J. Algal Biomass Utln. 2012, 3 (4): 89–100
ISSN: 2229- 6905

Commercial and industrial applications of micro algae – A review

Indira Priyadarshani and Biswajit Rath
Department of Biotechnology, North Orissa University, Sriram Chandra Vihar, Takatpur, Baripada-757003
Corresponding author Email ID: brath_2000@yahoo.com

Keywords: aquaculture, commercial, industrial , microalgae, pigments.

Indira Priyadarshani and Biswajit Rath. Commercial and industrial applications of micro algae – A review. *J. Algal Biomass Utln*. 2012, 3 (4): 89–100

ABSTRACT
Microalgae are microscopic photosynthetic organisms that are found in both marine and freshwater environments. Microalgae find uses as food and as live feed in aquaculture for production of bivalve molluscs, for juvenile stages of abalone, crustaceans and some fish species and for zooplankton used in aquaculture food chains. Therapeutic supplements from micro-algae comprise an important market in which compounds such as β-carotene, astaxanthin, polyunsaturated fatty acid (PUFA) such as DHA and EPA and polysaccharides such as β-glucan dominate The dominating species of microalgae in commercial production includes *Isochrysis*, *Chaetoceros*, *Chlorella*, *Arthrospira* (*Spirulina*) and *Dunaliella*. In the present review it has been focused on the utilility of microalgae(freshwater,marine and other such habitats) in commercial and industrial sector to harness the growing demands of such unexplored natural resources

1. INTRODUCTION

Microalgae are microscopic unicellular organisms capable to convert solar energy to chemical energy via photosynthesis. They contain numerous bioactive compounds that can be harnessed for commercial use. The potential of microalgal photosynthesis for the production of valuable compounds or for energetic use is widely recognized due to their more efficient utilization of sunlight energy as compared with higher plants. Microalgae can be used to produce a wide range of metabolites such as proteins, lipids, carbohydrates, carotenoids or vitamins for health, food and feed additives, cosmetics and for energy production. The first use of microalgae by humans dates back 2000 years to the Chinese, who used *Nostoc* to survive during famine. However, microalgal biotechnology only really began to develop in the middle of the last century. Nowadays, there are numerous commercial applications of microalgae such as microalgae can be used to enhance the nutritional value of food and animal feed owing to their chemical composition; they play a crucial role in aquaculture and they can be incorporated into cosmetics. Moreover, they are cultivated as a source of highly valuable molecules. For example, polyunsaturated fatty acid oils are added to infant formulas and nutritional supplements and pigments are important as natural dyes. Microalgae have three fundamental attributes that can be converted into technical and commercial advantages. They are genetically a very diverse group of organisms with a wide range of physiological and biochemical characteristics; thus they naturally produce many different and unusual fats, sugars, bioactive compounds, etc. They can cost-effectively incorporate the stable isotopes ^{13}C,^{15}N and^{2}H into their biomass and thus into various compounds they produce. They comprise a large, unexplored group of organisms, and thus provide a virtually untapped source of products. In recent years, microalgae apart from being used as single-cell proteins, they are projected as living-cell factories for the production of bio-fuels and various beneficial biochemicals used in food, aquaculture, poultry and pharmaceutical industries due to presence of different useful compounds (Table.1).

TABLE-1: Useful substances present in microalgae

Pigments/Carotenoids	B-carotene, astaxanthin, lutein, zeaxanthin, canthaxanthin, chlorophyll, phycocyanin, phycoerythrin, fucoxanthin
Polyunsaturated fatty acids (PUFAs)	DHA(C22:6), EPA(C20:5), ARA(C20:4), GAL(C18:3)
Vitamins	A, B1, B6, B12, C, E, biotin, riboflavin, nicotinic acid, pantothenate, folic acid
Antioxidants	Catalases, polyphenols, superoxide dismutase, tocopherols
Other	Antimicobial, antifungal, antiviral agents, toxins, aminoacids, proteins, sterols, MAAs for light protection.

2. COMMERCIAL APPLICATION OF MICROALGAE

2.1 Microalgae and Human Food

Microalgae are a rich source of carbohydrates, protein, enzymes and fiber. Besides, many vitamins and minerals like vitamin A, C, B1, B2, B6, niacin, iodine, potassium, iron, magnesium and calcium are abundantly found in microalgae. Being such a rich source of essential nutrients, they are a major source of food, especially in Asian countries like China, Japan and Korea. Green micro-algae have been used as nutritional supplement or food source in Asiatic countries for hundreds of years. Nowadays, they are consumed throughout the world for their nutritional value. Some of the most biotechnologically relevant microalgae are the green algae (Chlorophycea) *Chlorella vulgaris*, *Haematococcus pluvialis*, *Dunaliella salina* and the Cyanobacteria *Spirulina maxima* which are widely commercialized and used, mainly as nutritional supplements for humans and as animal feed additives. *Spirulina platensis*, a blue-green alga is gaining worldwide popularity as a food supplement, being one of the most nutritious food known to man. It is gaining worldwide popularity as a food supplement. It has been shown to be an excellent source of proteins (Colla *et al*., 2007), polyunsaturated fatty acids (Sajilata, 2008), pigments (Rangel-Yagui *et al*., 2004; Madhyastha and Vatsala, 2007), vitamins and phenolics (Colla *et al*., 2007; Ogbonda *et al*., 2007). Today the major use of *Spirulina* is for the extraction of phycocyanin, a blue photosynthetic pigment. Another potential microalgae used as food is the green algae *Chlorella*. Now a days *Chlorella*, like *Spirulina* is mainly sold in health food stores and as a fish food. The major economic important product of *Chlorella* are several by-products that are used in fruit and vegetable preservatives (Hills and Nakamura, 1976). There is another most important microalgae under modern cultivation is *Dunaliella salina*. This species is grown for a source of the photosynthetic pigment and beta-carotene. Beta-carotene is used as an orange dye and as a vitamin C supplement. At present microalgal market is dominated by *Chlorella* and *Spirulina* (Becker, 2004; Pulz and Gross, 2004), mainly because of their high protein content, nutritive value, and moreover they are easy to grow. The biomass of these algae is marketed as tablets, capsules and liquids which are used as nutritional supplement (fig.1). Microalgae are also added to pasta, snack foods or drinks either as nutritional supplements or natural food colourants (Becker, 2004). A functional food oil, rich in fatty acids and antioxidants, coloured with pigments (carotenoids) extracted with supercritical CO_2 from the microalga *Chlorella* vulgaris, was produced, having in view its use in food industry especially for derived seafood (Table.2). Microalgal biomass contains three main components: proteins, carbohydrates, and lipids (oil) (Um and Kim, 2009). In the following table (Table.3) the biomass composition of various microalgae in terms of there main components is mentioned.

J. Algal Biomass Utln. 2012, 3 (4): 89–100
ISSN: 2229- 6905

Fig. 1 Microalgal Commercial Nutritional Supplement

TABLE-2: Major microalgae commercialized for human nutrition (Adapted from Pulz and Gross, 2004, Spolaore *et al*., 2006 and Hallmann, 2007)

Microalga	**Major Producers**	**Products**	**World production (t/year)**
Spirulina (*Arthrosphira*)	Hainan Simai Pharmacy Co. (China) Earthrise Nutritionals (California, USA) Cyanotech Corp. (Hawaii, USA) Myanmar Spirulina factory (Myanmar)	powders, extracts tablets, powders, extracts tablets, powders, beverages, extracts tablets, chips, pasta and liquid extract	3000
Chlorella	Taiwan Chlorella Manufacturing Co. (Taiwan) Klötze (Germany)	tablets, powders, nectar, noodles powders	2000
Dunaliella salina	Cognis Nutrition and Health (Australia)	powders b-carotene	1200
Aphanizomenon flos-aquae	Blue Green Foods (USA) Vision (USA)	capsules, crystals powder, capsules, crystals	500

TABLE-3: **Biomass composition of microalgae expressed on a dry matter basis (Um and Kim, 2009;Sydney *et al*., 2010)**

Strain	**Protein**	**Carbohydrates**	**Lipid**
Anabaena cylindrica	43–56	25–30	4–7
Botryococcus braunii	40	2	33
Chlamydomonas rheinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	41–58	12–17	10–22
Dunaliella bioculata	49	4	8
Dunaliella salina	57	32	6
Dunaliella tertiolecta	29	14	11
Euglena gracilis	39–61	14–18	14–20
Porphyridium cruentum	28–39	40–57	9–14
Prymnesium parvum	28–45	25–33	22–39
Scenedesmus dimorphus	8–18	21–52	16–40
Scenedesmus obliquus	50–56	10–17	12–14
Scenedesmus quadricauda	47	–	1.9
Spirogyra sp.	6–20	33–64	11–21
Spirulina maxima	60–71	13–16	6–7
Spirulina platensis	42–63	8–14	4–11
Synechoccus sp.	63	15	11
Tetraselmis maculata	52	15	3

2.2 Microalgae and Cosmetics

The pigment content in microalgae is a specific feature of each species. Its evaluation is essential as an indirect measure of cell growth, as well as a parameter to check the trophic level of waters. Components of algae are frequently used in cosmetics as thickening agents, water-binding agents, and antioxidants. Some microalgal species are established in the skin care market, the main ones being *Arthrospira* and *Chlorella* (Stolz and Obermayer, 2005). Microalgae extracts can be mainly found in face and skin care products (e.g., anti-aging cream, refreshing or regenerant care products, emollient and as an anti-irritant in peelers). Microalgae are also represented in sun protection and hair care products. Typical species that are used for cosmetics are *Chondrus crispus*, *Mastocarpus stellatus*, *Ascophyllum nodosum*, *Alaria esculenta*, *Spirulina platensis*, *Nannochloropsis oculata*, *Chlorella vulgaris* and *Dunaliella salina*. Microalgae are a polyphyletic and biochemically diverse assemblage of chlorophyll-*a* containing microorganisms capable of oxygenic photosynthesis that are predominantly found in aquatic environments with observed high levels of ultraviolet (UV) radiation. Certain microalgae produce organic metabolites, such as sporopollenin, scytonemin and mycosporine-like amino acids, to protect themselves from UV radiation while allowing visible radiation involved in photosynthesis to pass through (Table. 4)

TABLE-4:. Sources of UV-Screening compounds from different microalgae.

UV SCREENING COMPOUND	MICROALGAE
Sporopollenin	*Characium terrestre, Coelastrum microporum, Enallax coelastroides, Scenedesmus* sp., *Scotiella chlorelloidea, Scotiellopsis rubescens,* and *Spongiochloris spongiosa, Dunaliella salina, Chlorella fusca*
Scytonemin	*Chlorogloeopsis* sp., *Calothrix* sp., *Scytonema* sp., *Rivularia* sp., and *Nostoc commune Lyngbya* cf. *aestuarii Chroococcidiopsis* sp., *Nostoc punctiforme*
Mycosporine-Like Amino Acids	*Ankistrodesmus spiralis, Chlorella minutissima, Chlorella sorokiniana, Dunaliella tertiolecta, Scotiella chlorelloidea, Isochrysis* sp., *Pavlova gyrans, Corethron criophilum, Thalassiosira tumida, Porosira pseudodenticulata, Stellarima microtrias, Thalassiosira weissflogii, Alexandrium catenella*

2.3 Microalgae and Food Colorant

Microalgal pigment has commercial uses as a natural food coloring and cosmetic ingredient. Some microalgae contain substantial amounts of Carotene (besides beta carotene). Other types of coloring appear in microalgae as well. Beta carotene is used as a food coloring (with a major application in providing the yellow color to margarine), as a food additive to enhance the color of the flesh of fish and the yolk of eggs, and to improve the health and fertility of grain-fed cattle (see survey by Borowitzka and Borowitzka, 1987). Natural Beta Carotene has physical properties that make it superior to synthetic. In particular, natural Beta Carotene is fat soluble. It was announced recently by the National Cancer Institute that Beta Carotene is anticarcinogenic; other studies have found that Beta Carotene is effective in controlling cholesterol and in reducing risks of heart disease. These new findings make Beta Carotene much more valuable and are likely to increase the demand for the product. By being fat soluble, the natural Beta Carotene is a much superior anticarcinogen and an antiheart disease agent. Thus, the new findings of these desirable medical properties are likely to increase even more the demand and desirability of natural Beta Carotene. The potential of micro-algae as a source of food coloring is limited, however, because algal-derived food coloring is not photostable and the color tends to bleach with cooking. Nevertheless, in spite of this limitation, the potential market for micro-algae-derived food coloring is vast. *Dunaliella salina* is grown for a source of the photosynthetic pigment, beta-carotene. Beta-carotene is used as an orange dye and as a vitamin C supplement.

2.4 Microalgae and High-Value Molecules

There are at least 30,000 known species of microalgae. Only a handful are currently of commercial significance. These are generally cultivated for extraction of high-value components such as pigments or proteins. Microalgae represent very large, untapped reservoir of novel compounds, many of which are likely to show biological activity. Microalgae can be a very interesting natural source of new compounds with biological activity that could be used as functional ingredients. In fact, some microalgae are organisms that live in complex habitats submitted to extreme conditions (for example, changes of salinity, temperature, nutrients, UV-Vis irradiation, etc.), therefore, they must adapt rapidly to the new environmental conditions to survive, producing a great variety of secondary (biologically active) metabolites, which cannot be found in other organisms. Also, considering their great taxonomic diversity, investigations related to the search of new biologically active compounds from microalgae can be seen as an almost unlimited field. Marine microalgae are recognised as an important renewable source of bioactive lipids with a high proportion of polyunsaturated fatty acids (PUFA), which have been shown to be effective in preventing or treating several diseases. Polyunsaturated fatty acids (PUFA), especially *n*-3 PUFA such as a-linolenic acid (ALA, C18:3*n*-3), eicosapentaenoic acid

(EPA, C20:5*n*-3), docosapentaenoic acid (DPA, C22:5*n*-3), and docosahexaenoic acid (DHA, C22:6*n*-3), have been shown to be effective in preventing or treating several diseases including cardiovascular disorders, cancer, type 2 diabetes, inflammatory bowel disorders, asthma, arthritis, kidney and skin disorders, depression and schizophrenia. *Dunaliella* species, *Chlorella* species and *Spirulina* species are three major type that have been used successfully to produced high concentrations of valuable compounds such as lipids, protein and pigments (Abe *et al.,* 1999; El-Baz *et al.,* 2002; Abd El-Baky *et al.,* 2002) (Table.5).

TABLE-5: Some High-Value Bioproducts Extracted from Microalgae (Li *et al.,* 2008)

Product group	Applications	Examples (producer)
Phycobiliproteins carotenoids	Pigments, cosmetics, pro vitamins, pigmentation	Phycocyanin (*Spirulina platensis*) β carotene (*Dunaliella salina*) astaxanthin and leutin (*Haematococcus pluvialis*)
Polyunsaturated fatty acids (PUFAs)	Food additive, nutraceutics	Eicosapentaenoic acid EPA) (*Chlorella minutissima*) docosahexaenoic acid (DHA) (*Schizochytrium* sp.) Arachidonic acid (AA) (*Parietochlorisincise*)
Vitamins	Nutrition	Biotin (*Euglena gracilis*) α-tocopherol (Vitamin E) (*Euglena gracilis*a) ascorbic acid (Vitamin C) (*Prototheca moriformis*, a *Chlorella* spp. a)

2.5 Microalgae and Biofuel

Microalgae have long been recognized as potentially good sources for biofuel production because of their high oil content and rapid biomass production. In recent years, use of microalgae as an alternative biodiesel feedstock has gained renewed interest from researchers, entrepreneurs, and the general public.

Algae offer many potential advantages:

● algae can potentially produce 1 000-4 000 gallon/ acre/yr significantly higher than soybeans and other oil crops.

● they do not compete with traditional agriculture because they are not traditional foods and feeds and they can be cultivated in large open ponds or in closed photobioreactors located on non-arable land

● they can grow in a wide variety of climate and water conditions; they can utilize and sequester CO_2 from many sources

● finally, they can be processed into a broad spectrum of products including biodiesel via trans-esterification, green diesel and gasoline replacements via direct catalytic hydrothermal conversion, and catalytic upgrading, and bioethanol via fermentation, methane via anaerobic digestion, heat via combustion, bio-oil and biochar via thermochemical conversion, and high protein animal feed.

There are several ways to convert microalgal biomass to energy sources, which can be classified into biochemical conversion, chemical reaction, direct combustion, and thermochemical conversion (Fig. 2). Thus, microalgae can provide feedstock for renewable liquid fuels such as biodiesel and bioethanol. (Table.6 &7)

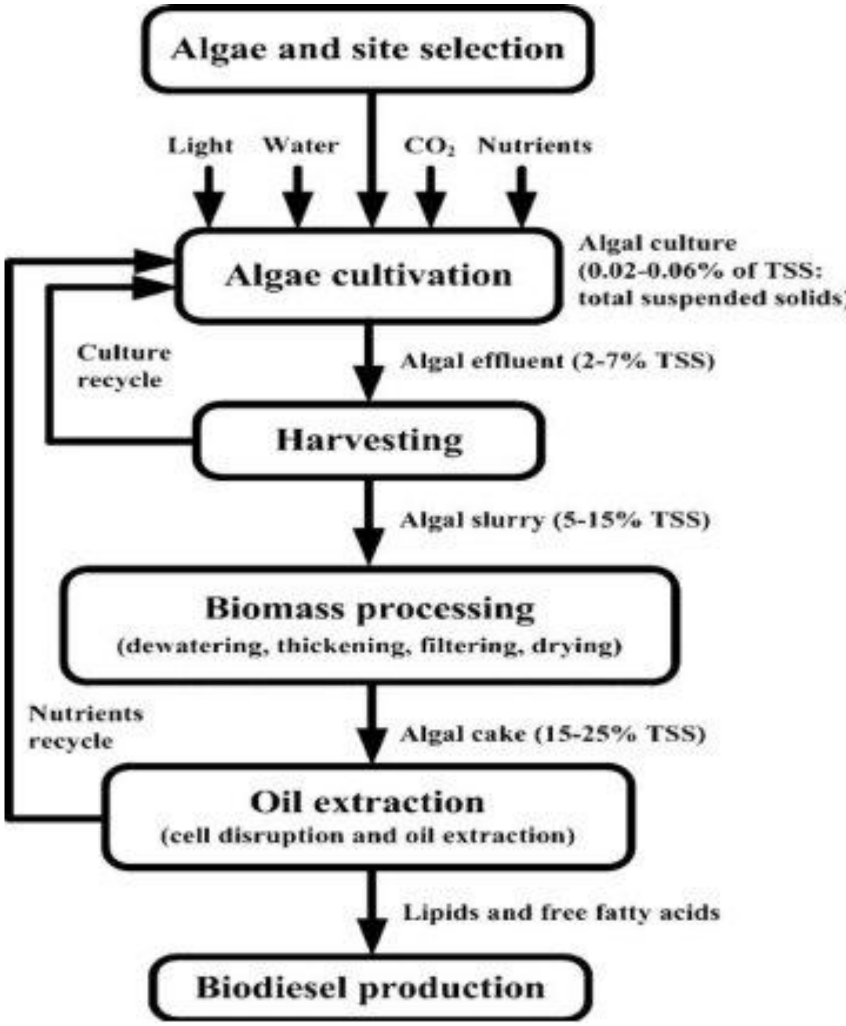

Fig. 2 Microalgae biodiesel value chain stages.

TABLE-6: Oil content of microalgae (Chisti 2007)

Microalga	**Oil content** (% dry weight)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis suecia	15–23

TABLE-7: Comparison of microalgae with other biodiesel feedstocks.

Plant source	Seed oil content (% oil by wt in biomass)	Oil yield (L oil/ha year)	Land use (m2 year/kg biodiesel)	Biodiesel productivity (kg biodiesel/ha year)
Corn/Maize (Zea mays L.)	44	172	66	152
Hemp (Cannabis sativa L.)	33	363	31	321
Soybean (Glycine max L.)	18	636	18	562
Jatropha (Jatropha curcas L.)	28	741	15	656
Camelina (Camelina sativa L.)	42	915	12	809
Canola/Rapeseed (Brassica napus L.)	41	974	12	862
Sunflower (Helianthus annuus L.)	40	1070	11	946
Castor (Ricinus communis)	48	1307	9	1156
Palm oil (Elaeis guineensis)	36	5366	2	4747
Microalgae (low oil content)	30	58,700	0.2	51,927
Microalgae (medium oil content)	50	97,800	0.1	86,515
Microalgae (high oil content)	70	136,900	0.1	121,104

3 INDUSTRIAL APPLICATION

3.1 Use as Biofertilizer

Microalgae are employed in agriculture as biofertilizers and soil conditioners. The majority of cyanobacteria are capable of fixing atmospheric nitrogen and are effectively used as biofertilizers. Cyanobacteria play an important role in maintenance and build-up of soil fertility, consequently increasing rice growth and yield as a natural biofertilizer (Song *et al*., 2005). The agricultural importance of cyanobacteria in rice cultivation is directly related with their ability to fix nitrogen and other positive effects for plants and soil. After water, nitrogen is the second limiting factor for plant growth in many fields and deficiency of this element is met by fertilizers (Malik *et al*., 2001). With the use of Blue green algae (BGA), apart from increase in yield and saving of fertilizer nitrogen, the soil physico-chemical properties also improved.There was gradual build up of residual soil nitrogen and carbon,improvement in soil p^H and electrical conductivity. The grain quality in terms of protein content improved. Blue green algae belonging to genera *Nostoc*, *Anabaena*, *Tolypothrix* and *Aulosira* fix atmospheric nitrogen and are used as inoculants for paddy crop grown both under upland and low land conditions. *Anabaena* in association with water fern *Azolla* contributes nitrogen up to 60 kg/ha/season and also enriches soils with organic matter. A variety of free-living cyanobacteria are now identified as efficient components of cyanobacterial biofertilizers. In addition to contributing nitrogen, cyanobacteria also benefit crop plants by producing various growth-promoting substances (Table.8)

TABLE-8: Growth promoting substances from different microalgae.

Examples of Cyanobacteria	Growth promoting substances
Cylindrospermum sp.	Vitamin B_{12}(Venkataraman and Neelakantan, 1967)
Tolypothrix tenuis	Vitamin B_{12} (Okuda and Yamaguchi, 1960)
Nostoc muscorum, Hapalosiphon fontinalis	Vitamin B_{12} (Misra and Kaushik, 1989a)
Nostoc, Hapalosiphon	Auxin like Indole-3-acetic acid, indole-3-propionic acid or 3-methyl indole(Misra and Kaushik, 1989b)

The algal production technology developed and reported by different Algologists is very simple in operation and easy in adaptability by Indian farmers. The technology has got potential to provide an additional income from the sale of algal biofertilizer. In general, there are four methods of algal production have been reported viz, (a) trough or tank method, (b) pit method, (c) field method and (d) nursery cum algal production method. The former two methods are essentially for individual farmers and latter two are for bulk production on a commercial scale.

3.2 *Use in Pharmaceuticals*

Algal organisms are rich source of novel and biologically active primary and secondary metabolites. These metabolites may be potential bioactive compounds of interest in the pharmaceutical industry (Rania and Hala, 2008). The existence of bioactive compounds in algae is to be expected due to cooccurrence of these organisms in aquatic natural communities, where an inhibitory interaction occurred between producers and competitors within the same habitat. Microalgae contain numerous bioactive compounds that can be harnessed for commercial use. They have emerged as important sources of proteins and value added compounds with pharmaceutical and nutritional importance. The microalgae have a significant attraction as natural source of bioactive molecules, because they have the potential to produce bioactive compounds in culture, which are difficult to produce by chemical synthesis. Both cell extracts and extracts of the growth media of various unicellular algae (e.g. *Chlorella vulgaris, Chlamydomonas pyrenoidosa*) have been proved to have antibacterial activity *in vitro* against both Gram-positive and Gram-negative bacteria. It has also been reported that a wide range of *in vitro* active antifungal activities are obtained from extracts of green algae, diatoms and dinoflagellates. Microalgae, such as *Ochromonas sp.*, *Prymnesium parvum* and a number of blue green algae produce toxins that may have potential pharmaceutical applications(Borowitzka and Borowitzka, 1992; Katircioglu *et al*., 2006). Various strains of cyanobacteria are known to produce intracellular and extracellular metabolites with diverse biological activities such as antialgal, antibacterial, antifungal and antiviral activity. Temperature of incubation, pH of the culture medium, incubation period, medium constituents and light intensity are the important factors influencing antimicrobial agent production (Noaman *et al*., 2004).(Table.9)

TABLE-9: Biotechnological applications of Bioactive compounds from Microalgae and Cyanobacteria

Species	Group	Product	Application	Culture system
Spirulina platensis	Cyanobacteria	Phycocyanins, biomass	Health food, cosmetics	Open ponds, natural lakes
Chlorella vulgaris	Chlorophyta	Biomass, Ascorbic acid	Health food, food supplement, food surrogate	Open ponds, basins, glass tube PBR
Dunaliella salina	Chlorophyta	Carotenoid, β carotene	Health food, food supplement, feed	Open pond, lagoons
Haematococcus pluvialis	Chlorophyta	Carotenoids, astaxanthin	Health food, pharmaceuticals, additives	Open ponds, PBR
Odontella aurita	Bacillariophyta	Fatty acids	Pharmaceuticals, cosmetics, baby food	Open food
Porphyridium cruentum	Rhodophyta	Polysaccharides	Pharmaceuticals, cosmetics, nutrition	Tubular PBR
Isochrysis galbana	Chlorophyta	Fatty acids	Animal Nutrition	Open ponds
Phaedactylum tricornutum	Bacillariophyta	Lipids, Fatty acids	Nutrition, fuel production	Open ponds, Basins
Lyngbya mujuscule	Cyanobacteria	Immune modulators	Pharmaceuticals, nutrition	Open ponds

3.3 Use As Aquaculture Feed

Microalgae feeds are currently used mainly for the culture of larvae and juvenile shelland finfish, as well as for raising the zooplankton required for feeding of juvenile animals (Chen, 2003). The most frequently used species in aquaculture are *Chlorella*, *Tetraselmis*, *Isochrysis*, *Pavlova*, *Phaeodactylum*, *Chaetoceros*, *Nannochloropsis*, *Skeletonema* and *Thalassiosira*. Mainly the microalgae *Spirulina* and, to some extent, *Chlorella* are used in this domain for many types of animals: cats, dogs, aquarium fish, ornamental birds, horses, poultry, cows and breeding bulls (Spolaore *et al*., 2006). . Favoured genera of microalgae for larval feeds include *Chaetoceros*, *Thalassiosira*, *Tetraselmis*, *Isochrysis*, and *Nannochloropsis*. These organisms are fed directly and/or indirectly to the cultured larval organism. Indirect means of providing the algae are through artemia, rotifers, and daphnia, which are, in turn, fed to the target larval organisms. Several companies produce aquaculture feeds using *Chlorella* and *Spirulina*, or a mixture thereof. Some examples of the use of microalgae for aquaculture includes; Microalgae species *Hypneacervicornis* and *Cryptonemia crenulata* particularly rich in protein were tested in shrimp diets (da Silva *et al.*, 2008). Microalgae such as *Dunaliella salina*, *Haematococcus pluvialis* and *Spirulina* are also used as a source of natural pigments for the culture of prawns, salmonid fish and ornamental fish. Over the last four decades, several hundred microalgae species have been tested as food, but probably less than twenty have gained widespread use in aquaculture.(fig.3)

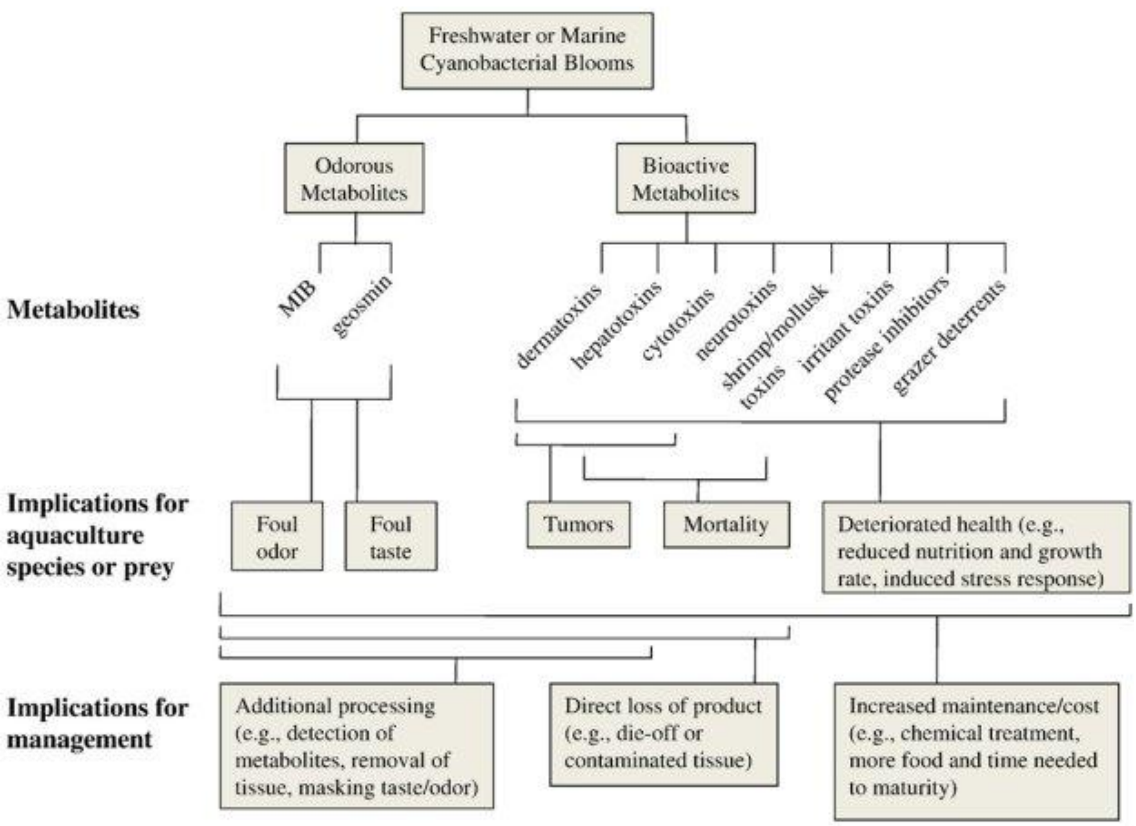

Fig. 3 Possible implications of cyanobacterial secondary metabolites for aquaculture species

4 CONCLUSION

Microalgae are a diverse group of microscopic plants with the wide range of physiological and biochemical characteristics and contain up to 50-70% protein (up to 50% in meat, and 15-17% in wheat), 30% lipids, over 40% glycerol, up to 8-14% carotene and a fairly high concentration of vitamins B1, B2, B3, B6, B12, E, K, D, etc., compared with other plants or animals (Avagyan, 2008). Moreover, microalgae are meant to be an important raw material for amino acids, vitamins and productions of other pharmateuticals. The cultivation of microalgae is known to be the most profitable business in the biotechnological industry. It is a wasteless, ecologically pure, energy and resource saving process.

5. REFERENCES

Abd El-Baky, H.H. Moawd, A. El-Behairy, A.N. and El-Baroty, G.S. 2002 Chemoprevention of benzo[a]pyrene-induced carcinogen and lipid peroxidation in mice by lipophilic algae extracts (phycotene). *J. Med. Sci.* **2**: 185–93.

Abe, K. Nishmura, N. and Hirano, M. 1999 Simultaneous production of β-carotene, vitamin E and vitamin C by the aerial microalga *Trentepohia aurea*. *J. Appl. Phycol*. 11: 33–6.

Avagyan, A.B. 2008 Microalgae: Big Feed Potential in a Small Package. *Feed International*. 16-18.

Becker, W. 2004 Microalgae in human and animal nutrition. In A. Richmond (Ed) Handbook of Microalgal Culture, Blackwell, Oxford, pp. 312-351.

Borowitzka, M.A. and Borowitzka, L.J. 1992 Microalgal Biotechnology Cambridge University Press USA, pp. 179.

Borowitzka, M. A. and Borowitzka, L. J. 1987 Vitamins and Fine Chemicals from Micro-Algae. In M. A. Borowitzka and L. J. Borowitzka (Eds) Micro-Algal Biotechnology, New York, Cambridge University Press.

Chen, Y.C. 2003 Immobilized *Isochrysis galbana* (Haptophyta) for long-term storage and applications for feed and water quality control in clam (*Meretrix lusoria*) cultures. *Journal of Applied Phycology*. **15**:439-444.

Chisti, Y. 2007 Biodiesel from microalgae. *Biotechnology Advances.* **25**: 294–306.

Colla, L.M. Reinehr, C.O. Reichert, C. and Costa, J.A.V. 2007 Production of biomass and nutraceutical compounds by *Spirulina platensis* under different temperature and nitrogen regimes. *Bioresour. Technol*. 98 (**7**): 1489–1493.

Da Silva, R. L. and Barbosa, J. M. 2008 Seaweed meal as a protein source for the white shrimp Lipopenaeus vannamei. *Journal of Applied Phycology.* **21**:193-197.

El- Baz, F.K. Aboul-Enein, M.A. El-Baroty, G.S. Youssef, A.M. and Abd El-Baky, H.H. 2002 Accumulation of antioxidant vitamins in *Dunaliella salina*. *Online J. Biol. Sci*. **2**: 220–3.

Hallmann, A. 2007 Algal transgenics and biotechnology. *Transgenic Plant Journal*. **1**:81-98.

Hills, C. and Nakamura, H. 1978 Food From Sunlight. World Hunger Research Publ., Boulder Creek, CA.

Katircioglu, H. Beyatli, Y. Aslim B. Yuksekdag Z. Atici T. 2006 Screening for antimicrobial agent production in fresh water. *Internet J. Microbiol*. 2(**2**).

Li, Y. Horsman, M. Wu, N. Lan, C.Q. Dubois-Calero, N. 2008 Biofuels from Microalgae. *Biotechnol. Prog*. **24**: 815-820.

Madhyastha, H.K. and Vatsala, T.M. 2007 Pigment production in *Spirulina fussiformis* in different photophysical conditions. *Biomol. Eng.*, 24(**3**): 301–305.

Malik, F.R. Ahmed, S. Rizki, Y.M. 2001 Utilization of lignocellulosic waste for the preparation of nitrogenous biofertilizer. *Pakistan Journal of Biological Sciences*. **4**: 1217–1220.

Misra, S. and Kaushik, B.D. 1989a Growth promoting substances of cyanobacteria. I. Vitamins and their influence on rice plant. *Proc. Indian Sci. Acad*. **55**:295-300.

Misra, S.and. Kaushik, B.D 1989b Growth promoting substances of cyanobacteria. II. *Proc. Indian Natn. Sci. Acad.* **55**: 499-504.

Noaman, N.H. Fattah, A. Khaleafa, M. Zaky, S.H. 2004 Factors affecting antimicrobial activity of *Synechococcus leopoliensis*. *Microbiological Research*. **159**: 395-402.

Ogbonda, K.H. Aminigo, R.E. and Abu, G.O. 2007 Influence of temperature and pH on biomass production and protein biosynthesis in a putative *Spirulina sp. Bioresour. Technol.* **98**: 2207–2211.

Okuda, A. and Yamaguchi, M. 1960 Nitrogen fixing microorganisms in paddy soils. VI. Vitamin B_{12} activity in nitrogen fixing blue green algae. *Soil Plant Food*. **6**: 76-85.

Pulz, O. and Gross, W. 2004 Valuable products from biotechnology of microalgae. *Applied Microbiology and Biotechnology*. **65**: 635-648.

Rania, M.A. and Hala, M.T. 2008 Antibacterial and antifungal activity of Cynobacteria and green Microalgae evaluation of medium components by Plackett-Burman design for antimicrobial activity of *Spirulina platensis*. *Global Journal of Biotechnology and Biochemistry*. 3(**1**): 22-31.

Rangel-Yagui, C.O. Danesi, E.D.G. Carvalho J.C.M. and Sato, S. 2004 Chlorophyll production from *Spirulina platensis*: cultivation with urea addition by fed-batch process. *Bioresour. Technol.* 92(**2**): 133–141.

Sajilata, M.G. Singhal, R.S. and Kamat, M.Y. 2008 Fractionation of lipids and purification of ã-linolenicacid (GLA) from *Spirulina platensis*. *Food Chem.* 109(**3**): 580–586.

Song, T. Martensson, L. Eriksson, T. Zheng, W. Rasmussen, U. 2005 Biodiversity and seasonal variation of the cyanobacterial assemblage in a rice paddy field in Fujian, China. *The Federation of European Materials Societies Microbiology Ecology*, **54**: 131–140.

Spolaore, P. Joannis-Cassan, C. Duran, E. and Isambert, A. 2006 Commercial applications of microalgae. *Journal of Bioscience and Bioengineering*. **101**: 87-96.

Stolz, P. and Obermayer, B. 2005 Manufacturing microalgae for skin care. Cosmetics Toiletries, **120**: 99–106.

Sydney, E.B. Sturm, W. de Carvalho, J.C. Thomaz-Soccol, V. Larroche, C. Pandey, A. and Soccol, C.R. 2010 Potential carbon dioxide fixation by industrially important microalgae. *Bioresource Technology*. **101**: 5892-5896.

Um, B.H. and Kim, Y.S. 2009 Review: A chance for Korea to advance algal-biodiesel technology. *Journal of Industrial and Engineering Chemistry*. **15**:1-7.

Venkataraman G.S. and Neelakantan, S. 1967 Effect of cellular constituents of nitrogen fixing blue green alga Cylindrospermum on root growth of rice plant. *J. Gen. Appl. Microbiol*. **13**: 53-62.