriculture, biofertilizer, biofuels, greenhouse gas

Introduction

Cyanobacteria (CB), known as blue-green algae (BGA), are a group of gram-negative photosynthetic bacteria [1-6]. That has colonized the earth's surface for nearly 3.5 billion years [7-8] and is considered as the predecessors of the modern-day chloroplast [9-13]. They exist in different morphologies including unicellular and filamentous forms [14-15]. Blue-green algae (BGA) have enormous morphological and metabolic diversity (Stal 1995), which makes BGA special choice in economic development and environment management like atmospheric fixation of nitrogen, land reclamation, reclaim salinity affected soils and wastewater treatment. Cyanobacteria are also used in many biotechnological applications that were hoping for possible uses in, Colorants, mariculture, food, fuel, fertilizers and production of various secondary metabolites including toxins, enzymes, and pharmaceuticals. Cyanobacteria is also rich source of bioactive compounds and considered as most promising groups of an organism to produce them [16-17]. Cyanobacteria bioactive compound include antifungal [18], antibacterial [19], antiviral [20], anticancer [21], antiplasmodial [22], algicide [22], and Immuno supressressive agents [23]. BGA have been also investigated for the production of different biofuels including biohydrogen, biodiesel, bioethanol and biomethane.

Agriculture

Nitrogen fixer

Nitrogen (N2) is derived from the nitrogen fixation process and present in amino acids, proteins and DNA [24]. The source of soil nitrogen is the Earth’s atmosphere and it is the most abundant gas in (about 79% of the total atmospheric gases.), it is extremely unreactive [25]. Unfortunately, no plant species on the earth that can reduce atmospheric dinitrogen into ammonia and use it directly for its growth. It appears that only a number of prokaryotic microorganisms including cyanobacteria and bacteria have been shown to possess the ability to fix dinitrogen [26-29]. Biological fixation of the atmospheric nitrogen can be about 70% of all nitrogen fixed on the Earth per year, the remaining is by some micro-organisms, autotrophs or heterotrophs ‘free’ fixers [30]. Bacteria known collectively as the ‘‘Rhizobia’’ are famous for their ability to induce nodules on the roots and sometime on the stems of legume plants [31]. Inside these nodules, the differentiated, ‘‘bacteroid’’ forms fix atmospheric nitrogen and the ammonia being formed and used as a source of fixed nitrogen. In this symbiosis relationship bacteria get niche and, in return, the plants obtain a nitrogen source [32]. They occur in the so-called free-living forms e.g. aerobic azotobacter, anaerobic Clostridia or in symbiosis with certain higher plants e.g. Rhizobia with legumes or Azolla Anabaena. Cyanobacteria can be an important source of nitrogen for supporting aquatic primary productivity [33] and important for the global nitrogen cycle [34]. It has been reported that nitrogen availability to plants is increased due to the application of cyanobacteria in agriculture ecosystems, particularly the rice fields. (Stewart *et al*., 1968; 35-40).

Biofertilizer

The importance of biofertilizers is increasing rapidly since chemical fertilizers (nitrogenous fertilizers) damage the environment. Biofertilizers (BGA) lead to soil enrichment and are compatible with long-term sustainability. Further, they are eco-friendly and pose no danger to the environment. BGA, are the major N fixers in freshwater and marine systems [15]. BGA has been assessed for use as green fertilizer in rice fields and positive effects have been reported in India [16] and other countries [17-18]. The application of BGA in the rice paddy fields promotes rice growth and yield [41-42]. Many Asian countries like China, Vietnam, India, etc., have been utilizing cyanobacteria in paddy cultivation as the alternative to nitrogen fertilizers [43-44].

Fertility of tropical rice field soils was given credit to the activity of diazotrophic cyanobacteria [45] more or less all dominant CB inhabiting rice fields are diazotrophic and it gives an indication how rice has been grown for centuries without any external supply of N2 [46] Most rice soils have a natural population of BGA, which provides free of cost, nitrogen. So we can say that BGA provides an ideal environment for their luxuriant growth for plant. According to Agronomist of rice field trial BGA commonly contribute nitrogen in the order of 20-30 kg/ha [47]. Thus using BGA in the rice field, a farmer can save to the extent of 20-30 kg N/ha without compromising with the normal yield. The beneficial effect of BGA, inoculation has also been reported in other crops (oat, tomato, radish, barley, cotton, sugarcane, maize, chili, and lettuce). Besides the contribution of nitrogen, BGA also liberate growth-promoting substances play an important role in sustaining the crop yield. A number of growth-promoting substances [vitamins (B12), nicotinic acid, pantothenic acid, folic acid amino acids, sugars, polysaccharides, etc.), including hormone] have been documented [48-49].

Soil conditioner

BGA also has huge potential in environmental management as a soil conditioner. Organic changes not only act by improving soil structure but also strongly influence soil microflora [50]. It had been seen that a continuous layer of colonies of different CB species in rice fields commonly yield a significant amount of biomass [50]. BGAs excrete a number of compounds (polysaccharides, peptides, lipids during growth in soil [51-53]. which assumed to be diffuse through soil particles and hold them together as macroaggregates. Moreover, polysaccharides can also implicate clay particles and form clusters. Then these clusters or macroaggregates, in turn, grow and take the shape of macroaggregates and subsequently of larger soil aggregates. The interwoven nature of algal filaments may also help in binding soil particles along with organic carbon added through algal biomass. A significant increase has been observed in soil aggregate stability due to an increase in polysaccharide content of the soil as a result of algal inoculation [54-55].

Reclaim Salinity Affected Soils

BGA also holds the potential to reclaim salinity affected soils. In the 1950s, a biological approach to the problem of saline soils using BGA was proposed, where in natural populations of nitrogen fixing BGA were employed for reclamation of saline/alkaline lands typical of certain North Indian States. [56-57] Potential of a brackish-water, BGA, Anabaena torulosa, to grow and enrich N status of moderately saline coastal (Kharland) soils have been demonstrated. Most of the sodium removed by BGA remains extracellularly trapped in their mucopolysaccharide sheaths [58]. Rogers and Burns (1994) CB is also known to solubilize and mobilize phosphorus (P) and make it available to plants. N fixing BGA, Tolypothrix tenuis, N fixing CB, Tolypothrix tenuis, Hapalosiphon fontinalis solubilize Mussoorie rock phosphate (MRP), a source of P2O5. Similarly, Westiellopsis prolifica and A. variabilis showed good growth and N fixing ability in the presence of mineral phosphate sources (MRP and TCP) in addition to solubilizing these insoluble phosphate sources [59-60].

Food

BGA is being used as a food for a human being a long time [61-65]. Nostoc is a more common dietary supplement for the native populations of Thailand, Peru, China, Ecuador, Fiji, Java, Japan, Mexico, Mongolia, and Siberia are taking different forms of Nostoc like N. commune var. flagelliform, N. edule, N. ellipsosporum, N. verrucosum and N. pruniforme [66] N. commune has a high amount of fiber and protein can play an important physiological and nutritional role in the human diet. Nostoc commune is rich in fibres and Aphanizomenon sp. is collected from natural blooms in Lake Klamath (Oregon, The USA) to be used as healthy food [67].

Spirulina-cyanobacteria have been eaten for centuries by Kanembu people, who live along the shores of Lake Chad in northcentral Africa. Quantities of proteins and other compounds in spirulina are, varies between 50% and 70% of its dry weight. These levels are quite exceptional, even among microorganisms. It has the highest protein of any natural food (65%); far more than animal and fish flesh (15-25%), soybeans (35%), dried milk (35%), peanuts (25%), eggs (12%), grains (8-14%) or whole milk (3%). Moreover, the best sources of vegetable protein achieve only half these levels; for example, you can compare to soya flour contains "only" 35% crude protein. However, the protein content of spirulina varies by 10-15% according to the time of harvesting in relation to daylight [68]. The highest values were obtained at early daylight. Due to its high protein content and various possible health-promoting effects (alleviation of hyperlipidemia, suppression of hypertension, protection against renal failure, growth promotion of intestinal lactobacilli and lowering of elevated serum glucose level), Spirulina has been exploited commercially and recommended as a protein supplemen [69-73]. They can act as the nutritional supplement or represent a source of natural food colorants [74-81].

Spirulina also contains a considerable amount of carbohydrate (~20%), lipid (~5%), and mineral (~7%). It is a very rich source of β-carotene, thiamine, riboflavin and is one of the richest sources of vitamin B12. (82-83). It also contains 20 antioxidants, 68 minerals, and 70 trace elements, all amino acids, B vitamins, and important enzymes [84-94].

Hainan Simai Enterprising located in the Hainan province of China is the largest producer of Spirulina in the world. On the other hand, Earthrise Company (Caliptera, CA, USA) has the largest Spirulina production plant and their products are distributed in over 20 countries. Besides, some other companies selling BGA Commercial preparations like

"Zyrulina" and "Recolina" (Zydus Cadila), "Nuclina" (Mapra Laboratories), "Vitalinaa" containing dry powder of Spirulina is available in the Indian market. Capsules containing dry powder of Aphanizomenon flos-aquae, under the trade name of Kalmath's Best ® Blue-Green Algae by Kalmath Valley Botanicals LLC, USA have gained popularity in the USA, Japan, Germany, Canada, Korea, and Austria [95]

Feed for animals and aquaculture

Spirulina is now mainly used as feed supplements for various organisms and more than half of the total population of spirulina used as feed [96]. There is no side effect, for e.g. when soy protein in feed for pigs was replaced by spirulina there wasn't any adverse effect seen apparently on the gastrointestinal. Breeders use spirulina as a tool to change coloration, accelerate growth and attaining earlier sexual maturity & improve fertility rates in parrots, lovebirds & canary, finch. It is also used by breeders to increase reproduction rates in ostrich and turkey. Moreover, the intake of spirulina can increase desirable yellow skin color in chicken & also enhance the deep yellow color of egg yolks [97]. The digestive system of birds was also enhanced with increased good bacteria population, feather color & its shine was also increased altogether. Spirulina is also being used as feed for bivalve mollusks, penacide shrimp larvae, brine shrimps and marine rotifers etc. spirulina content when increased up to 10% in brine shrimp feed, it increased their survival rates allowing the wing fish to reach market size sooner [97]. It is now considered as the best food for tiny brine shrimps. Those BGA, who fix nitrogen in marine also used as fish food, therefore, marine BGA used in aquaculture. The Tilapia fish showed high growth rates when fed with marine cyanobacteria in indoor and outdoor cultures [98]. In India, Phormidium valderianum has been used as a complete aquaculture feed source based on its nontoxic nature and nutritional value.

Species of various BGA like Nostoc, Anabaena and Calothrix increase body weight of Telapia hybrid fish with excellent food conversion ratio. As a feed, 5-20% of Spirulina enhanced the color pattern of Champion Koi fish, thereby being fascinating and attractive for a customer, therefore, a farmer can increase its benefit and value in the market by several folds [97].

Biotechnology

Cyanobacteria have gained a lot of attention in recent years because of their potential applications in biotechnology. Some cyanobacteria found which accumulates polyhydroxyalkanoates (PHA) [99] which are similar in properties to polyethylene and polypropylene [100]. These biodegradable plastics could replace by oil derived thermoplastics in some fields. Recent research also shows that cyanobacteria form ideal association with Chemotrophic bacteria can effectively clean oil-contaminated sediments and waste waters [101-105].

Enzymes

A number of studies also confirmed the detection of enzymes produced by BGA (nitrogenase, hydrogenase, phosphatase, β-Lactamase, elastase, hydroperoxide lyase, arylsulfatase, chitinase, L-asparaginase, L-glutaminase, amylase, protease, lipase, cellulase, urease and lactamase) [106-110]. An anti-fertility enzyme, elastase, has been purified from Oscillatoria sp. Several unique sequence-specific restriction endonucleases are produced by BGA, and its potential use exploited in recombinant DNA technology.

Biofuel

BGA have been investigated for the production of different biofuels including biohydrogen, biodiesel, bioethanol and biomethane.

Biohydrogen

Hydrogen gas is seen as a future energy source [111], since it is renewable, does not emit the ''greenhouse gas'' CO2 in combustion, liberates large amounts of energy per unit weight in combustion [112-114]. The advantage of using Hydrogen gas, if used as a fuel, will not cause environmental pollution because its only by-product is water and it is one of the most abundant elements in the universe, and has maximum energy per unit weight (122 KJ g-1). On a weight basis, it is calculated that the heating value of H2 is 141.65 MJ Kg-1, which is the highest amongst known fuels [115]. More over it can be stored as gas-metal hydride or as liquid, and has greater energy conversion efficiency than petroleum. Several Cyanobacteria genera including Anabaena, Calothrix, Oscillatoria, Cyanothece, Nostoc, Synechococcus, Microcystis, Gloeobacter, Aphanocapsa, Chroococcidiopsis, and Microcoleus are known for their ability to produce H2 under various culture conditions [116-118]. BGA, can produce different feed-stock for energy generation like H2 by photosynthesis, lipids for biodiesel, jet fuel and hydrocarbons, isoprenoids for gasoline and carbohydrates for ethanol production [119-120]. Biological hydrogen production has several benefits over hydrogen production by thermochemical or photoelectrochemical processes. In cyanobacteria, two natural pathways for H2 production can be used: first, H2-production as a by-product during nitrogen fixation by nitrogenases; and second, H2-production directly by bidirectional hydrogenase [121]. Nitrogenases require ATP whereas bidirectional hydrogenases do not require ATP for H2-production, hence making them more efficient and favorable for H2-production with a much higher turnover. Cyanothece sp. ATCC 51142, a unicellular, diazotrophic cyanobacterium with capacity to generate high levels of hydrogen under aerobic conditions. Wild-type Cyanothece sp. 51142 can produce hydrogen at rates as high as 465lmol/mg of chlorophyll/h in the presence of glycerol. Hydrogen production in this strain is mediated by an efficient nitrogenase system, which can be manipulated to convert solar energy into hydrogen at rates that are several fold higher, compared to other previously described wild-type hydrogen-producing photosynthetic microbes [122].

Many unique features of cyanobacteria among them, generation of useful by-products and bio-fuels, enhancing the soil fertility and reducing greenhouse gas emissions, have collectively make Cyanobacteria as the precious bio-resource for sustainable development. Now a days genetically engineered cyanobacteria have been devised with the novel genes for the production of a number of bio-fuels such as bio-diesel, bio-hydrogen, bio-methane, synga, and therefore, open new avenues for the generation of bio-fuels in the economically sustainable manner [123].

Reduction of global warming

CO2 sequestration

The CO2 sequestration by BGA is receiving increased awareness in the current situation of global warming [124].

Being photosynthetic, contribute a large share of the total photosynthetic conversion of solar energy and assimilation of CO_2. The CO_2 fixation rate in cyanobacteria is about 10-50 times faster than the terrestrial plants. So the use of BGA, can be considered one of the effective method to reduce the concentration of atmospheric CO_2 and thereby, to help in reduction global warming [125]. It is predicted that half of global photosynthesis is fixed by phytoplankton, among them mostly includes Cyanobacteria members [126]. If we consider more specific, about 25% of the total global photosynthesis can be accounted for by only two efficient marine Cyanobacteria genera, Synechococcus and Prochlorococcus [127]. Cyanobacteria CO_2 fixation in photobioreactors has recently gained more attention for reduction of CO_2 mitigation, because its efficiency increased to many fold. A number of studies have been conducted during the past few decades related to this strategy for CO_2 sequestration [128-131].

Reduction of methane

Methane (CH_4) has negative effect, as it is a potent Green House Gas (GHG) with approximately 20 times more impact of CO_2 [132] cyanobacteria may possibly minimize the emissions of CH_4 from flooded rice soils at the levels of production, transport, and consumption. Bioagents like methanotrophs [133] can play a very significant role to remove significant amount of the most potent and dangerous GHGs such as CH_4 from the soils of various ecosystems in association with cyanobacteria [134-136].

Antibiotics and other potential drugs

Medicinal merit of BGA was first recognized as early as 1500 BC when Nostoc species were used to treat gout, fistula and several forms of cancer [137-138] cyanobacteria are a rich source of potentially useful natural products [139-141] And produce a number of bioactive compounds of potential therapeutic use including fatty acids, having activities such as anti-HIV, anticancer, antifungal, antimalarial and antimicrobial [142-149]

Antibacterial activity

Noscomin, a diterpenoid from N. commune, showed antibacterial activity against Bacillus cereus, Staphylococcus epidermidis, and Escherichia coli [150] L. majuscula shows antibacterial activity against B. cereus, B. subtilis, Mycobacterium balnei, etc. [151]. Norharmane, produced form Nodularia harveyana have anti Cyanobacteria activity against other cyanobacteria [152] thus, could be useful in controlling harmful Cyanobacteria blooms.

Fungicidal activity

Natural products of Nostoc sp. are effective against Cryptococcus sp. as a causal agent of secondary fungal infections in patients with AIDS [153]. Majusculamide-C, a microfilament depolymerizing agent from L. majuscula, has shown potent fungicidal activity and may find application in the treatment of resistant fungal-induced diseases of plants and agricultural crops. Fischerella ambigua and Haplosiphon hybernicus produce Ambiguines, which show anti-fungal activity on Aspergillus oryzae and Candida albicans [154]. Tjipanazoles produced from Tolypothrix tjipanasensis have antifungal activities, especially against fungi responsible for wheat leaf rust rice blast and [155].

Antiviral activity

Cyanovirin-N analogs and Cyanothece show antiviral activity against a large panel of viruses. The first one, cyanovirin-N analogs, have been isolated from Nostoc ellipsosporum [156] and Cyanothece sp. [157] Cyanovirin show inhibitory activity against HIV-1, HIV-2, simian immunodeficiency virus (SIV), feline immunodeficiency virus, HHV-6, and measles virus (156-157). Also, they inhibit Ebola and influenza viruses. Lipophilic and hydrophilic are strains of cultured CB were examined and they have the ability to inhibit enzyme Reverse Transcriptase (RT) of Avian Myeloblastosis Virus (AMV) and HIV type [156-157-158] Fibre [oxalate oxalic acid-soluble substances (OOSS)], extracted from N. commune, and possesses a hypocholesterolemic effect in rats.

Antimalarial activity

Symplocamide A obtained from a BGA, Symploca sp. was found to be active against parasite of malaria (P. falciparum W2), Chagas disease (*Trypanosoma cruzi*) and leishmaniasis (*Leishmania donovani*) [159-163].

An anti-cancer

An anti-cancer factor has been identified in Phormidium tenue, *Scytonema* sp. and Anabaena variabilis.

Curacin A, isolated from L. majuscula an antimitotic agent (an antiproliferative agent), and its function exploited in inhibiting growth of colon, renal and breast cancer derived cell lines [164-167].

Cryptophycin-1, isolated from a Nostoc sp. GSV 224 [165-167], its function had been identified as mitotic inhibitor by blocking the cell cycle at the G2/M phase via inhibition of tubulin polymerization [168-169].

Nostoc linkia produce borophycine: Can be another anticancer compound (boron containing polyketide) [170]

Tolypothrix nodosa produce Tolyporphin: Its function is to photo sensitising activity against tumour cells and it is 5,000-times more effective than the photodynamic treatment [171].

Calotoxin isolated from Scytonema ocellatum depolymerized actin to disturb cell division and seems to be a potent anti-cancer drug.

Anti-inflammatory

BGA also have Anti-inflammatory property, Consumption of BGA has been demonstrated to promote immunity and to protect against inflammatory diseases, such as colitis, arthritis, and allergic rhinitis in animal and human studies [172-175].

Hormone

CB produce Auxins [176-178], Gibberellins [179-180], Cytokinins [181-182] abscisic acids [183]. Ethylene [184]

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