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Microalgae and Cyanobacteria for Food Applications

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Abstract:

Microalgae are a large diverse group of microorganisms comprising photoautotrophic protists and prokaryotic cyanobacteria—also called blue-green algae. These microalgae form the source of the food chain for more than 70% of the world's biomass. Photosynthetic prokaryotes called cyanobacteria have been used in enhancing human health. Due to solubility issues, only 10% of the microalgal bioactive components have made it to commercial platforms. A novel method for creating new cancer treatments may include using nanoformulations that contain a wide range of nanoparticles. Cyanobacteria and microalgae can be transformed into a variety of products of commercial significance, including biofuels, cosmetics, renewable chemicals, and other important molecules, as well as animal and human food, particularly as sources of proteins, lipids, and phytochemicals. The production of cyanobacteria in artificial and natural environments has been fully exploited. In this review the use of cyanobacteria and microalgae, production processes are discussed in it.

Keywords: Microalgae, diversity, Cyanobacteria, Nutritional composition, photosynthetic growth.

1. Introduction:

Microalgae and cyanobacteria are typically found in water bodies, desert crusts, or even in symbiosis with other organisms. Cyanobacteria are prokaryotic green-blue algae. They can survive in various environmental circumstances, including low or high temperatures, intense or diffuse lighting, pH, and salinity [Barsanti L. et. al. 2008]. Growing consideration has been given in recent years to the possibility of producing these sorts of creatures for commercial use. The ability to be employed in both human and animal nutrition accounts for a portion of the added value of this form of biomass (i.e., fish feed in aquaculture facilities). Additionally, some microalgae extracts may be utilised to create medicinal compounds, cosmetics, and a wide range of other bioactive items [Apt KE et. al. 1999; Luiten EE et. al. 2003; Yamaguchi K. 1996]. Cyanobacteria and microalgae have an incredibly diverse range, with new species, genera, and even classes being identified every year (Martnez-Francés, E., et al. 2018).

The unicellular photosynthetic microorganisms known as microalgae are found in both freshwater and marine habitats (Bhattacharya and Goswami 2020). When eukaryotic species such as chlorophylls (green algae), bacillaryiophytes (diatoms), dinophytes (dinoflagellates), euglenophytes, prymnesiophytes (coccolithophorids), and prokaryotes such as cyanophytes are included, the name "microalgae" has no phylogenetic connotations (Enzing et al. 2014). Microalgae are often employed in a variety of biotechnological applications, including the creation of biodiesel, the bioremediation of wastewater, and the manufacturing of food items (Barkia, Saari, and Manning 2019; Barros de Medeiros, et al. 2022).

By 2030, there will be 21 million new instances of cancer and 13 million cancer-related deaths, predicts a World Health Organization (WHO) assessment. A 30% reduction in cancer-related mortality is thought to be possible by reducing or eliminating the main risk factors, such as smoking, radiation exposure, drinking, and infections. Currently, cancer is the cause of 13% of all deaths globally. However, there is a sizable reservoir of marine organisms in the ocean that contain valuable natural medicinal ingredients. Since marine bioprospecting is a relatively new phenomenon, the study of aquatic life is still in its infancy [Grothaus, P.G. et. al. 2010; Demain, et. al. 2011; Cragg, G.M. 2012; Basmadjian, C. et. al. 2014]. The majority of naturally occurring substances with medicinal efficacy come from terrestrial life [Cragg, G.M. et. al. 2005]. Globe over, sea flora has long been used for its possible therapeutic benefits [Wang, W. et. al. 2012]. Seaweed, sponges, actinobacteria, bacteria, and fungi are examples of marine species that have been successfully used to cure cancer. Natural ingredients are the most effective anti-cancer medications. However, the phases of invention and research for natural products are costly, laborious, and time-consuming [Gerwick, W.H. et. al. 2012; Montaser, R. et. al. 2011].

About 70.8% of Earth is covered by the dynamic and very delicate global marine environment [Townsend, M. et. al. 2018]. A very diverse range of micro- and macro-organisms is included in this high biodiversity. Microorganisms that are both producers and decomposers, such as marine bacteria, fungi, and microalgae, play a crucial part in re-establishing the equilibrium in the aquatic environment [Snelgrove, P.V.R. 1999]. Since ancient times, people have used marine microalgae as food and medicine since they are crucial to ecosystem health. Marine microalgae are eukaryotic plants that aid in the development of new drugs because of their metabolic flexibility, which can cause the synthesis of several substances that could be used to treat a variety of ailments, including cancer [Lauritano, C. et. al. 2016]. (Mondal, A. et. al. 2020).

The bulk of bioactive peptides used in formulations for health-promoting foods, dietary supplements, pharmaceuticals, and cosmetics are created chemically or by partially digesting animal proteins. Due to the dangers associated with solvent pollution or the usage of chemicals originating from animals, they are thus not usually well-regarded by the users. As an alternative, peptides produced by plants and microalgae are known to be selective, beneficial, nontoxic, and well-tolerated when taken. They have tremendous potential for usage in functional foods, medications, and cosmetics. In addition, research has focused on examining novel antibacterial chemicals obtained from various natural habitats due to the growing problem of antibiotic resistance against dangerous bacteria [Mundt, S. et. al. 2001; Safonova, E. et. al. 2005; Ghasemi, Y. et. al. 2007; Prakash, O. et. al. 2011].

As a nutritional resource for disease prevention, functional foods are becoming more prevalent. They can be characterised as substances created by technical means that explain certain effects on human health. Because they contain useful compounds, cyanobacteria and microalgae are attracting attention from all around the world as potential sources of functional meals and preventative medications.

Both cyanobacteria and microalgae are prevalent in freshwater, marine, terrestrial, and a variety of severe settings, from hot springs to the bare rocks of deserts. As a result of their adaptability, they are the main producers of biomass under sustainable circumstances since they do not rob agriculture of resources, while also allowing water recycling and reducing damaging gas emissions [Camacho, F. et. al. 2019]. In addition, cyanobacteria and microalgae can be transformed into a variety of products of commercial significance, including biofuels, cosmetics, renewable chemicals, and other important molecules [Camacho, F. et. al. 2019], as well as animal and human food, particularly as sources of proteins, lipids, and phytochemicals (Ferrazzano, G. F. et. Al. 2020).

Microalgae have become one of the newest players in the food supplement market, emerging as nutraceutical components with positive health impacts. A broad class of predominantly autotrophic unicellular prokaryotic and eukaryotic organisms are microalgae. The biotechnology community has become increasingly interested in marine microalgae over the past ten years as a source of sustainable chemicals, proteins, and metabolites due to their high growth and productivity rates [Barra, et. al. 2014]. Some species, including *Chlamydomonas reinhardtii*, are already acknowledged as potential industrial biotechnological platforms for the manufacture of a variety of bioactive chemicals (Hippler, M. 2017).

Due to their ability to produce beneficial bioactive substances like carotenoids, which are known to have health advantages [Galasso, C. et. al. 2017], as well as other antioxidant chemicals [Smerilli, A. et. al. 2017], microalgae also provide exciting potential in the realm of functional foods. This trait adds value since it strengthens the positive impact of several families of bioactive chemicals on human health through synergism (Hamed, I. et. al. 2015; Lordan, S. et. al. 2011). Due to their high quantity of polyunsaturated fatty acids (PUFAs), important amino acids (such as leucine, isoleucine, and valine), pigments (such as lutein and -carotene), and vitamins, marine microalgae are presently being used as functional foods (e.g., B12). The word "nutraceutical" is a combination of the words "nutrition" and "pharmaceutical," and it describes foods or other items that are connected to nutrition but have physiological advantages that can help prevent or guard against chronic illnesses. Nutraceuticals are combinations and isolated pure chemicals from herbs, as well as dietary derivatives, modified foods including cereals, spices, sauces, and drinks with positive health benefits. (Galasso C. et al., 2019).

There are multiple examples of cyanobacteria and microalgae being consumed by humans in the past. The native community in Chad has been gathering and utilising *Spirulina*, or *Arthrospira* as it is officially named (Tomaselli et al., 1996), for everyday sustenance for decades (Ciferri 1983). Daily, Kanembu women gather the blue-green biomass from Lake Kossorom near the north-eastern edge of Lake Chad (Gantar, M., et. al. 2008).

At least in Mexico and China, there is historical evidence of the usage of algae, microalgae, and cyanobacteria in animal and human diets. Despite several successes, the most common applications for algal biomass have occurred as higher-value health foods for animals or humans (Spirulina powder and b-carotene derived from Dunaliella) and in chemical food chains, which utilise as an essential feedstock for the aquaculture husbandry of crustaceans, molluscs, and fish. Microalgae have thus far not been employed as a full biomass replacement option in the human diet or animal feedstock, save in aquaculture and during specific periods of animal development. This review goal is to examine the current level of technology and the knowledge gaps that must be filled to use microalgae biomass or its main protein and lipid components in livestock and human consumption (Koopman et. al. 2014).

Since ancient times, people have routinely consumed some microalgal and cyanobacterial species as food or nutritional supplements. They have historically been consumed as human food in a variety of places, including Mexico, Chad, China, Japan, Mongolia, Myanmar, Thailand, Vietnam, India, and other South American nations. The cyanobacteria *Spirulina (Arthrospira platensis, Arthrospira maxima), Nostoc (N. commune, N. flagelliforme,* and *N. punctiforme), Aphanotheca sacrum, Anabaenaflos-aquae*, and *Aphanizomenonflos-aquae*, as well as the microalgal species *Chlorella*, *Spirogyra*, and *Oedogonium* (Garc´ıa, J. L. et. al 2017, Markou, G. et. al. 2021).
Microalgae/cyanobacteria are powerful producers of a range of nutritional components, including necessary amino acids, essential fatty acids, vitamins, and minerals (particularly Fe), and they also exhibit antioxidant, anti-inflammatory, anti-cancerous, or anti-microbial action (Nethravathy, Mehar, Mudliar, & Shekh, 2019). (Markou, G. et. al. 2021).

2. Fundamental properties of microalgae and cyanobacteria:

2.1 Classification and morphology:

Microalgae are oxygen-evolving, eukaryotic, unicellular, photosynthetic microorganisms with cells that are generally several micrometres in size. Although they lack a cell wall like a plant, they can undertake photosynthesis. They are primarily found in watery situations. Since cyanobacteria are photosynthesizing prokaryotes without membrane-bound organelles, they are not categorised as microalgae but rather as the Eubacteria division of cyanophytes. Their existence dates back around 3,465 million years, and now they are highly diversified. The estimated number of algal species in existence range from 30,000 to more than 1 million (Guiry 2012). A recent thorough estimate identifies around 72,500 distinct species of algae, 44,000 of which have been identified and 28,500 of which have yet to be classified. Microalgae and cyanobacteria have cell walls that confine and restrict them. Algal cell walls are extremely varied, ranging from multi-shaped scales to crystalline glycoprotein coatings. Many of them include microfibrillar networks that are integrated into matrices of various polysaccharides and proteins (Domozych 2016) (Grossmann, L. et. al 2019).

2.2 Phototrophic versus heterotrophic growth:

All microalgae and cyanobacteria use photosynthesis to transform light energy into chemical energy, however not all of them can survive entirely on this form of energy. Heterotrophic growth uses an external supply of reduced carbon to produce energy, whereas phototrophic growth uses the energy from photons for metabolic activities.

3. Microalgal diversity:

Microalgae have a huge variety and are an untapped resource. According to Norton T. A. et al. (1996), microalgae are typically unicellular and tiny (generally 5–50 µm) in size. Algal farming is feasible along coasts between 45 and 30°N. (Singh J. et al. 2010). The most effective and appropriate pond system for growing algae would likely be an open or closed system. There are plenty of marginal lands in Libya, Cyprus, and Turkey as well for harvesting algae. These nations use recycled brackish or salt water, therefore their limited water supply is not a problem. Blue-green algae (Cyanobacteria), green algae (Chlorophyta and Streptophyta), and diatoms (Bacillariophyceae, Ochrophyta) are the three main evolutionary pedigrees that terrestrial microalgae belong to (Fritsch F. 1907). Phylogenetically and economically, the group of green algae has been the focus of most research. The spatial distribution of terrestrial algae is, however, not well understood (Lewis L.A., et al. 2004).

4. Nutritional composition of microalgae:

Some microalgae groupings (mainly green microalgae) have nutrient profiles that are comparable to those of higher plants. These secondary metabolites include vitamins, pigments, antioxidants, trace metals, and the main metabolites (lipids, protein, and carbs). Temperature, light, pH, as well as the amount of minerals in the growth media all, have a significant impact on the ratio of these micronutrients of microalgae (Ho et al. 2012; Pancha et al. 2015). Microalgae under nitrogen constraint accumulated a lot of fat and carbohydrates; however, their protein composition was degraded (Chen et al. 2013; Pancha et al. 2015; Singh et al. 2015). With balanced essential amino acid profiles, microalgal biomass with high protein content competes effectively with traditional protein sources (eggs, soybean, etc). (Becker 2007; Sarker et al. 2018; Carneiro et al. 2020). *Spirulina* sp. contains 50–70% protein (depending on the strain), whereas Dunaliella sp. may generate 50–100% more protein per unit area than typical plants and animals (Ejike et al. 2017). Animals, including fish, are unable to produce the 10 necessary amino acids. Therefore, it is necessary to provide these important amino acids through meals. The entirety of the essential amino acids has also been somewhat finally found as algal amino acid compositions. All microalgal genera have a comparable profile of amino acids, according to research that has been done by Brown et al. in 1997 on 40 different types of microalgae. Table 1 displays the LEA content of various algal as well as the essential amino acid composition in overall microalgae. As a feedstock for aquaculture companies, microalgal protein has a lot of promise. Future research must identify appropriate microalgae species that are simple to grow commercially and generate large amounts of protein with balanced necessary amino acids. In heterotrophic microalgae, cellulose on the inner cell walls and starch in the chloroplast make up the majority of the carbohydrates. Lignin and cellulose together are absent from the algal cell (Ho et al. 2012). Glucose, which accounts for 28–86% of the total carbohydrate in polysaccharides of various algae species, is the most prevalent sugar. To locate acceptable microalgal species with desirable characteristics, such as rich carbohydrates and a rapid growth rate while growing on affordable media for large-scale culture, further study is still needed. The development and feed consumption of aquafeed can be enhanced by the addition of heterotrophically grown algal meal (Kupchinsky et al. 2015).

Table 1: Composition of essential amino acids in whole and lipid-extracted microalgae

Microalgae	**Whole/ LEA**	**Essential amino acid**										**Reference**
		Unit	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Arg	
N. granulata	Whole	mg/g	7.5	17.4	32.4	24.1	8.7	19.1	16.5	0.4	21.5	25.4	Tibbetts et al. 2015a
N. granulata	LEA	mg/g	7.6	18	33.1	21.2	9	19.3	18.1	0.4	22.7	26.3	Tibbetts et al. 2015a
Nannochloropsis sp.	Whole	mg/g	26.26	47.22	94.04	68.31	23.6	55.26	48.56	-	60.24	60.82	Kent et al. 2015
Nannochloropsis sp.	Whole	%W/W	2.6	0.2	0.1	2.2	0.2	-	0.2	-	1.2	2.6	Subhash et al. 2020
Nannochloropsis sp.	Whole	%W/W	2.5	0.3	0.7	1.8	0.2	-	0.3	-	1.5	2.5	Subhash et al. 2020
Tetraselmis	Whole	g/100g protein	2.01	4.06	9.45	6.52	2.78	5.62	5.17	1.61	5.72	5.01	Schwenzfeier et al. 2011
S. pacifica	Whole	g.16 g/N	2.03	5.79	8.74	4.72	3.52	4.94	5.41	0.83	6.3	8.05	Misurcova et al. 2014
S. platensis	Whole	g/100 g protein	1.69	6.34	9.8	4.49	2.4	5.16	4.85	1.42	6.91	6.72	Parimi et al. 2015
Scenedesmus sp.	Whole	mg/g	26.06	44.1	91.89	66.61	24.4	55.72	56.27	-	61.76	64.13	Kent et al. 2015
Dunaliella sp.	Whole	mg/g	25.03	45.08	93.22	62	25.3	59.59	50.53	-	59.83	65.92	Kent et al. 2015
Scenedesmus sp	Whole	Mg/g DW	4.7	13.7	27	18	7	19.4	17.2	7	18.4	19.2	Tibbetts et al. 2016
Scenedesmus sp	LEA	Mg/g DW	7.2	18.3	36.3	20.7	8.7	22.3	23.7	6.5	26	25.4	Tibbetts et al. 2016
Chlorella sp.	Whole		1.2	0.2	-	1.5	1.2	-	0.2	-	1.9	3	Subhash et al. 2020
Tetradesmus obliquus	Whole	g/100g	1.86-2.9	4.1–4.97	5.44–8.5	4.27–7.4	1.2–2.2	3.12–6.5	2.95–3.2	-	3.2–3.91	-	Oliveira et al. 2021
Pavlova sp. 459	Whole	% Of DW	0.51	1.58	3.32	1.46	1.01	1.80	1.72	0.03	2.39	2.7	Tibbetts et al. 2020
Picochlorum sp.	Whole	%W/W	1.2	0.2	0.3	2.2	0.3	-	1.3	-	2.2	2.9	Subhash et al. 2020

The omega-3 fatty acids EPA, ALA, and DHA are among the necessary fatty acids found in microalgal lipids (Table 2). (Guedes and Malcata, 2012; Ratledge 2010). Lipid contents of microalgae vary from strain to strain, according to the method of growth, and also depending on the stage of harvesting. Fatty acid content is also influenced by the microalgal strain and growth conditions. Microalgae can collect up to 70% of lipid (DCW) as a result of stressful situations (Stephenson et al. 2011). According to D'Alessandro and Filho (2016), *Botryococcus braunii* has a lipid yield that ranges from 14 to 75% and *Chlorella vulgaris* from 12 to 26%. Numerous methods, including stress-induced lipid accumulation (varying nutrient concentrations, such as N, P, K, EDTA, and Fe), high salinity, temperature, light intensity, and various carbon sources, can increase lipid accumulation (Singh et al. 2015). Different from freshwater species, some marine microalgae have a large amount of DHA. Higher DHA concentrations may be seen in heterotrophically grown algae, such as *Amphidiumcaryerea* (17%), *Schizochytrium mangrove* (33–39%), and *Thrautocytrium* (16.1%). 30–50% of the DHA in the overall components was generated by *Crypthecodinium cohnii* (Yaakob et al. 2014). The addition of ALA, DHA, and EPA in aquaculture feed must be prioritised since these nutrients are necessary for healthy growth and development. Table 2 displays the PUFA content in several microalgae. Due to its high EPA concentration, *Nannochloropsis* sp. is mostly used as a supplement in aquaculture. EPA production rates for *Chaeotoceros mulleri* and *Isochrysis galbana* are 3.5% and 4.8%, respectively (DCW) (Yaakob et al. 2014). *C. vulgaris* (7.5%*), Micractinium reisseri* (6.2%), *N. bacillris* (9.5%), and *Tetracystis* sp. (9.5%) are high in ALA, another important PUFA (Tibbetts et al. 2015a). The use of microalgal lipids in aquaculture calls for additional, in-depth research on the physiological effects of nutrients and stress mechanisms on the microalgae in order to promote lipid accumulation and find appropriate microalgae with high PUFA content.

Table 2: Composition of polyunsaturated fatty acids in various microalgal sp. (Ansari, F. A. et. al. 2021).

Microalgae	**ALA (C18:3) % (n-3)**	**AA (20:4) % (n-6)**	**EPA (C20:5) % (n-3)**	**DHA (C22:6) % (n-3)**	**Reference**
C. muelleri	0.9	3.0	20.3	0.6	Chen et al. 2015
C. vulgaris	34.02	0.22	-	-	Gladyshev et al. 2016
C. vulgaris	0.53	-	-	-	Viegas et al. 2021
S. obliquus	1.18	-	-	-	Viegas et al. 2021
Chlorella sp.	0.36	-	8.9	3.24	Sahu et al. 2013
Chlorella sp.	12.8	-	-	-	Malibari et al. 2018
C. protothecoides	7.12	-	0.03	-	Solana et al. 2014
C. calcitrans	-	2.0	17.8	1.3	Delaporte 2003
C. affinis	3.1		13.2	18.6	Suh et al. 2015
C. didymus	3.7	3.9	8.8	24.1	Suh et al. 2015
C. zofingiensis	23	-	-	-	Zhou et al. 2018
Cryptomonas sp.	16.27	0.34	13.95	3.53	Gladyshev et al. 2016
Chatoceros sp.	0.2	-	19.9	2.9	Suh et al. 2015
Nannochloropsis sp.	-	-	24.8	-	Malibari et al. 2018
N. salina	0.3	-	1.5	-	Solana et al. 2014
N. gaditana	0.8	-	12.2	-	Matos et al. 2015
N.gaditana	0.3 mg/g	-	175 mg/g	-	Ryckebosch et al. 2014
N. oculata	0.7 mg/g	-	193 mg/g	-	Ryckebosch et al. 2014
N. gaditana	2.1	2.4	16.9	-	Carrero et al. 2015
Dunaliella sp.	8	-	4.8	-	Malibari et al. 2018
I. galbana	2.7	Trace	Trace	9.5	Chen et al. 2015
Tetraselmis sp.	16.2	-	10	**<0.01**	Tsai et al. 2016
T. suecica	10.5	0.5	5.4	0.1	Delaporte 2003
T. chui	13.6	6.3	4.2	Trace	Chen et al. 2015
T. suecica	68 mg/g	-	16.3 mg/g	0.8 mg/g	Ryckebosch et al. 2014
T. suecica	1.9 mg/g	-	81 mg/g	0.9 mg/g	Ryckebosch et al. 2014
T. weissflogii	1.4	-	10.1	9.6	Suh et al. 2015
Isochrysis sp.	5.7	0.1	0.4	7.8	Delaporte 2003
P. lutheri	10 mg/g	-	92 mg/g	40.9 mg/g	Ryckebosch et al. 2014
P. tricornutum	0.8 mg/g	-	111 mg/g	8.3 mg/g	Ryckebosch et al. 2014
P. cruentum	1.42 mg/g	-	35.6 mg/g	-	Ryckebosch et al. 2014
P. tricornutum	0.22	-	30.26	0.98	Qiao et al. 2016
S. menzelii	0.62	0.17	11.42	3.6	Jiang et al. 2016
Hindakia sp.	20.08	-	-	-	Daroch et al. 2013
Isochrysis T-iso	29 mg/g	-	2.8 mg/g	46 mg/g	Ryckebosch et al. 2014
R. salina	92mg/g	-	18 mg/g	11.1 mg/g	Ryckebosch et al. 2014
Microalgae	**ALA**	AA	**EPA**	**DHA**	**Reference**

	(C18:3) %	(C20:4) % (n-6)	(C20:5) %	(C22:6) %	
A. sanguinea	0.6	5.5	20.1	23.8	Suh et al. 2015
Alexandrium sp.	0.2	0.2	22.3	5.8	Suh et al. 2015
P. minimum	1.3	13.8	14	28.1	Suh et al. 2015
P. micans	3.9	6.1	13.1	22.8	Suh et al. 2015
P. dentatum	17.3	7.6	11.2	21	Suh et al. 2015
P. tricornutum	-	2.6	52.6	5.5	Suh et al. 2015
H. triqutra	5.5	10.8	12.7	25.4	Suh et al. 2015
S. trochoidea	13.2	8.1	12.8	22.4	Suh et al. 2015
S.costatum	2.3	4.6	27.8	7.3	Suh et al. 2015
Scenedesmus sp.	18.3	-	-	-	Tibbetts et al. 2016

4.1 Microalgae as a source of polyunsaturated fatty acids:

Long-chain polyunsaturated fatty acids generated from microalgae are major products that are currently employed in the food and feed industries (Pulz and Gross 2004). Since neither humans nor animals are capable of producing these fatty acids, they must be consumed regularly. Because they help produce prostaglandins, thromboxanes, and other substances crucial for lowering blood triglycerides and cholesterol, it is well-recognised that these acids are beneficial for both human and animal health (Simopoulos 2002, Gouveia et al. 2008). Microalgae oil has a greater energy yield per hectare than terrestrial oil seeds, such as sunflower and rapeseed, making it a viable option for the production of biofuels (Brennan and Owend e 2010). Furthermore, because microalgae eat ambient CO2, they generate ecologically benign biodiesel. Compared to petroleum-based fuels, this biodiesel emits less carbon dioxide (Gouveia and Oliveira 2009) (Christaki, E.et al. 2011).

4.2 Microalgae as a source of protein:

Microalgae provide critical amino acids that cannot be produced in human or animal bodies (Gouveia et al. 2008). The amino acid concentration of certain microalgae is equivalent to that of egg or soybean. Microalgae are being grown as an alternative ingredient to help hungry people in impoverished nations (Becker 1994; Becker 2007; Christaki, E.et al. 2011).

4.3 Microalgae in the human diet:

Spirulina, Chlorella, Dunaliella, and Aphanizomenon are the only microalgae species currently consumed by humans (Soeder 1986; Halama 1990). Throughout the nutritional food industry, they have mostly utilised primarily nutritional supplements in the form of powder, capsules, pastilles, or tablets (Pulz and Gross 2004; Christaki et al. 2010). They may be used in dishes including pasta, bread, biscuits, candy, beverages, and soft drinks (Christaki, E.et al. 2011).

5. Cyanobacterial Diversity:

Nitrogen-fixing, photoautotrophic prokaryotes called cyanobacteria live in a variety of aquatic and terrestrial habitats. They emerged on Earth during the Precambrian period (about 2.6–3.5 billion years ago), and they appear to have been crucial in the atmospheric change from a reductive to an oxidative state (Hedges et al., 2001).

According to Häder et al. (2007), cyanobacteria are among the most significant biomass producers on Earth. They have similar biochemical and structural structures to eukaryotic plants (Whitton and Potts, 2000). They are a great source of bioactive substances, biofuel, biopolymers, pharmaceuticals, dietary supplements, and biofertilizers (Namikoshi and Rinehart, 1996; Welker and von Döhren, 2006). Cyanobacteria may live in practically any environment, from seas to fresh water, deserts to ice shelves, hot springs to Arctic and Antarctic lakes, including as endosymbionts in plants, lichens, and also many protists (Carr and Whitton, 1982; Vincent and Quesada, 1994; Quesada and Vincent, 1997; Baracaldo et al., 2005; Thajuddin and

Subramanian, 2005). In the fossil record, stromatolites & oncolites are the most prevalent cyanobacterial structures (Herrero and Flores, 2008).

Photoautotrophic microorganisms such as cyanobacteria have significantly influenced the ecosystem of the Earth. The capacity of cyanobacteria to transform carbon dioxide and sunlight into oxygen and bioproducts like nutrients and biofuels makes them crucial for many biotechnological applications. In significant industrial settings, they are employed more frequently to produce food and nourishment. Prokaryotic organisms called cyanobacteria employ pigment-protein antenna complexes to capture light energy and transport it to reaction centres. Numerous inclusion bodies and compartments, such as the carboxysome, are also present in these bacterial cells, aiding the carbon-concentrating mechanism (CCM) that is crucial for effective carbon fixation. Their metabolic diversity lends these organisms to bioengineering applications for the sustainable production of a wide range of goods (Liu, D. et. al. 2021).

6. Food, Feed, and Value-Added Products:

Because they are loaded with nutrients including protein, carbs, vitamins, & minerals and are simple to digest, cyanobacteria are a great choice for dietary supplements. Large-scale cultivation of *Anabaena*, *Nostoc*, *Spirulina*, *Aphanizomenon*, and *Phormidium* species is done in ponds or commercial photobioreactors. They are offered for sale in the Philippines, China, Japan, Korea, Chile, Mexico, and other nations (Abed et al., 2009; Priyadarshani and Rath, 2012). In addition to being one of the richest sources of vitamin B12, *Spirulina* is also high in proteins, carbs, sterols, thiamine, beta-carotene, and riboflavin (Watanabe et al., 1999). Healthy cultures of *Spirulina* typically contain 54% protein, 23% carbs, and 8.6% lipids in addition to vitamins, enzymes, minerals, and glyconutrients. Additionally, some marine cyanobacteria could be used to produce significant amounts of vitamins B and E. (Abed et al., 2009).

The primary family of water-soluble proteins, phycobiliproteins, is used as a significant source of blue colour in the food industry (Jespersen et al., 2005). Compared to spinach, *Spirulina* is 100 times more nutritious and contains a high amount of gamma-linolenic acid (GLA). Within the human body, GLA is transformed into prostaglandin E2, which controls lipid metabolism by bringing blood pressure down. *Spirulina* is the primary source of nutrition for NASA (CELSS) and the European Space Agency (MELISSA) long-term space missions (Sies, 1996). *Nostoc commune* has more proteins and fibre, which may play a vital nutritional function in the human diet (Abed et al., 2009). *Aphanizomenon* sp. from Lake Klamath in Oregon, USA, is a great source of food supplements (Carmichael and Gorham, 1980). *P. valderianum*, a marine nitrogen-fixing cyanobacterium, has been exploited as an aquaculture food supplement in India.

Exopolysaccharides (EPSs), enzymes, hormones, vitamins, and medicines are just a few of the useful compounds that may be found in cyanobacteria. Microalgal EPSs have received a lot of interest recently due to their biotechnological uses. These EPSs, or extracellular polymeric substances, are more desirable for commercial use because they possess important biological features (Kumar, J. et. al 2009). Enzymes from cyanobacteria may be obtained by commercial means and have a wide range of uses. Amylase, alkaline phosphatase, protease, -lactamase, lipase, chitinase, l-glutaminase, urease, cellulose, superoxide dismutase, and chitinase are just a few of the industrially useful enzymes that have been identified from cyanobacteria (Prabhakaran et al., 1994; Wikstrom et al., 1997; Sato et al., 2007). Modular nonribosomal peptide synthetase (NRPS) and polyphosphate synthase (PKS) pathways are only found in cyanobacteria (Kumar, J. et. al 2009). High amounts of protein and other nutrient-rich elements can be found in cyanobacterial biomass. *Arthrospira* (commercially known as *Spirulina*) is a well-known cyanobacterium that was ingested long ago near Chad Lake in Africa and by the Aztecs in Central Mexico. Strategies of cultivation and processing optimization to increase biomass output have been included in several research and reviews. We are concentrating on applying synthetic biology to increase biomass production and productivity (Liu, D. et. al. 2021).

7. Future prospective:

The lack of information, the possibility of adverse consequences on the environment, human welfare, security, and maintainability are still issues [Santos, C. et. al., 2014]. Concerns exist over the potential danger of the nanoparticles themselves. Many of the nanomaterials and nanotechnologies showed here are not usable in industrial settings. The application of nanotechnology in current water treatment has the potential to change many of these cycles by lowering treatment costs and enabling the treatment of previously untreatable contaminants. It includes nanoparticle-reinforced plastics and metals, enhanced fuel cell technology and hydrogen storage, catalytic nanoparticles as a fuel additive, and other innovations (Subhan, M. et. al, 2021).

8. Conclusion:

Typically, water bodies, desert crusts, or even in association with other creatures are where one may find microalgae and cyanobacteria. They can endure a variety of environmental conditions, such as those with high or low temperatures, harsh or gentle illumination, pH, and salt. It is believed that lowering or eliminating the major risk factors, such as smoking, radiation exposure, drinking, and infections, will result in a 30% decrease in cancer-related mortality. Several marine organisms, including seaweed, sponges, actinobacteria, bacteria, and fungi, have been utilised to successfully treat cancer. In the food sector, the main family of water-soluble proteins, phycobiliproteins, is a substantial source of blue colour. Spirulina has a high concentration of gamma linolenic acid and is 100 times more nutrient-dense than spinach (GLA). Prostaglandin E2, which regulates lipid metabolism, is produced from GLA.

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