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Blue Green Algae for Secondary Agriculture

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Blue Green Algae (BGA) or cyanobacteria are photoautotrophic microorganisms widely distributed in terrestrial and aquatic habitats. These have tremendous metabolic diversity with the ability to produce a range of metabolites like pigments, polysaccharides, amino acids, lipids, vitamins, enzymes, antimicrobial compounds and many more. Till now the major application of cyanobacteria is in the form of biofertilizers, especially in India and a few South Asian nations, nonetheless due to the production of a number of industrially important molecules like phycobiliproteins, amino acids, bioactive lipids, biofuels, their mass cultivation has tremendous scope in secondary agriculture. Many of these compounds are of high value and have applications in the food, feed and pharmaceutical industries. Nevertheless, commercial exploitation of cyanobacteria in secondary agriculture is still in its infancy. Appropriate research efforts and suitable policy decisions are required to establish these versatile organisms as a secondary agriculture option and a profitable commercial venture.

Key Words: Bioactive metabolites, Biorefinery approach, Cyanobacteria, Secondary agriculture, *Spirulina*

Introduction

Blue Green Algae are the most primitive prokaryotic photoautotrophs responsible for the oxygenation of the earth's atmosphere. These are considered as the most successful and sustained prokaryotic organisms during the course of evolution. BGA can produce an array of metabolites, such as phenols, flavonoids, carotenoids, phycobiliproteins, steroids, vitamins, amino acids, enzymes, polysaccharides etc. which can be potentially used for agricultural and industrial applications. BGA are used as food or health supplements, superfood bar, or fine chemicals in nutraceutical industries, their biomass are used as a source of biofertilizers, natural soil conditioner, and their pigments such as phycobiliproteins (phycocyanin and phycoerythrin) are used in different cosmetic products or natural food colorants. However, the major application of cyanobacteria in most countries is in the form of biofertilizers for rice.

Primary agriculture mainly aims to produce or cultivate natural resources for human consumption. However, many a time value addition or the processing is generally avoided which can otherwise render more return to the producers. On the other hand, secondary agriculture is generally defined as processing or adding value to the primary agricultural commodities and can make a remarkable positive contribution towards the national economy (Yadav *et al.,* 2020). Secondary agriculture contributes more than 25% of India's GDP (Yadav *et al.,* 2020). It utilizes renewable agro-bioresources or agri-wasteby value addition. Nurseries, biofertilizers, biopesticides, compost, flavours, dyes, essential oils, and biofuels are some of the avenues of secondary agriculture (Yadav *et al*., 2020). The demand for bioactive foods, and green health products is increasing with increased health awareness. Such products can be one of the important constituents of secondary agriculture. Cyanobacteria can be a useful resource for secondary agriculture due to the production of the wide range of metabolites with commercial application, photoautotrophic growth and ease of mass multiplication. Further to this, the biorefinery approach toward commercial exploitation of cyanobacteria can multiply the return by many folds.

In this present review, we aim to briefly present the applications and prospects of cyanobacteria pertinent to secondary agriculture and challenges for commercial exploitation.

BGA as a Source of Natural Pigments

Cyanobacterial pigments such as phycobiliproteins, chlorophyll, and carotenoids possess commercial significance and have sparked research interest. Phycobiliproteins (PBP) can be a natural alternative to harmful synthetic dyes and colorants. Due to its

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carcinogenic nature and potential allergic reactions, the use of synthetic food colors has been restricted by European Food Safety Authority (AESA) and the American Food and Drug Administration (FDA) (Vigani *et al*., 2015). Cyanobacterial phycocyanin (C-PC) has been used as a natural colorant in food industries such as in chewing gum, ice cream, candies, dairy products, beverages such as soft drinks; drug and cosmetics; and have economic potential due to its non-toxic properties and health benefits (Chakdar *et al.,* 2012). Phycocyanin has been approved as a permitted food colorant by FDAs of USA and Japan which has expanded its application. In the aquaculture industry, C-PCs are used as feed supplements due to their high nutritional value (Yusoff *et al.,* 2020). Species of genera such as *Spirulina, Synechococcus,* and *Anabaena* contain abundant natural blue pigment. Phycocyanin with a purity >0.70 is considered a food grade while a purity above 4.0 is considered a pharmaceutical grade. The cost of pharmaceutical-grade phycocyanin can go up to thousands of USD per milligram. According to Future Market Insights, the overall market of phycobiliproteins was USD 112.3 million in 2018 which is predicted to double by 2028 (Pagels *et al.,* 2019). Phycocyanin pigment alone has a market of about $100 million USD.

BGA as a Source of Cosmeceuticals

Globally, India ranks fourth for generating revenue from beauty and health care products and the Indian cosmetic industry is expected to reach 20 billion USD by 2025. With the rising awareness among consumers regarding the side effects of chemical cosmetic formulations, the demand for green cosmetics is increasing. Being phototrophic microorganisms with ubiquitous distribution, cyanobacteria possess excellent photoprotective and antioxidative mechanisms. The metabolites like pigments, exopolysaccharides, and amino acids have tremendous potential to be used in green cosmeceuticals. Mycosporin-like amino acids (MAA) and Scytonemin (SCY), extracted from different cyanobacteria are potential UV protectants and provide protection against harmful solar radiations (Kageyama *et al.,* 2018). Tetrahydropyridines, an MAA derivative, used as sunscreen pigments not only prevent UV damage but also suppress inflammation and have antioxidant activity. SCY extracted from *Nostoc commune* and *Rivularia* sp., can have significant antioxidant and photoprotective activities.

Cyanobacterial exopolysaccharides (EPS) can be a potential source of natural moisturizer as they protect cells from dehydration. Li *et al.* (2010) reported that EPS obtained from *N. commune* could be exploited as a natural humectant in cosmetic industries demonstrating 10.1% water absorption and 28% water retention capacity as compared to urea with 5.8% water absorption and 15.9% water retention capacity. Sacran, an exopolysaccharide obtained from *Aphanothece sacrum* possess higher water absorption efficiency than hyaluronic acid, the most widely used ingredient in moisturizing products.

Due to their beneficial effect on human skin, EU has included Methylsilanol spirulinate (CAS 188012–54-6) *Arthrospira platensis* (CAS 223751–80-2)*, Limnospira maxima* in the Cosmetic Ingredient Database (Verma *et al.,* 2022). *Spirulina* extracts are used as moisturizers and skin softeners in beauty products manufactured by Nykaa E-Retail Pvt. Ltd. (India,). Blue Green Algae Hair Rescue Conditioning Mask marketed by Aubrey Organics, Inc. (USA) has been reported to help in hair strengthening. Phormiskin Bioprotech G from Codif Recherche and Nature (Paris, France) is derived from *Phormidium persicinum* which has unique photo-protective properties (Chakdar and Pabbi, 2017). Blue Therapy (Lift and Blur) manufactured and marketed by Biotherm (France) uses extracts of *Aphanizomenon flos-aquae* and *Laminaria ochroleuca* which confer anti-ageing effects. Global leaders in the cosmetics industry like Louis Vuitton (France) and Danial Jouvance (France) have developed their own microalgal production systems for manufacturing microalgae-based cosmeceuticals (Verma *et al.,* 2022).

BGA as a Source of Nutraceuticals

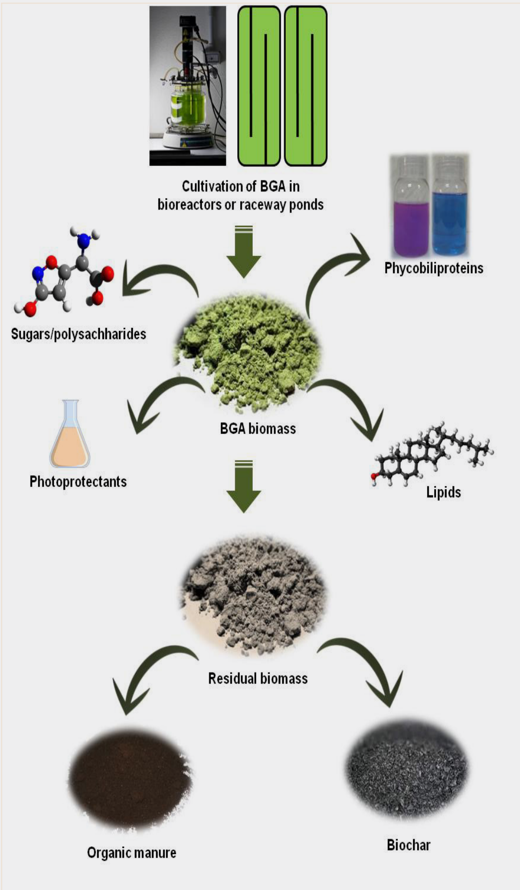
Cyanobacteria are a rich source of protein, minerals, vitamins, healthy lipids and antioxidants (Pulz and Gross, 2004; Rosenberg *et al.,* 2008). Cyanobacterial biomass has been utilized as a source of traditional food in many Asian and African countries for centuries. *Spirulina* was consumed as nutritious food in central Africa by Kanembu people, the indigenous population of Asia and North America for a long time. “Dihé” a sun-dried hardened mat of *Spirulina* (*Arthrospira*) collected from Lake Chad is used by the locals as nutrient-rich food (Carcea *et al.* 2015). *Nostoc, Anabaena* and *Spirulina* are used as popular food supplements in many South American countries. *Spirulina* is regarded as a superfood with ~70% protein content as compared to 15-25% from animals or fish. Free fatty acids may account for up to 70% to 80% of the total lipids in *Spirulina* which is also a rich source of gamma-linolenic acid (GLA). Besides, *Spirulina* is also an excellent source of Vitamin B-complex. According to NASA, the nutritional value of 1 kg of *Spirulina* equals 1000 kg of assorted vegetables and fruits. Hence, NASA (CELSS) and the European space agency (MELISSA) proposed *Spirulina* as a major source of nutrition in long-term space missions (Sies, 1996).

Spirulina is reported as the most dominant commercial cyanobacteria in biomass production with >10000 tons annual production globally (Guidi *et al*., 2021). A number of commercial preparations are available in many countries including India. In India, EID Parry, Tamil Nadu, Sannat Group, Tamil Nadu, NB Laboratories, Maharashtra, Shibin Exports, Tamil Nadu are some of the major *Spirulina* growers. Annual production of *Spirulina* in India is more than 600 tons per annum. *Spirulina* production can be easily taken up by farmers and entrepreneurs as *Spirulina* powder itself can be sold at a price of Rs. 600-1200.00 per kg. Further, when sold in the form of capsules, each capsule (500 mg) can cost up to Rs. 3-5.0. Conservatively, a *Spirulina* production unit with a capacity of 1000 kg (dried) biomass per year will cost around Rs. 6.0-7.0 lakhs. Therefore, *Spirulina* farming can be an excellent option for secondary agriculture. Apart from *Spirulina*, other cyanobacteria like *Aphanizomenon flos-aquae* (Kalmath's Best ® Blue Green Algae) have also been marketed by Kalmath Valley Botanicals LLC, USA. This product has a considerable market in the USA, Germany, Canada, Korea, Japan and Austria.

Challenges and Prospects

No doubt, the application of cyanobacteria can be a potential avenue in secondary agriculture. The beneficial effects of cyanobacterial biomass, pigments and extracts in nutraceuticals, pharmaceutical, and cosmeceutical industries cannot be overlooked and these have gained much attention in recent years. Increased demand for safer and more efficient natural raw ingredients has further proved the potential of cyanobacteria in the industrial sector. The major advantage of using cyanobacteria for industrial application is their photoautotrophic and diazotrophic growth which can significantly cut down the cost of commercial cultivation considering a very low or no requirement of C and N sources. Furthermore, this can also reduce the chances of bacterial or fungal contamination. Despite such advantages, the commercial exploitation of cyanobacteria is comparatively low as compared to bacteria or fungi and interestingly, most of the products commercialized are based on *Spirulina*. The majority of the cyanobacterial products in the market are available either as food supplements or food products containing cyanobacterial pigments. It is true that *Spirulina* is a rich source of various nutritional factors and pigments but there are a number of other cyanobacteria which have tremendous commercial potential but have not been exploited. For example, *Nostoc* spp. is rich in nutritional components and *Lyngbya* spp. are a rich source of antimicrobial compounds. Though the research efforts towards understanding the diversity and metabolic potential of cyanobacteria are meagre as compared to bacteria or fungi, and to exploit cyanobacteria for fine chemicals and pharmaceuticals at a commercial scale for use in secondary agriculture, microbiologists and algologists need to reorient their research focus. Cyanobacterial biomass production under outdoor open cultivation is highly influenced by changing environmental conditions which ultimately affect the economic viability. Especially, light quality, quantity and temperature are very critical to cyanobacterial biomass production. Therefore, it is required to identify cyanobacterial species which can sustain a wide range of environmental conditions and result in economically viable biomass production. Lack of high-yielding strains and limitations in improving the inherent yields are the major factors behind relatively lower commercial exploitation. Furthermore, isolation of specific compounds requires downstream processing including extraction and purification.

Large-scale cultivation of cyanobacteria is also critical for commercial exploitation. Raceway ponds and photobioreactors are generally used worldwide for the mass cultivation of cyanobacteria. However, such facilities require huge investments in terms of infrastructure and operational costs. In many instances, a combination of both raceway and photobioreactor systems (Hybrid) has been recommended to cut down the cost of mass cultivation (Bravo-Fritz *et al.,* 2016). The profitability of commercial cultivation of cyanobacteria can be further increased by a biorefinery approach



Blue Green Algal Biorefinery

The biorefinery concept relies on extracting maximum benefits from algal biomass. Harvesting multiple products from blue green algal biomass makes it economically attractive. The biomass can be used as feed stock for several bioprocesses to generate a number of bioproducts. For example, the same blue green algal biomass can be used for extracting pigments, lipids, other biomolecules and the residual ones can be converted to biochar or organic manure or can be used as stocks for other bioprocesses. In a closed loop bioreinery appraoch, the components are reutilized to generate a number of valorized products. Closed loop refinery approach improves the economic feasibility, applicability along with sustainability for multiple commodity production. On the other hand, Self-sustainable biorefinery (SSB) model maximizes utilization of resources with no waste discharge by doing away with the external energy and material input.

which enhances the economic feasibility by allowing the exploitation of different co-products that can be individually utilized (Bastiaens *et al.,* 2017).

Conclusion

Blue-green algae have tremendous commercial potential and can significantly contribute to the Indian economy. However, lack of awareness, poor availability of commercial strains and process optimisation for cost minimization with output maximization are some of the bottlenecks for their limited commercial exploitation. Nonetheless, industrial exploitation in India has increased significantly in the last two decades with a considerable increase in the number of commercial algae growers. Despite many advantages as a secondary agriculture resource, it is not yet very popular as compared to crop-based or medicinal plant-based products. A concerted effort to explore more avenues in the biorefinery approach and policy decisions to provide capital support from the government (as provided in the case of biofertilizers or biopesticide production units) is urgently required to harness the potential of BGA.

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