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Cyanobacteria - A potential Gram-Negative Bacteria as an alternative for Fertilizers and Bioremediation

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ABSTRACT: Cyanobacteria are the only Prokaryotes which perform oxygenic-photosynthesis, cosmopolitan in nature and adapted well in harsh condition of environment. It is being used in agriculture, food processing, biotechnology etc. from a long time due to its contents. Proteins, carbohydrates, mineral, vitamins present in it make it a nutritious food supplement and ability to fix dinitrogen make it useful for agricultural activities. Quick and short growth span is one of advantage which makes it more useful. Cyanobacteria is being used by research scholars in treating sodic soils and increasing soil productivity for different crops. It helps to replace the chemical fertilizers and hence contributes to reduce pollution and proved as a potential biofertilizer. In addition, it is being used in production of biofuels including biodiesel, methane, alkane, alcohol etc. Along with agricultural benefits its uses are mentioned in treatment of waste water, sewage too. Disease and Pest controlled is also an achievement using cyanobacterial strains. Inconsistent performance of cyanobacterial strains is a major problem though, research scientist used different strains in different state like dry powder, tube cultures and solid coverings of mass.

Keywords: Blue-green algae, oxygenic-photosynthesis, nitrogen, biofuels, food.

INTRODUCTION

Cyanobacteria also known as “Blue-Green Algae” (BGA) are smaller gram-negative micro-organism which are related to bacteria but are photosynthetic, hence they can produce their own food. It is a bacterium which can perform’ oxygenic-photosynthesis’. These were placed under kingdom “Monera” and division “Eubacteria”. These are prokaryotic bacteria which are known to be the prior life form on earth around 3.5 billion years back. Found in aquatic sources i.e., precisely in fresh and marine water. It is a unicellular bacterium which grows in a sizeable colony which is visible and covers more than 150 genera. These are ubiquitous in nature and can survive on and below the soil surface. In an exposed environment where other microorganisms may not survive, they can adapt well and hence can be easily found everywhere on earth. In addition, in some species U.V absorbing sheath pigments were found, which survive U.V rays by floating or sinking through gas vacuoles and in frosty conditions, these produce mucopolysaccharides to slow the liquid circulation.

These Cyanobacteria show symbiotic relationship with eukaryotic species like algae and fix the nitrogen present in atmosphere which further can be used as a biofertilizer for plants. Its cytoplasm has non organized pigmented lamella in which they also store metabolites and nutrients in cytoplasm. Other pigments include chlorophyll, xanthophylls and carotenes which help in efficient utilization of light spectrum including allophycocyanin, phycoerythrin, phycocyanin. Cyanobacteria has two important cells naming “Heterocysts” for nitrogen fixation to synthesize ammonia and “Vegetative” for photosynthesis and growth.

Natural population of cyanobacteria can be found in rice fields. These can uptake ammonia and ammonium (NH_4+) also these can use dinitrogen (N2) from atmosphere as nitrogen source by enzyme “Nitrogenase”. Due to this nitrogen fixing property, it can be utilized effectively as a potential biofertilizer (Meena, 2019). Now a days research on algalization (inoculation of algae) is going on which is showing a significant increase in grain yield from 15 to 20%.

According to Sahu *et al.*, (2012), the supreme Cyanobacteria which fix the nitrogen are *Plectonema, Nostoc*, *Anabaena*, *Aulosira* and *Calothrix*. These do not cause pollution and is a good resource for farmers having small farm holdings (Kulasooriya, 2011). Positive results of these cyanobacteria were observed and reported on many crops including oats, chilli, cotton, sugarcane, rice, radish, barley, lettuce and tomato (Thajuddin and Subramanian, 2005; Mutale *et al.*, 2020) due to their biofertilizing capacity (Pan *et al.*, 2019; Dymtryk and Chojnacka, 2019). Prasanna *et al.*, (2009) reported that after introduction of Calothrix cyanobacteria leads to 21% gain in grains yield than the NPK recommended dose and in the reports of Rana *et al.*, (2012) it was shown that these can possibly reduce the Fe and Zn malnutrition. Fe and Zn content can be increased by adding cyanobacterial biofertilizer in soil (Belnap and Harper, 1995). Adding *Nostoc muscorum* in fields increase the carbon content by 56% and nitrogen content by 120% (Rogers and Burns, 1994). Dhanalakshmi *et al.,* (2020) reported the presence of 42 species from 25 families in a total of 25 ponds in Tamil Nadu which live in a symbiotic relationship and helps to shoot the growth of other species.

Cyanobacteria is also known for being a functional food which may be edible, having nutritional value and some therapeutic use also. This is now a days available as capsule, liquid syrup and tablet in the food market (Radmer, 1996). *Spirulina cyanobacteria* is being used as human food from many years due to high protein content (Meena, 2016). They are rich source of minerals and vitamins including vit. A, B1, B2, B3, B6 and B12 which are fundamental supplements for bone and teeth. Their secondary metabolites also are very helpful as they are anti-viral, anti-microbial, anti-tumour and immunosuppressive agents etc. (Burja, 2001; Sharma and Sharma, 2017).

A. Mass production of cyanobacteria: (In rice-inoculum production)

Open conditions:

Advantage:
This method is so much easier to process as starter is built from soil with very little inputs and hence it can be performed by farmers with minimum expedient also.

Disadvantages:
As this process is performed in open air production is feasible for countable months in a year. In addition, with more peril to adulteration of culture its production rate is low and slow and due to low population density additional supplement of inoculum required/acre.

B. Production under controlled conditions
Under controlled conditions, there is minimum fear of impurity and bulk loads having longer shelf life of inoculum can be produced which in turn drop the inoculum requirement per acre. A poly house or any glasshouse is worthy for inoculum production under appropriate environment.

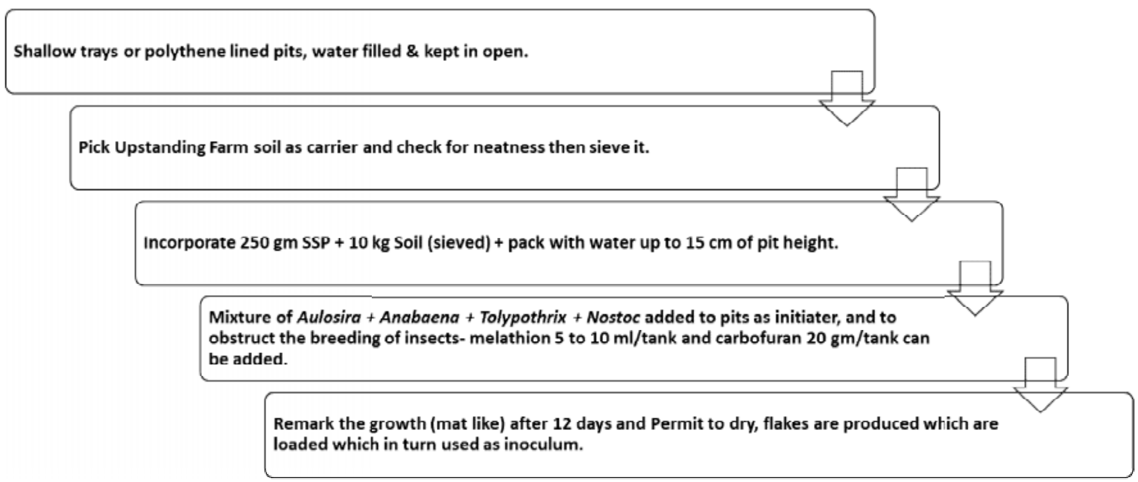
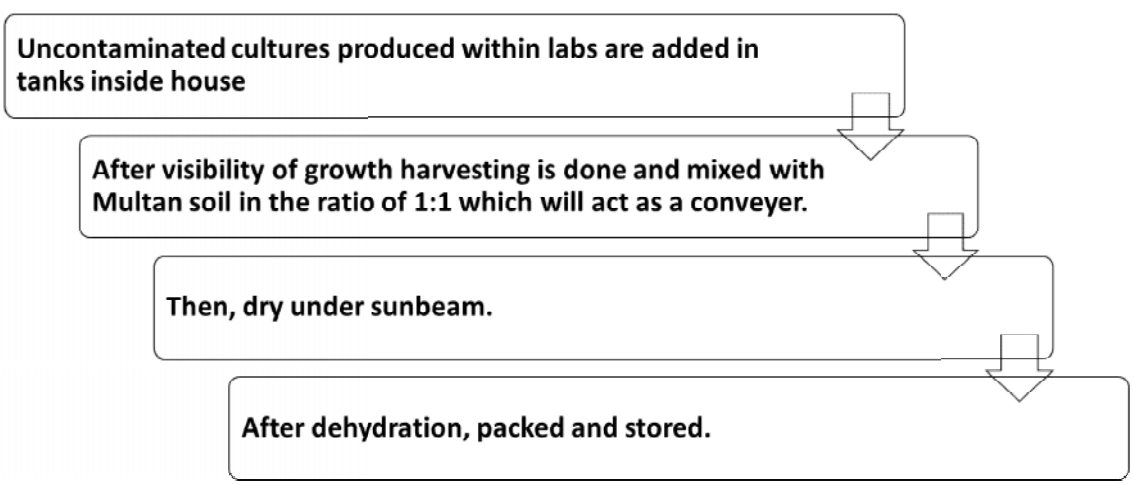


Fig. 1. Flow chart of mass production of Cyanobacteria in open conditions.



*High propagule amount i.e., 10000-100000 /gm is present, so its requirement is less.

Fig. 2. Flow chart of mass production of Cyanobacteria in closed/controlled conditions.

C. Cyanobacteria in Agriculture

Nitrogen fixation. Nitrogen is the highly required macro-nutrient for best growth and yield performance of crop. Naturally, dinitrogen (N_2) is present in atmosphere and in soil and water, but plants are unable to use it due to chemical structure except those plants having a symbiotic relationship with nitrogen fixing organisms. But there are only some micro-organisms that can fix his N_2 like cyanobacteria by specific methods (Prasanna *et al*., 2013). In addition, ARA (Acetylene reduction Assay) of soil is higher when *Nostoc carneum, N. piscinale, Anabaena doliolum, A. torulosa* combination incorporated into soil.Prasanna *et al*., (2012) discussed in his reports that the addition of cyanobacteria in the wheat and rice field in turn increases the nitrogen fixing ability for the surface populations. In marine habitat, mats of cyanobacterial mass can fix 1-75 g N per m^2 annually. Fields of paddy depends upon cyanobacteria for nitrogen in Asia region, in addition, it increases the fertility of fields and it provides a best habitat for cyanobacteria to grow. Vaishampayan *et al*., (2001) reported that from 1 ha of land, cyanobacteria can provide 4 kg of nitrogen to paddy and also by applying this cyanobacteria in rice fields of India and Japan increased the content of produce. Plants and other organisms also gets advantage from the nitrogen supplied by cyanobacteria. It is economical than chemical fertilizers (Rana *et al*., 2012). To add cyanobacterial inoculum at about $1/3^{rd}$ price and nitrogen available for first crop after inoculum added is around 25- 28% and increases in further crop seasons (Prasanna *et al*., 2013).

D. Growth enhancing matter production

Mader *et al*. (2011) reported that cyanobacteria produce a lot of growth enhancing materials which in turn increases the uptake rate and availability of nutrients. These materials are PGR'_s (Plant Growth $Regulator_s$) like auxins, cytokinins and giberallins, amino acids (Sood *et al.,* 2011) and vitamins (Roger and Reynaud, 1982). A lot of species also found to produce the IAA growth regulator when applied in wheat fields like *Nostoc, Plectonema, Anabaena, Anabaenopsis* (Natarajan *et al.,* 2012). Mazhar and Hasnain (2011) assessed that Phormidium SM-14 and SM-15 when added with tryptophan, produced IAA. Karthikeyan *et al.,* (2009) reported that through the tumors created by auxin or through wounds, cyanobacteria enter inside the wheat plants from roots and brace its growth. In addition, wheat crop's yield, shoot growth, weight of seed yield, length of spikelet was found to be increased when it was inoculated with Anabaena Ck1 and Chroococcidiopsis Ck4 species of cyanobacteria (Hussain and Hasnain, 2011). Some species including *Nostoc, Chlorogloea, Anabaena, Schytonematopsis, Aulosira, Tolypothrix, Camptylonema, Nodularia, Nostochopsis, Cylindrospermum, Scytonema, Wollea, Aphanothece, alothrix Plectonema, Westiella, Anabaenopsis, Mastigocladus, Westiellopsis, Fischerella, Stigonema, Haplosiphon, Chlorogloeopsis, Gloeotrichia and Rivularia* can fix nitrogen at a rate of 20-25 Kg (De, 1939; Singh, 1961; Watanabe and Cholikul, 1979; Vaishampayan, 1998). Hence, these growth promoting phenomenon from cyanobacteria is very useful for the crop grown and hence provide an economic as well as environmental benefits too as no chemicals used.

E. Effect of cyanobacteria on soil

Rao and Burns (1991) studied the effects of cyanobacteria on the soil sub-surface properties, they found increase in the urease, dehydrogenase, phosphatase activities, polysaccharides and increase in aggregates of soil. These soil aggregates are very important to make the soil structure stable (Burns and Davies, 1986). Soil aggregates improvement leads to a good water holding capacity (Chaudhary *et al.,* 1979). Proteoglycans present in algae are adhesive in nature which aggregate the soil by fastening the cells to solidify the surface (Flaibani *et al.,* 1989). Addition of Nostoc strains in clay soil decrease the negative effects of addition of water (Falchini *et al.,* 1996). Insoluble inorganic phosphate can be solubilized by adding cyanobacteria inoculum (Kleiner and Harper, 1977). Saha and Mandal (1979) reported an initial increase in soil pH. Subhashini and Kaushik (1981) in their report revealed the decrease not only in pH but in electrical and hydraulic conductivity of soil and soil aggregation also. Cyanobacteria, through gelatinous sheath can chelate the Zn, Cu, Mn, Co, Fe and Mo (Lange, 1976). Rao and Burns (1991) reported that there is an increase of soil microbial community eight times as higher than initial after adding cyanobacteria inoculum. After addition of *Tolypothrix tenuis* species of cyanobacteria microbial community mostly *Azotobacter* and *Clostridium* was found to be increased in a pot experiment (Ibrahim *et al*., 1971). In the reports of Acea *et al*., (2001) there was an increase of more than 4 log segments in algae and fungi propagules, actinomycetes and heterotrophic bacteria and a total of 3 log segments of fungal mycelia when burnt soil was added with cyanobacteria. So, a positive impact of cyanobacteria on soil was reported by many researchers through different studies.

F. Cyanobacteria in treating dispersive/sodic soil

In sodic soils, there may be a rise in alkalinity to 10 on pH scale which can leads to bad aeration, dispersion of clay particle, reduce in hydraulic conductivity (Gupta and Abrol, 1990).

In recent research, to treat these sodic soils, algalization technique in paddy fields was proved to be very efficient method (Kaushik and Subhashini, 1985). Blue-green algae is tolerant and can establish well in alkaline soil (Singh, 1950) and saline soil (Gollerbach *et al*., 1956). Kaushik (1990) reported the species *Plectonema, Calothrix, Nostoc, Scytonema* and some others have dominating establishment in sodic soils.

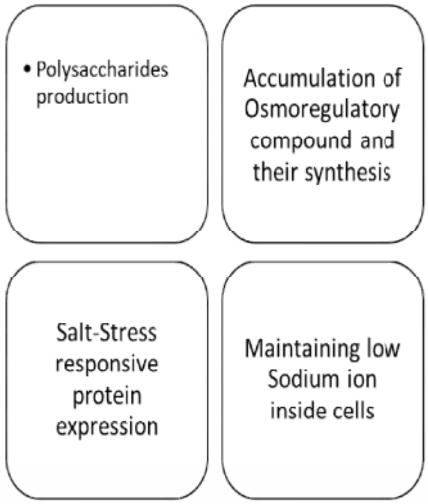


Fig. 3. Cyanobacteria strategy to establish in a saline environment.

Kaushik (2005) stated that due to this tolerance ability of cyanobacteria, it may prove as a potential treatment strategy for saline and alkaline soils. Use of cyanobacteria as a treatment of saline soil was undertaken in research (Singh, 1950; Singh, 1961). Applying a mixture of *Calothrix braunii+ Hapalosiphon intricatus + Scytonema tolypothricoides + Tolypothrix ceylonica* species of cyanobacteria in sodic soil for 105 days continuously helped in management of sodic soil and had equal impact as gypsum (Kaushik and Subhashini, 1985). Kaushik (2005) noted the importance of continuous application of cyanobacteria for approximately 3 years in sodic soil for its reclamation. Apte and Thomas (1997) reported the use of *Anabaena torulosa*, a halotolerant species of cyanobacteria in moderate saline soil (Kharland) for its treatment.

Hence, it is proved in many studies that cyanobacteria help in nursing the sodic soils.

G. Symbiont Azolla-Anabaena

Azolla and cyanobacteria fix the nitrogen and helps to enhance growth and gives a boost to production of Rice. *Azollae - Anabaena* is a common example for an effective bio-manuring as its growth is very fast and it fix the nitrogen at a boosting rate and symbiont can fix approximately 10 kg of nitrogen in a day in 1 ha area (Vaishampayan *et al*., 2001). Talley *et al*., (1977) outlines 1.2 kg of nitrogen fixation rate in 1 ha area. Dao and Tran (1966) reported a total production of 864 kg N in 1 ha area in 1 year. In symbiotic association, they help in mobilizing the phosphate, which is fixed, weed suppression, release plant growth enhancers. *Azolla* gets growth promoters and nitrogen fixed by *Anabaena* in return of protective cavity and nutrients that it provides to *Anabaena* (Walmsley, 1976).

H. Biological Control of Diseases

Some researchers also found the antagonistic effects of cyanobacteria species on the plant diseases. Campbell (1989) reported the use of organisms to limit the diseases. In addition, Whipps and Quilken (1993) enlisted the possible agents for controlling diseases including amoebae, arthropods, nematodes and some virus strains. Bonjouklian *et al., (*1991) outlined the fungicidal properties of *Tolypothrix tjipanasensis* against *Aspergillus flavous, Candida albicans and Trichophyton mentagrophytes*. Growth of some fungi viz. *Aspergillus oryzae, Penicillium notatum, Candida albicans, Saccharomyces cerevisiae* and *Trichophyton mentagrophytes* can be inhibited by *Anabaena laxa*, as crude extracts (ethanolic) are produced from it (Frankmolle *et al.,* 1992). Mohamed *et al.*(2011) outlined the production of metabolites having characteristics that can be used as anti-bacterial, anti-viral, anti-fungal and anti-algal.

A research work at School of Engineering and Technology, (Noida International University), Greater Noida was done in 2014, they tested the antifungal activity of blue-green algae against *Alternaria solani* and *Aspergillus niger* and results outlined by them were positive and inhibition of fungal strains was observed especially in *Aspergillus niger*.

In some findings, it is already proved that cyanobacteria possess allelopathic effects. *Fischerella* produce fishrellins A/B and indole alkaloids which in turn damage the functioning of Photosystem II or completely stop it (Ganter *et al*., 2008).

Against Insects: Biocidal activity of blue-green algae is similar to insecticides in its mode of action (Goldin, 2012). When *Anabaena cylindrica, Nostoc muscorum, Anabaenaoryzae* and *Tolypothrix tenuis* added in soil as inoculums +72 kg of nitrogen in 1 ha, it helped in controlling the population of stem borer (*Chilo agamemnon*) and leaf miner (*Hydrellia prosternalis*) (Yanni and Abdallah, 1990). Weight of larvae of cotton bollworm (*Helicoverpa*) was found to be low/reduced when treated with *Nostoc* (Biondi *et al*., 2004). Cyanobacteria with *B.t* subsp. *isralensis* in recombinant form have ultimate toxicity against larvae of *A. aegypti* (Kiviranta and Abdel, 1994).

Against Disease: Nostocyclyne A, nostocin A, Ambigol A and B, hapalindoles and scytophycins are the major anti-microbial metabolites produced by cyanobacteria (Falch *et al.,* 1995; Juttner *et al.,* 2001; Hirata *et al.,* 2003). *Tjipanazoles, Tolypothrix tjipanensis*, show fungicidal effect against *Aspergillus flavus* (Bonjouklian *et al.,* 1991). There are many examples of antagonistic cyanobacteria against several plant pathogens including *Nostoc muscorum* against *Rhizoctonia solani* (De-caire *et al.,* 1990), *Fischerella* against *Uromyces appendiculatus, Erysiphe graminis, Phytophthora infestans* and *Pyricularia oryzae* (Hagmann and Juttner, 1996), *Tolyphothrix tjipanensis* against *Aspergillus flavus* (Bonjouklian *et al.,* 1991), Spirulina platensis against *Candida albicans* (Ozdemir *et al.,* 2004).

A. As a Biofertilizer in different crops. In this era of modernization, exploitation of resources is increasing day by day due to growing population. Use of chemical fertilizer is a main concern for crop environment and consumers also. Cyanobacteria can provide an effective alternative which is environmentally friendly and may be fascinating than chemical fertilizers to increase the overall productivity in many crops. As, cyanobacteria can take up Ammonium (NH_4^+) through special methods and by passive diffusion, it can uptake Ammonia also. In addition, N_2 can be utilized as a source of Nitrogen by it. Enzyme nitrogenase can easily reduce the nitrogen to ammonia when hydrogen is available. So, undoubtedly cyanobacterium can be a potential biofertilizer in agriculture. Cyanobacteria is a good option as it provides material for growth promotion and a hopeful mean for biocontrol in several crops including rice, wheat, cotton, different legume crops and vegetables (Manjunath *et al.*, 2010; Prasanna *et al.*, 2013; Swarnalakshmi *et al.*, 2013; Prasanna *et al.*, 2014; Prasanna *et al.*, 2015).

Many research works were conducted since many decades on cyanobacteria as a biofertilizer on different crops including:

B. Rice: A natural population can be easily observed in many rice growing fields without any supplementation which provide nitrogen without any charges on farmer. As mentioned earlier the first study of adding cyanobacteria in rice field and its effects was carried out in Japan in mid 1950s. In addition, many countries carried out the same experiment which resulted in 15-20% increase of grain yield. Also, if cyanobacteria is applied for 3 to 4 cropping season continuously it can make permanent colonies within the field.

Many trials under field conditions were conducted by using inoculum from indoor production method i.e., 500 gm/acre which showed definite positive results. These trials were conducted in Bahadurgarh tehsil, Jhajjhar, Haryana in 3 villages (given in General article; Cyanobacteria. A potential biofertilizer for rice by Upasana Mishra and Sunil Pabbi at Centre for Conservation and Utilization of Blue Green Algae, IARI, New Delhi).

a. Asoda Todran – grain yield increased by 19.48%.

b. Asoda Siwan – grain yield increased by 15.81%.

c. Jakhoda – grain yield increased by 12.26%.

But different research shows the inconsistent results of cyanobacteria, but best results were obtained when inoculum is mixed with nitrogenous fertilizers at low level which increase the speed of growth and also when frequent ploughing of soil is done. Algalization is very useful to reduce the natural inoculum present.

If inoculum produced in open condition is used then 10-12 Kg is sufficient for 1 ha which can be applied after 3 to 4 days of transplantation and if inoculum produced in Indoor conditions is used- 500 gm/acre is found sufficient.

C. Lettuce: A research was conducted in 2012 at College of Agriculture, University of Hawassa, Ethiopia and a pot experiment in green house was done with lettuce crop. It reported that the application of dried cyanobacteria gave the best results in every aspect i.e. highest leaf length (23.5 cm), fresh wt. of leaf (239.16 gm), highest no of leaf (9.5), highest dry wt. of leaf (11.79 gm), largest leaf area (2046.33 cm2), more dry wt. of root (1.92 gm per plant). Research work concluded that using cyanobacteria in place of chemical fertilizer will increase the growth, yield and production of lettuce.

D. Wheat: There has been a scarce for using cyanobacteria for wheat as a biofertilizer but because of high Nitrogenous fertilizer requirement by wheat crop, cyanobacteria was tested in Integrated Nutrient Management strategy. *Nostoc* and *Anabaena* isolates formed positive coalition with liquid culture grown wheat crop. Gantar *et al.*, (1991) measured the wheat seedling and cyanobacteria associations. Many species that were studied formed a close association, but some were free-living also.

A research study in IARI, New Delhi was undertaken by Karthikeyan *et al.,* (2006) and they outlined that isolates from rhizosphere which were attached to roots of wheat when studied, found to produce growth-enhancers. They selected three conditions for the wheat growth in pot under Phytotron, Glasshouse and Agronomic conditions using three cyanobacterial strains *Hpalosiphon intricatus, Nostoc* sp and *Calothrix ghosei* and experiment done with 10 different treatments. They reported the positive growth and yields parameters by minimizing the chemical fertilizers and supplements of cyanobacteria helps to mitigate the chemical fertilizers needs and hence, leads to sustainability.

E. Okra: An experiment at IIVR, Varanasi was conducted by Manjunath *et al.*, (2015) to check the effect of the *Azotobacter* and *Anabaena* on soil to increase the yield of Okra and they found the positive effects on soil enzymes, in which cyanobacterial inoculants were added. In addition, in the treatment that was added with *Calothrix* cyanobacteria, a high value of available nutrients was recorded during harvest stage, and highest root weight was observed in the treatment in which a mixture of *Azotobacter* and Anabaena applied as a film.

F. Onion: Geries and Elsadany (2021) reported the increment in bulb quality and overall yield content of onion when inoculated with *Arthrospira platensis* strain.

I. Cyanobacteria in treatment of agro-industrial waste and wastewater

Agriculture activities along with industries generate an unthinkable heap of waste every year which may also have nutrients (inorganic/organic). This dumped waste causes soil pollution by accumulation of toxins and water pollution by wastewater/effluent mixing/air pollution by gas emission. Huge wastes are prompt by poultry farm, lubricant mills, milk pasteurizing plant and ranch farm also. A lot of methods are being used from past years to nurse this solid waste and wastewater (Imbeah, 1998; Burton and Turnor, 2003; Burton, 2007; Aryanitiyanis *et al.*, 2008; Bernet and Beline, 2009) but only digestion methods are popular (anaerobic and aerobic) which mostly nurse the organic pollutants and inorganic in nominal amount (Westerman and Bicudo, 2005). Removal of inorganic pollutants is a tedious job (Bashan and Bashan, 2010). Cyanobacteria are well known for its scavenging activity but in alone it may not be sufficient, hence a synergic establishment can be created with microalgae. Oxygen production by microalgae used up by BGA and decomposition yields

CO_2, P and NH_3 which are useful for microalgae spreading (Gantar *et al.,* 1991; Ogbonna *et al.,* 2000; Traviesco *et al.,* 2006).

Many studies showed the cultivation of BGA in swine wastewater, poultry waste, dairy waste and cattle waste can be possible. Chung *et al.,* (1978) cultivated *Spirulina platensis* on the waste material of pig farm which resulted in 76% removal capability of N. Noüe and Bassers (1989) outlined the response of cyanobacteria growth with high temperature when grown in pig waste. A total efficiency of 76-96% of N removal, 99% removal of P and NH_3-N by 100% was resulted when 2% effluent of pig waste was added in sea water (Olguin *et al.,* 1994; 1997; 2003). A very faster growth of *Spirulina* was observed without any stoppage when grown on diluted cattle waste (Lincoln *et al.,* 1996). Mahadevaswamy and Venkataraman (1986) reported the use of poultry manure for Spirulina cultivation and was found effective when 2% diluted effluent used. A total of 69% efficient removal of P from cheese was recorded after 4 days of inoculation of *P. bohneri* (Blier *et al.,* 1995). Also, cyanobacteria addition in various wastewaters from industries was studied by many researchers. Vargas and Ayala, 1987 reported the *Spirulina* cultivation on waste remains after yeast production in industries and obtained a positive growth rate. Costa and Andrade (2007) reported the use of molasses for *S. platensis* cultivation and a good heterotrophic growth was resulted.

J. Cyanobacteria for value-based products / industrial applications

Due to genetic engineering capacity, photosynthetic ability and low-cost inputs for cyanobacteria, it is very much luring for industrial application. In addition, it has very short life cycle. Hence, it is a promising material for genetic engineering and it has a wide adaptation so it can save a huge amount of transportation. It can be used in production of various products possessing a high value and demands.

A. Coir Biodegradation for Manure production: Cyanobacteria is a great biodegrador of waste materials like coir waste to make a healthy heap of manure for field application. As, coir proved to be a conditioner for soil due to C: N ratio of 75:1 it also contains high lignin and cellulose content which are hard to degrade naturally and falls under a pollution category, hence by using cyanobacteria as a degrading agent it can be used as manure after degradation. A research study was carried out in the year 2009 at Bharath University, Chennai with three cyanobacterial species i.e., *Anabaena azollae, Oscillatoria* sp. and *Phormidium* sp. for the biodegradation of coir. Their results depicted the positive impact of cyanobacteria on coir including decrease of C: N in Azollae-Anabaena symbiont, cellulose content in *Oscillatoria* sp. and hemicellulose in *Phormidium*.

B. Isoprene Production: Isoprene is used for synthetic rubber production after polymerization by different chemicals. Lindeberg *et al.,* (2010) reported that it is a naturally produced compound in plants but to remove or isolate it from its natural host is quite impractical but in past years its production has been investigated in fresh water cyanobacteria naming PCC-6803 strain of *Synechocystis* sp. bys isoprene synthase enzyme from a fabaceae family plant Kudzu (*Pueraria montana*).

C. Sugar Production: Sugar production is reported recently from *S. elongates* strain as it generate a blend of fructose and glucose or build lactic acid (Niederholtmeyer *et al.,* 2010). In addition, they also used the mechanism of proton-couples transporters to take out the lactate out of cyanobacterial cells.

D. Biofuel production:

i. Alcohol. Alcohol production by fermentation process is very common and is being used from several years (Goldemberg and Guardabassi, 2009). Efficiency of biofuel production is very low, so to increase this efficiency a lot of efforts were made including the use of genes Pyruvate decarboxylase and Alcohol dehydrogenase II in 2 different species of cyanobacteria by genetic engineering strategy (Deng and Devroe, 1999). Along with cyanobcteria, now a days euglenoides are popular for research in biotechnology as *Euglena gracils* produce β-1, 3-glucan paramylon in cultures (Calvayrac *et. al*., 1981).

ii. Alkane production was studied by Schirmer (2010) a researcher in LS9, 2 genes present in cyanobacteria which are Aldehyde decarboxylase and acyl-acyl carrier protein reductase which make alkanes or alkenes from fatty acid.

iii. Hydrogen. Also, some evidences of hydrogen production in cyanobacteria was also reported but it is less than 0.1% (Dutta *et al.,* 2005). Hydrogen produced in cyanobacteria when hydrogenase activity is reversed. 14 species of cyanobacteria can produce Hydrogen including *Calothrix, Oscillatoria, Cyanothece, , Nostoc, Anabaenopsis, Synechococcus, Chroococcidiopsis Gloebacter, Mycrocystis, Synechocystis, Gleocapsa, Aphanocapsa, Microcoelus and Anabaena* (produce the biggest amount) (Das and Veziroglu, 2001; Dutta *et al.,* 2005; Abed *et al.,* 2009). Some years back a total of € 4 million to start a project on 'SOLAR-H2' for Hydrogen production photo-biologically under a programme – FP7 from 2008 to 2012.

iv. Ethanol production from cyanobacteria is very promising as it can be blend well with present diesel directly without any further engineering (Kaygusuz, 2009). Also, it can be fermented naturally unlike other crops in which to produce ethanol yeast culture is added. Heyer and Krumbein (1991) reported the 16 strains after fermentation which produced the ethanol out of 31 strains tested and *Oscillatoria* produced most positive amount of ethanol. Also, production of ethanol form cyanobacteria is an environment friendly procedure as it doesn't leads to any pollution and itself required less energy to produce ethanol (Luo *et al.,* 2010).

v. Methane-*Spirullina maxima*is used to produce methane through digestion process (anaerobic) (Samson and Leduy, 1982; Samson and Leduy, 1986; Varel *et al.,* 1988). In some other studies it was shown that cyanobacteria along with some other species in combination can yield a great amount of CH_4 and also helps to control pollution. Gantzer and Maier (1990) studied the reduction of cyanides to CH_4 and NH_3 by nitrogenase enzyme in *Anabaena* at the rate of 10x faster than normal. Koshland (2009) reported the CH_4 production from *Synechococcus* PCC 7942 by utilizing CO_2 and solar energy from environment using acetic acid or glucose as key nutrients. The 'Baltic Eco-Energy Cluster's project' for Hydrogen and methane production in high amount during biogas production was a good strategy too, predicted to be accomplished till 2013.

Biodiesel production from biodiesel was also studied by a lot of researchers. Griffiths and Harrisons (2009) reported the manufacture of biodiesel from 55 species of microalgae. Biodiesel production needs high lipid content production. *Synechococcus* produced 75mg/L lipid amount /day (Highest production). Synthetic genomics Inc., in agreement with another company'ExxonMobil' in year 2009, make an announcement to produce biofuels of next generation from algae which can produce photo-synthates and a total investment of 600 Million dollar (US) was announced for oil harvest efficiently.

E. Electricity Production: Some reports focused on production of electric energy from light energy by photo-electro-chemical cells. Dr. Ilia Baskakov's was provided with funds of reputable award of 'Elkins Professorship Award' after her research on cyanobacteria and electricity production from it at Baltimore Uni. of Maryland, USA.

F. Fuel Cells: Dawar *et al.,* (1998) studied the cyanobacteria for using in fuel cells as Hydrogen. For H2 production in fuel cells, some researchers also employed the cyanobacteria strains *Spirulina*.

K. Cyanobacteria as a food source

Due to this increase in population, there is a high risk to food security, to avoid any kind of hazards to be occur a lot of researchers focus their work on alternative sources of food and they are trying to get as many as possible to reduce the risk to food security. A lot of positive results were being presented to world including the cyanobacteria. In many countries, different cyanobacterial strains of *Spirulina, Nostoc and Anabaena* is being utilized as a source of healthy food. *S. spirulina* strain is grown within industries and after harvesting they are converted in different forms including powder, capsules and tablets and sold in market and their demand is increasing day by day due to their nutritious and easy to digest value. Also some species possess highly nutritious so their addition in human diet can lead to completing the daily nutrition profile including high protein and fibre in *Nostoc commune*. Carmichael and Gorham (1980) outlined a species naming *Aphanizomenon* sp. as a food which was isolated from 'Lake Klamath blooms', USA. In addition to human food some tests were conducted to use the cyanobacteria as feeding material for fishes (Mitsui *et al.,* 1983) and a positive growth was shown in the Tilapia fish. *Phormidium valderianum* is being utilized from past several years as a feeding material for aquaculture in India as it is nutritional as well as non-toxic. It is a functional food as it provides fats, carbohydrates, vitamin, mineral and proteins. Farrar (1966) reported the use of cyanobacteria as a functional food, he outlined the selling of *Spirulina maxima* in dried form in Mexico market in 1521. Evidence of use of *Spirulina* since 1940 in African Kanembu tribe as a protein source (Abdulqader *et al.,* 2000) and use of *N. filiforme* and *N. punctiforme* by Chinese (Soeder, 1980) are also present. Although filamentous form is more acceptable by sellers and consumer in many parts of world while a specific slot is being created by the unicellular form in world market example includes *Aphanotheca sacrum* in Japan is very popular (Fujishiro *et al.,* 2004). Also, *Spirulina* contribute a worth of 40 Million dollars in USA as a food (Singh *et al.,* 2005).

The cyanobacteria as a functional food is gaining attraction of world due to high nutritious nature, easy to digest, great content of mineral and vitamins in it, require less space and time to grow, didn't require highly fertile soil but can grow on infertile one also it requires very less amount of inputs like water, present across the globe and can tolerate harsh weather conditions also.

CONCLUSION

Cyanobacteria are photosynthetic bacteria, ubiquitous in nature and are only Prokaryotes which perform oxygenic-photosynthesis. Due to easy and economical cultivation practices in open and closed conditions too, a lot of research carried on cyanobacteria. Hundreds of research results in finding the true effects and benefits of cyanobacteria in real-life situations, if it be agriculture or pharmaceutical or industrial or any other. Approximately 200 species of are identified and recorded with their potentials and research works are going on to identify more if present and to find the best potentials of these cyanobacterial species. Their total efficiency is not discovered completely but it is proved as a potential food, fertilizer, biodegrading, soil treating and a disease controlling agent. It can fix the dinitrogen through specific mechanism and is eco-friendly. It provides N as well as growth promoters to enhance the plant growth hence providing double benefit and save a lot of effort. Its ability enhances when it is being applied with azolla as a symbiont. With the positive control of diseases and pests its ability to ameliorate the sodic soil is being studied at different locations. Apart from its benefits in agriculture sector, its study as a potential food material is being carried by many scholars due to its nutritional benefits and a proper diet supplement.

FUTURE PROSPECTS

Regarding the future of this blue-green algae, having a useful present directly shows the bright future with its different strains. In past, due to restricted technology its abilities are not 100% known but as technology is advancing, more diversification with this potential cyanobacteria will possible in different sectors be it be agriculture or food or any other commercial sector. Cyanobacteria leads to a sustainable way of agriculture as it provides bioenergy as biofertilizers, feed to poultry and fishes, etc. Also, it helps to mitigate the climate problem as it tends to reduce the level of CO_2 in atmosphere. Hence, it needs a production on large scale. Nitrogen cycle of cyanobacteria is not completely studied as it is proved that it fixes the atmospheric nitrogen in marine habitat in fields but it fails to do so in ocean, hence further studies will give the answer to it. The pathway of sugar phosphate and a weak TCA cycle were recorded in some strains and hence these will provide a good base to produce compounds of sugar. In addition, U.S. Proterro Inc. carried out sugar production and also sunscreen is available produced from *Anabaena variabilis. Synechoccus* 2973 was recently evaluated to produce sugar feedstock which shows 51% glycogen content and 35.5 mg/L/h. of sucrose which was highest ever recorded in other strains. Hence, with more efforts a sure development will be seen in near future.

CONFLICTS OF INTEREST

Authors neglects the presence of any conflicts of interest. All authors have already seen the manuscript completely and approved without any problem.

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