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PHOTOAUTOTROPHIC CYANOBACTERIA: A POTENTIAL MICROORGANISM AND ITS APPLICATIONAL ROLE IN DIFFERENT FIELDS

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Abstract

Nowadays, the world facing so many problems like an increase in human population, global warming, energy crisis, decrease in food availability, disease outbreak, and other so many environmental-related problems that require a solution. One of the solutions to all this is cyanobacteria, which is also known as blue-green algae. Cyanobacteria are Gram-negative bacteria, widely distributed, havea simple genome, required simple nutrients for growth, and performed oxygenic photosynthesis. Cyanobacteria possess such types of mechanisms that are easily adaptable to environmental changes and grow rapidly and dense. Cyanobacteriaare useful in agriculture as biofertilizers, increase soil fertility, and nitrogen fixation, etc. can convert nitrogen into ammonia and help in nitrogen fixation. Cyanobacteria can produce bioactive compounds which having different biological activities like antibacterial, antifungal, antialgal, anti-cancer, etc. They are also helpful in bioremediation. Cyanobacteria produce pigments, enzymes, and vitamins that are helpful for industrial purposes. Besides all this, they are also used as food or nutrient supplements. Cyanobacteria are widely distributed, and easily grow enabling their use in so many different fields and development at the industrial level. Maybe there are so many hurdles we facing to solve all problems but cyanobacteria give hope to solving all these.

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Introduction:-

Cyanobacteria which is also known as “Cyanophyta” are gram-negative and the first oxygenic photosynthetic bacteria on earth. They are also known as “Blue-Green algae” because of their color. They are one of the oldest microorganisms on the earth for over 3 billion years. Cyanobacteria are found in almost every terrestrial and aquatic habitat like oceans, fresh water, damp soil, rocks, deserts, soil and bare rock, and Antarctica rocks as planktonic cells or form phototrophic biofilms. Some of our endosymbionts in lichens, plants, various protists, or sponges provide energy for the host. They also live in cold and hot springs, and in environments where no other microalgae can exist. Some species of cyanobacteria are also able to live in high concentrations of salt.

Cyanobacteria need basic nutrient requirements like water, carbon dioxide, and sunlight. They have different types of mechanisms that make them adaptable to different environments. Cyanobacteria are capable to switch from one mode to another mode easily and that helps them with their rapid and dens growth. Cyanobacteria havea simple genome and they need basic nutrients for growth so they can easily cultivate.
Nowadays world facing so many different problems like an increase in human population, global warming, an energy crisis, a decrease in food availability, disease outbreak, and other so many environmental-related problems that require a solution. The incredible growth rate of cyanobacteria is one of the major aspects to think about when considering their management in different ways [1]. Cyanobacteria are helpful in solving so many different problems that ultimately lead to human and environmental welfare. Cyanobacteria are all-in-one solution that makesit easy to solve so many different problems and are also useful in different fields.

Some species of cyanobacteria produce bioactive compounds like antibacterial, antifungal, antialgal, anticancer, antiviral, etc. They are also useful as biofertilizers, production of biofuel, bioremediation, food source, etc. Cyanobacteria open doors for so many different fields for their use. One dark side of cyanobacteria is that some of its species produce toxic blooms which are toxic to humans and animals. Cyanobacteria are potential and diverse use in so many different fields and have incredible future aspects which are elaborated in this review paper.

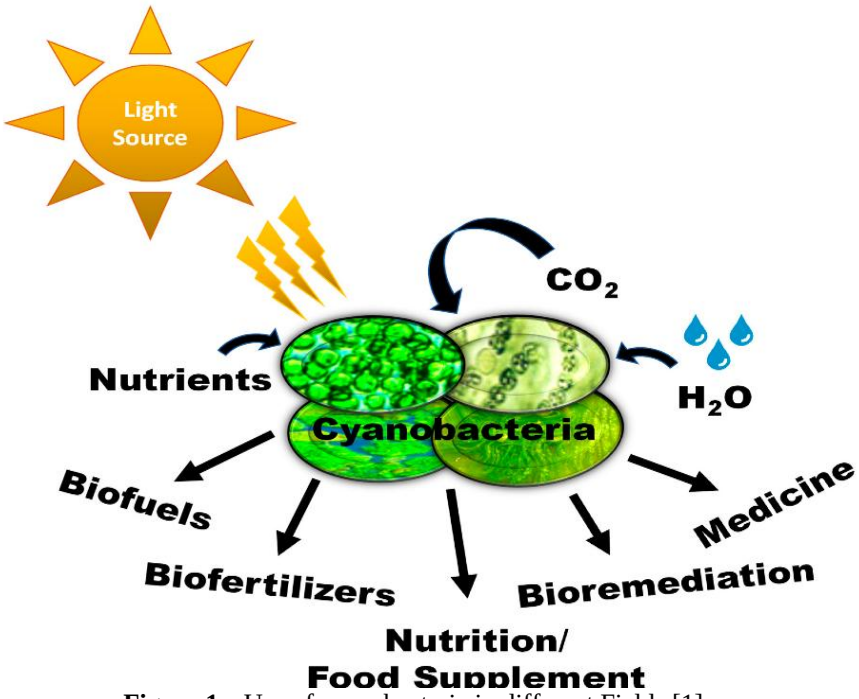

Figure 1:- Use of cyanobacteria in different Fields [1].

Cyanobacteria- the solution

As a Food/Nutrient supplements

Cyanobacteria are considered a good source of food and nutrient supplements. They have complex sugar, proteins, amino acids, active enzymes, phycocyanin, chlorophyll, beta-carotene, essential fatty acids, minerals, carbohydrates, and vitamins. As we know there is incredible death that occurs worldwide due to poor dietary composition. There are such countries that do not afford good and healthy food for their people. Cyanobacteria are a good solution for solving this problem. Strain odSpirulina, Anabaena, and Nostoc are consumed as human food in many countries including Chile, Mexico, Peru, and the Philippines (R.M.M et al., 2008). Arthrospira platensis grown large scale and used as a whole food supplement in a form of tablets, powder, flakes, and capsules. It has richness in nutrients, and good digestibility, contains more than 60% protein, beta-carotene, and thiamine, and is one of the richest sources of vitamin B12. Nostoc commune is rich in fibers and proteins and can play an important physiological and nutritional role in the human diet [2]. Marine nitrogen-fixing cyanobacteria have also been used for aquaculture. This is a good option to overcome the poor dietary issue and fulfill the human need for food.

As a source of Biofertilizer

The present worldwide population of about 7.9 billion is expected to cross 9.6 billion by the end of 2050. We need to fulfill the food demand of this the much population and for that, we need to increase the production of cereals. This work of action creates pressure on the agriculture sector. This much large quantity of food production can be achieved either by bringing more and more land under cultivation or by enhancing the productivity of cultivated land available. The first option is not possible due to the limited option of land so the option of increasing soil fertility and agricultural productivity with help of a better eco-friendly way is a successful way for food security. Due to soil infertility, deterioration and salinization have reduced arable land that threatens food security.

Cyanobacteria are a good source of biofertilizer and contribute to enhancing productivity in a variety of agriculture and ecological condition. Inthe agriculture sector, phosphate is the second most important element that is required for plant growth and development [1]. Cyanobacteria can increase soil phosphate due to their improved organic acid production [3]. Cyanobacteria species, for example, Nostoc and Anabaena, have outstanding capabilities to treat the soil salinization issue by fixing atmospheric nitrogen and producing an extracellular matrix and compatible solutes [4]. Some cyanobacteria members are endowed with the specialized cell known as heterocyst – thick-walled modified cells, which are considered the site of nitrogen fixation by the nitrogenase enzyme [5].

These species play the role of biofertilizer and help maintain long-term soil fertility and sustainability by fixing atmospheric dinitrogen and allowing for conversion to ammonium, solubilization of fixed nutrients, or conversion of insoluble phosphorus in the soil to phytoavailable forms [6]. Spirulina platensis play an important role in food production to meet the demand of increasing population and environmental protection. Cyanobacteria play an important role in the soil microbial community and help to restore the soil deterioration effect in biological ways [5]. Cyanobacterial and microalgal biomass is applied to soils as fertilizer that helps to improve the water-binding capacity and nutrient composition of exhausted soils [7]. Overall study says that cyanobacteria are a very excellent option to increase agricultural product production with eco-friendly and environmental sustainability. Researchers studied the effect of two cyanobacteria species that are *Nostoc entophytum* and *Oscillatoria angustissima* as biofertilizers on some metabolic activities, growth, and yield of a pea plant. They also go for a comparative study of chemical fertilizer and biofertilizer and half of chemical and biofertilizer and for this they got a good result for the combined use of both fertilizers [8]. Another study was conducted by researchers that cyanobacteria cultivation using olive milling wastewater for bio-fertilizer of celery plants. For these cyanobacteria grow on wastewater to obtain two biofertilizers one Spirulina platensis and the second one mixed culture of *S. platensis*, *N. muscorum*, and *A. oryzae*.These biofertilizers were applied to the celery plant and led to a significant increase in height of the plant, root, and stem length [9].

Cyanobacteria as Bioremediation

There are so many harmful environmental contaminants that should be removed from the environment. Compounds like crude oil, pesticides, naphthalene, heavy metals, xenobiotics, etc are harmful and should be treated by accumulation or degradation. Wastewater systems, agro-industrial waste, and oil spills affect the aquatic ecosystem. Cyanobacteria have the potential to be used for the bioremediation of various contaminants. They are autotrophic in nature and ability to fix atmospheric nitrogen which makes them self-sufficient for growth and maintenance and adaptability to survive in polluted and heavily polluted environments [10]. Due to high metal sorption capacity and high multiplication rate, cyanobacteria could play a potential role in the detoxification of various industrial effluents such as oil refinery, brewery, and distilleries, paper mills, sugar mills, dye and pharmaceuticals industries [5].

Cyanobacteria such as *Oscillatoria, Phormidium*, *Aphanocapsa* and Westiellopsiswasobserved to remove nitrogenous and phosphate ions from wastewater. The biomass of Spirulina strains contains different functional groups, for example, carboxyl, hydroxyl, sulfate, and other charged groups that are important for metal binding and they have great potential in metal pollution control and biosorption of zinc and nickel by several sp of cyanobacteria [11]. One of the drawbacks that limit the practical application of cyanobacteria in wastewater treatment is the difficulty in the separation of biomass from the effluent before discharge [12]. The use of immobilization to entrap cyanobacteria in matrices (agarose, carrageenan, chitson, alginate, and polyurethane foam) can help to solve the harvesting problem [11]. Cyanobacteria members such as *Synechoccus elongatus*, *Anacystisnidulans*, and *Microcystis aeruginosa*degrade many organo-phosphate and organo-chloride insecticides from polluted aquatic systems [12]. Cyanobacterial species *Oscillatoria salina*, *Plectonematerebrans*, *Aphanocapsa sp.*, and *Synechococcus sp.*, develop mats in aquatic environments and been successfully used in the bioremediation of oil spills in different parts of the world [13, 14]. A consortium comprising *Phormidium*, *Oscillatoria*, *Chroococcus*, and

the oil-degrading bacterium, Burkholderia cepacian, was successfully developed and employed on a rotating biological contactor to efficiently degrade petroleum compounds [15].

Cyanobacteria's capability for bioremediation can be enhanced through genetic engineering [16], and be used as the economical and maintenance-free remediation technology for the contaminated ecosystem [5]. This by naturally or genetically engineering cyanobacteria are a potential solution for the removal of pollutant make the environment sustainable.Researchers studied zinc and nickel biosorption with the help of cyanobacterial strains of *Spirulina*. In this experiment cyanobacteria were cultured in different concentration of zinc and nickel and the biosorption activity of the selected cyanobacteria strain were evaluated by doubling time, chlorophyll content, and protein content [17].

Cyanobacteria in Medicinal Application

Death due to antibiotic resistance is increasing day by day, so there need to find new therapeutic agents by which we can find a new path in the medicinal field. Cyanobacteria possess secondary metabolites like bioactive compounds which can be used in the medicinal field. Cyanobacteria show interesting bioactivities like antibacterial, antifungal, antialgal, antiviral, anti-inflammatory, antitumor, antimalarial, immunosuppressant, and anti-HIV activities [18-20].

Cryptophycin is a natural analog isolated from Nostoc species which is a potent anticancer drug and is currently being tested in phase I clinical trials. Several synthetic Cryptophycin analogs were created to explore potent anti-cancer substances [21]. Different bioactive compounds and their effects are shown in figure 2 [1].The cell constituents of cyanobacteria are known to reduce the incidence of Botrytis cinerea on strawberries and Erysiphe polygoni causing powdery mildew on turnips and damping-off disease in tomato seedlings, besides reducing the growth of saprophytes-Chaetomium globosum, *Cunninghamellablakesleeana*, and *Aspergillus oryzae*, and plant pathogens such as *Rhizoctonia solani* and Sclerotinia sclerotiorum[21]. Among cyanobacteria, Nostoc muscorum has been shown to be antifungal against soil fungi and especially those producing "damping off" [22]. Extracts from *N. muscorum* inhibited the in vitro growth of fungal plant pathogens such as *S. sclerotiorum* and *Rhizoctonia solani* [21].

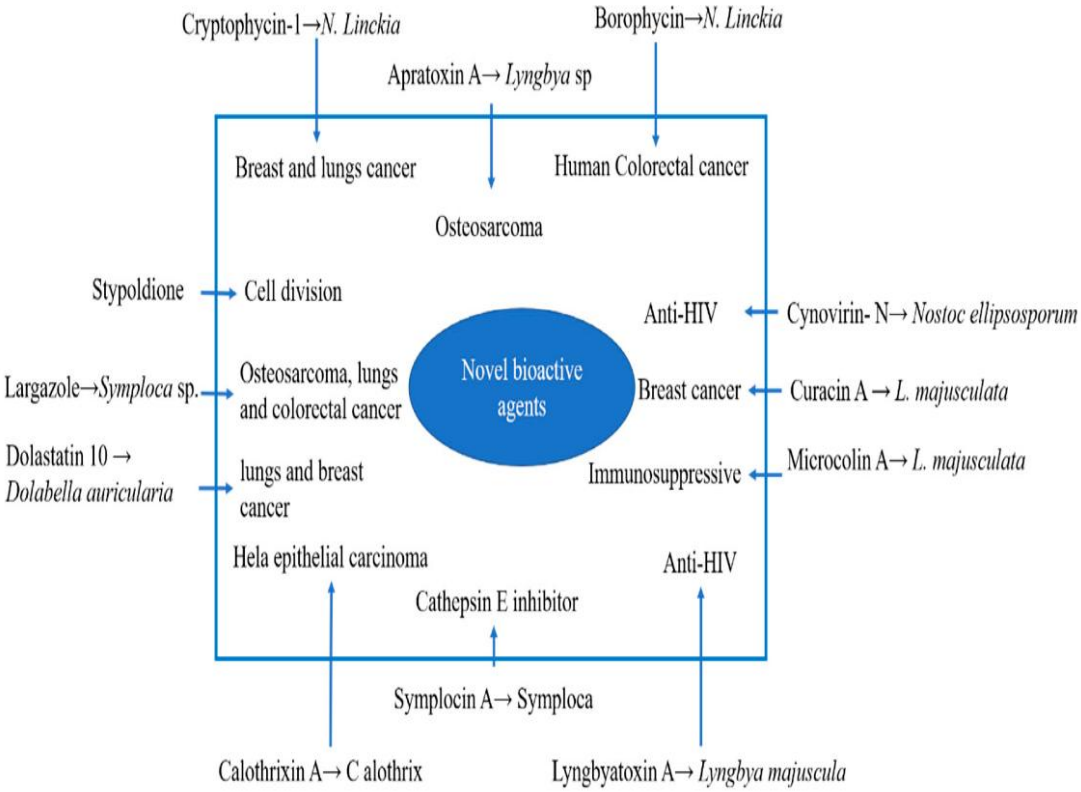

Figure 2:- Bioactive compounds from cyanobacteria and their potential effect[1].

It seems that efficient cyanobacteria strains can be used as bio-control agents to secure higher agricultural yields [5]. Spirulina is a potent dietary supplement having antioxidant, anti-inflammatory, anticancer, and low-density lipopolysaccharide and triglyceride-lowering effects. Some compounds possess potent immunomodulatory characteristics and play a role as antimicrobial and antiviral agents that promote the growth of useful gut microflora [23]. Cyanobacteria serve as promoting offering a wide range of substances for the discovery of new drugs, and development in the area still needs to be further explored [24]. These de novo drugs help in so many different therapies which ultimately lead to human welfare.Researchers studied on antimicrobial and antifungal activity of cyanobacteria against different microorganisms and they get a better result against bacteria [25]. Another study was done on two metabolites of cyanobacteria and it has both antibacterial and antifungal activity. In this way, different study shows that cyanobacteria have good potential in the medical field [26].

Cyanobacteria as a source of co-products

Cyanobacteria are considered for the production of valuable co-products that have an interest in commercial-scale production. Products such are pigments, vitamins, enzymes, biopolymers, etc are producing from cyanobacteria. Two important cyanobacterial pigments, phycobiliproteins, and carotenoids are extensively used in the bioindustry and have high commercial values [11]. Phycobilisomes consist of phycobiliproteins such as phycocyanin, allophycocyanin, and phycoerythrin and major carotenoids are beta-carotene, zeaxanthin, nostoxanthin, echinenone, and canthaxanthin. These pigments are used in different ways as food colorants, food additives, and supplements. Carotenoids are a good antioxidant and play role in the prevention and control of human health and disease conditions, for example, cancer, cardiovascular problems, cataracts, and muscular dystrophy have been reported [27].

Some marine cyanobacteria are a good source of vitamins and they are used commercially for large-scale production such as vitamin B and E. Spirulina is a good source of vitamin B12 and they are available in the market in a form of capsules, powder, granules, or tablets. Commercially available Spirulina tablets contain up to 244 µg of vitamin B12 per dry weight [27]. Some cyanobacteria are found to be a secret broad spectrum of enzymes that have good commercial value. These enzymes are protease, amylase, and phosphatase.

Biopolymer, polyhydroxyalkanoate (PHA) is a type of biodegradable polymer that can serve as a substitute for petroleum-based plastics and a biocompatible material that has promising applications in biomedical or pharmaceutical fields [11]. Several cyanobacteria including *Aphanothece sp.* [28], Oscillatoria limosa[29], some species of the genus Spirulina [30, 31], and the thermophilic strain Synechococcus sp. MA19 [32] arethe natural producer of PHA. Direct photosynthetic production of PHA is less in cyanobacteria but nutrient-limiting conditions and carbon feedstock enhance the PHA accumulation. The application of phosphorus deficiency, gas–exchange limitation culture conditions as well as fructose and acetate addition had resulted in a remarkable increase in PHA accumulation up to 38% of the dry cell weight in *Synechocystis sp*. PCC 6803 [33]. Some cyanobacteria, like S. platensis, can accumulate PHA under phototrophic and/or mixotrophic growth conditions with acetate [2]. Another way for PHA production is, by introducing acetoacetyl-CoA synthase which catalyzes the irreversible condensation of acetyl-CoA and malonyl-CoA to acetoacetyl-CoA and was found to have a positive impact on PHA production [34]. Genetically engineered cyanobacteria are also used for PHA production which gives good results for that.

Future outline

Cyanobacteria is having great advantages that we all need to fulfill our aim to solve different problems which make our lives easy and breathable. Cyanobacterial output is used on a large scale to make an eco-friendly and sustainable environment. In future research needs to focus on the satisfactory results of cyanobacteria in order to facilitate their exploitation.

New methods should need to be developed to allow the cultivation of previously “uncultivable” strains [2]. This cultivation should be done in an extreme environment for example salinity, high temperature, pH, UV, and light intensity where their chances to find out novel strains with strong potential. The major technical challenge we faced is the cultivation, harvesting, and genetic engineering of cyanobacteria. Most of the cyanobacteria cultivation occurred in unsophisticated artificial open pond systems with low productivity [35]. Open pond system only a limited number of species can grow but need a closed pond system for the growth of other species. Another challenge is proper light because the light is main energy driver for growth. The high light intensity can lead to photoinhibition or overheating. This is why the proper distribution of light is one of the major challenges in designing a bioreactor for its cultivation at the industrial level [36]. Harvesting techniques such as centrifugation,

filtration, sedimentation, and flocculation are usually used, but all these methods are costly and energy-intensive and are not applicable at a large scale, especially for low-cost harvesting to get low-energy products [1].

Moreover, for the successful development of cyanobacteria as a platform to produce fatty acid-based biofuels, various challenges can be addressed using gene manipulation, enzyme, and metabolic engineering, or synthetic biology-based approaches [1]. The clone libraries are then screened for the presence of functional genes that are involved in the biosynthesis of certain biotechnologically significant compounds [37].

There are numerous bioactive compounds that are produced from cyanobacteria that have characteristics like antibacterial, antifungal, antimalarial, antitumor, antiviral, etc. these all compounds are present in very small quantities that are not sufficient for further use. The challenge is to identify the strain that produces good bioactive compounds and its most important future direction for novel bioactive compounds.

The potential biotechnological production of cyanobacteria has interest for the high yield of industrial products from cyanobacteria is the challenge. While the biotechnology potential of cyanobacteria is attracting increasing attention, most of the commercial compounds were isolated from freshwater cyanobacteria but a marine environment with different environmental conditions is likely to be a good source for novel cyanobacteria species that may have high biotechnological significance [2]. Therefore, cyanobacteria have good potential to solve different problems that mankind suffering. By using a different genetic engineering tool, the strains with high productivity need to be further studied in detail [1]. There are lots of perspectives related to cyanobacteria are need to be explored in near future. This may not be simple and quite challenging for us but by using different genetic techniques, different upgrading methods, maintenance of growth rate, cell potential improvement, etc we may achieve good results.

Conclusion:-

Nowadays the world facing so many problems due to the increasing environmental pollution and population. Carbon dioxide levels increase in the environment due to global warming, decrease in the availability of crude oil, decreasing cultivation lands, rainfall problems, food-related problems, Disease rates are increasing due to antibiotic resistance, and other so many problems. We need to solve all these problems and have to find out some solutions. Cyanobacteria are not able to solve all these problems 100 % but this tiny one helps a little bit to solve these problems. Cyanobacteria possess a cellular mechanism that makes them adaptable to environmental change and grows easily in it. They have the capacity to switch from one mode to another mode very fast. Their genome is also simple that can easily engineer. Cyanobacteria used basic energy sources and play important role in oxygen production. They have structures like heterocysts which help in nitrogen fixation and are also used as biofertilizers. They are also helpful for biosorption, wastewater treatment, etc. Cyanobacteria produce pigments, vitamins, and enzymes which are very helpful for industrial use. Cyanobacteria have antioxidant properties. Cyanobacteria are a good source of protein so they are also used as a food source in some countries. Cyanobacteria can produce biopolymers. Cyanobacteria have been used in the medical field as antibacterial, antifungal, anticancer, and antialgal, agents. The limitation of cyanobacteria is that some species of cyanobacteria can produce toxins that are harmful. This toxin degrades the water quality, and threatens aquatic life and also human health.

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