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Microalgal Nutraceutics: Opportunity for Nutritional Market

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Abstract: ***Sedentary life style and improper food habits make the way for occurrence of a number of chronic diseases like hypertension, cancer, alzheimer, Parkinson and few more. Proper nourishment to attain the nutritional requirement of the people with the ongoing world populations is a global challenge. Sustainable sources of nutraceuticals are needed to solve these problems. Microalgae are simple, photosynthetic, rapidly growing organisms, rich in nutritional profile and contain a variety of bioactive compounds. Hence these can be utilized as a sustainable source of nutraceuticals. The algal biomass and the bioactive compounds from these organisms can be used as ingredients for the preparation of functional foods. The algal nutraceutical market is expected to become $6.91billion by 2026. However, an integrated approach including the improvement of strain, multiplication of the strain using bioreactors and improvement of extraction by using small biorefinery technology is required for the effective utilisation of algal biomass and sustainability of the process.***

Keywords: Microalgae**,** Nutraceuticals, Bioactive compounds, Functional food, *Chlorella*

1. Introduction

Conventional source of nutrients is no longer sufficient and sustainable to maintain balanced nutrition for each individual in rapidly growing global population. Malnutrition, poor dietary habits and sedentary lifestyle are mainly responsible for the occurrence of complex non communicable diseases such as chronic respiratory diseases, hypertension, Parkinson, cancer, Alzheimer, metabolic syndrome, cardiovascular diseases, type 2 diabetes that affect the world's poor and also some rich people **(Etchegoyen et al., 2018; Ullah at al., 2019)**. This reality has driven our research towards the exploration of sustainable natural source of nutrient to meet the global nutritional gap and to provide health benefits, especially to the marginalised poor. In this context nutraceuticals and functional food have been emphasized in an attempt, to reduce the risk of contracting these diseases and also for health improvements **(Sahidi F, 2012)**. The term 'nutraceutical', as described by the Innovation in Medicine Foundation, is any food or components of food that assures health support. Similarly, functional food has certain physiological benefits **(Cencic et al., 2010).** Global nutraceuticals' market size was $184,092 million in 2015 and is likely to attain $ 302,306 million at the end of 2022 with a CAGR of 7.04% from 2016 to 2022. The nutraceuticals have multipurpose application as these are being used in several industries such as food, pharmaceuticals, and cosmetics. The noteworthy fact is, in the global nutraceutical market scenario, algal production market accounts for $3.40 billion in 2017, which is anticipated to reach $6.90 billion by 2026 at a CAGR of 6.7% **(Anonymous, 2019b)**.

Microalgae have drawn global attention as a source of food supplements and nutraceuticals. Indeed, algae are the autotrophs found in freshwater, marine and even in many adverse environments. Concomitantly, microalgae exhibited variable morphological, physiological and metabolic diversity. Through photosynthesis they utilize the atmospheric carbon to enhance their biomass. Conventionally, a few microalgae have been used as food in certain regions of Asia and exploited for the commercial production of hydrocolloids **(Wijesinghe at al., 2012)**. Therefore, these are the prime source of certain essential nutrients for metabolism and promotion of health. Moreover, these are proved to be an excellent source for the extraction of a verity of commercially important compounds such as colour pigments, protein, peptides, polysaccharides, unsaturated fatty acids, antioxidants, and few more such substances. Indeed, *Chlorella* sp. and *Spirulina* sp are especially good for supplementing the needs of people suffering from malnutrition in Africa, India, and the broader developing world by providing nutraceuticals at affordable price **(Raja et al., 2018; Nasseri et al., 2011)**. The social impact of providing balanced nutrition for every individual and to meet the global nutritional gap of supply and demand is immensely important. In addition to that, sportspeople, pregnant women, and the elderly people can also lead a healthy life by taking algal nutraceuticals as immunity booster.

The micro-algal resources are sustainable and have great potential for the production of dietary supplements. Some of novel strains have been studied for their biomass production rate, types of bioactive compounds, and their application in several commercial industries. The biochemical composition, genetic variability, and improvement of technology must be taken into account for large scale production of such biomass and bioactive compounds that are needed for food fortification. In this context, for efficient use of algal biomass and process sustainability, the integrated concept of using bio-reactors, bio-refinery, and biotechnology is advisable. This review summarizes utilization of algal biomass as food and nutriceutics; coproducts, its challenges, market opportunities, and the future prospects.

2. Current prospects of micro-algal nutraceuticals

2.1 Role of Microalgae in nutrition

Microalgae represent a group of polyphyletic organisms, mainly photosynthetic, single-celled to multi-cellular thallus structures that are minute in size. The most primitive member of microalgal forms are found in several habitats and differ from each other on the basis of morphology, cytology, biochemical composition, and pigments variations (**Dominguez, 2013**; **Anis, 2017).** Moreover, several of primitive strains have been reported as pharmaceutical and nutraceutical supplements that have been cultured at large scale. Indeed, genetically improved algal strains have been adopted for commercial scale food, animal feed, cosmetic, medicine and a few more products in developing countries **(Saha, 2018; Dominguez, 2013**).

2.2 Algal biomass

2.2.1 *Chlorella*

Chlorella is one of the well-known single cell green alga found mostly in the aquatic habitat. About 2500 tons of dried *Chlorella* is produced in USA, China, Japan, Indonesia and Taiwan every year. Nutraceuticals and food supplements are the major marketed outcomes from this strain as it is available in abundant quantities, in addition to its positive health effects. For the human dietary consumption, *Chlorella* sp. is regarded as better supplement for its property of nourishing and rapid growth pattern. According to a scientific report, about 9-18% fibres, 55-67% of protein, 1-4% of chlorophyll, and numerous vitamins and essential minerals are the major constituents present in *Chlorella* sp. (**Chen et al., 2015**). The essential amino acid contents of the protein, porphyrin rings in chlorophyll and glutathione in vitamin B12 found in *Chlorella* sp. are highly recommended for nutrition and detoxification of pesticides and metals **(Nicoletti et al, 2016).** Besides this, it is also useful for preventing the muscular degeneration and cataract due to production of lutein. Some other properties like anti-oxidant, anti-inflammatory, antitumor, and antimicrobial activities are the major useful properties of *Chlorella* extract. Diseases like blood pressure and cholesterol are lowered by using *Chlorella*. Wound healing, enhancement of the immune system and improve quality of life in people are some advanced application of this strain **(Bishop et al., 2012**).

2.2.2 *Dunaliella*

Dunaliella is another single cell green alga containing a large amount of protein, β carotene and glycerol. These components can be easily extracted through its thin outer cell surface. It can't grow in water utilized in domestic and agricultural purposes as it is highly resistant to saline conditions. About 1,200 tons dry weight of *Dunaliella* is processed each year. China, Israel, Australia, and United States have a number of organizations that produce *Dunaliella* for the production of value added components. It produces different types of carotenoids in varying concentrations such as beta-carotene, alpha-carotene, lutein, and lycopene (**Chen et al., 2015)**. These extracted carotenoids are capable of free radical scavenging that reduces levels of enzyme inactivation and lipid peroxidation, and hence, restores the enzymatic activity. Beta (β)carotene has antioxidant capability of entrapping the reactive oxygen species in old age people and prevent cancer in several organs like pancreas, stomach, colon, lungs, rectum, breast, cervix, prostate, and ovary **(Bishop et al., 2012**). It also influences the immune response, intracellular communication, hepato protective effects, reduces the occurrence of liver lesions, and protects against neoplasm. The amount of the antioxidant enzymes like superoxide dismutase, peroxidase and catalase, and their activity and bioavailability are significantly greater in beta-carotene from *Dunaliella* in comparison to the synthetic compounds **(Saha et al., 2018).**

2.2.3 *Haematococcus*

Among the various unicellular green algae, *Haematococcus* is one of the most common algal strains. India, United States, and Israel are the major producers, accounting for around 300 tons of dried *Haematococcus* per annum. During the unfavourable conditions this algal cell usually goes into a latent phase of growth and the appearance of the cell becomes red indicating the presence of astaxanthin pigment. It comprises of about 1.5-3% of the algal dry cell weight. This pigment costs approximately $2,500 per kilogram dry weight and the annual market revenue is estimated to be $200 million **(Saha et al., 2018)**. The commercial cultivation of this strain is commonly done in photobioreactors and large-scale outdoor systems. It is also a kind of carotenoid pigment which showed the property of antioxidants, 1000 times effective than vitamin E and 10 times stronger than β carotene (**Chen et al., 2015)**. It effectively decreases triglycerides level, arterial blood pressure, and fatty acids. This pigment has some more impressing effect on human metabolic functions such as safeguarding against UV radiation effects, inhibits oxidation of essential polyunsaturated fatty acids, enhance vision, immune response, reproductive behaviour, and pigmentation. Some more activities like anti-bacterial, anti-oxidative, anti-cancer, and anti-inflammatory property, prevention and treatment of age-related macular degeneration, neural damages, spinal cord injury, Parkinson's disease, Alzheimer's are the most studied diseases which can be cured by astaxanthin **(Bishop et al., 2012**).

2.2.4 *Aphanizomenon*

Aphanizomenon, a blue green alga is available in fresh water ecosystems. It is produced about 500 tons in the dried form per annum. The leading producers are found in the Upper Klamath Lake, Klamath Falls, Oregon in North America which currently controls a significant part of nutraceuticals production industry throughout North America. It contains a good amount of chlorophyll mainly 1-2% of the dry cell weight which commonly stimulates the liver function and increases bile secretion. It has one more light-harvesting pigment C-Phycocyanin that has a significant antioxidant and anti-inflammatory property **(Kuddus et al., 2013)**. It has also high hypo-cholesterolemic activity that lowers the cholesterol and triglyceride levels in blood. Polyunsaturated fatty acids (i.e., omega 3 and omega 6) are also the major products from this strain which treats immune suppression, cardiovascular diseases, arthritis, dermatological problems, and mental health issues. This strain has also the property of

raising the number of natural killer cells which can easily induce apoptosis in cancerous and virus-infected cells along with antibacterial properties **(Bishop, 2012**).

2.2.5 Spirulina

Among all the cyanobacteria, *Spirulina* is one of the most commercially produced algal strains in the past thirty years commonly used as vitamin supplements, food, aquaculture, pharmaceuticals, food dyes and nutraceuticals. United States, India, Thailand, China, Taiwan, Pakistan and Burma are the major *Spirulina* producing countries (3,000 tons dry weight). Companies like Valley Naturals, Springtime Inc., Puritan's Pride, Bio-Alternatives, and Watershed Wellness Center are major biomass producing companies. These are specifically cultivated in designed photobioreactors and raceway ponds to meet the trending demand **(Baky et al., 2008).** It is a rich source of nutritional components like chlorophyll, vitamins, phycocyanin, omega 6 fatty acids and various minerals. It comprises of 60-70% protein of its dry weight along with some amount of β carotene (**Chen et al., 2015)**. It exhibited the health benefits such as controlling diabetes, high blood pressure, weight loss and hypertension along with the antiviral and anticancer properties. Reports are also available indicate enhancement of antigen-specific antibody binding capacity and phagocytosis activity in macrophages which is supposed to treat attention-deficit hyperactivity and depression like disorders **(Nicoletti et al., 2016).** This strain positively affects the cholesterol metabolism by increasing the level of HDL that leads to healthy cardiovascular functions. At the other hand C-phycocyanin content of *Spirulina* shows anti-inflammatory and antioxidant properties and improves the food absorption, digestion, and also stimulates the immune system that help against infections **(Bishop et al., 2012**).

2.3 Co-products of micro-algal origin

The food bio-active compounds are used as functional food ingredients due to its significant role in health promotion and disease risk reduction. The nutraceuticals from microalgae are rich in health promoting compounds **(Anis et al., 2017).** The amount and form of co products present in algal population are mainly affected by the following parameters-

(i) Variation in environmental parameters such as availability of light, nutrients, CO_2, temperature, pH, salinity etc.
(ii) Variation in strain type
(iii) Biotic interactions

Algae are used as healthy foods because they are of low calories and are rich in high quality proteins, vitamins, n-3polyunsaturated fatty acids (PUFAs) like eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and n-6 (PUFA) such as linoleic acids. In addition to that microalgae are the best reservoir of essential minerals like Ca, Na, Mg, P, K, Fe and Zinc, are the best source of iodine **(Wells et al., 2017)**. Microalgae are also rich metabolites like polyphenols, carotenoids and one of the best store houses of dietary fibres. It contains many physiologically active substances which are rarely found in other life forms. The metabolites present in algae are responsible for the protection of body from oxidative stress and chemopreclusion properties. Algal polysaccharides show anti-tumour, antiviral and anticoagulant properties. Microalgal dietary fibres show several influence on physiological activity of human beings having antioxidant, hypo cholesterolaemic and antihypertensive effects. The proteins and amino acids present in microalgae have influence on programmed cell death, cancer cell differentiation, antibiotics, inhibiting HIV virus, inhibition of human platelet aggregation etc. **(Lefranc et al., 2017).** Microalgae used as functional food in order to check the chronic diseases like cardiovascular diseases and diet-related cancers.

Astaxanthin: This is an important type of carotenoid synthesized by the aquatic microalga *Haematococcus pluvialis* and is a keto-carotenoid product. This microalga generally grows by two stages, one is biomass stage and another is metabolite accumulating stage where aplanospores are the distinguishing features. Three types of astaxanthin are generally observed (3R, 3´R), (3R, 3´S) (meso) and (3S, 3´S) and are available in 1:2:1 ratio **(Kuppusamy et al., 2014).** This is used in food industries as nutraceuticals and also utilised as a pigmentation source. Astaxanthinis is also derived from *Chlorella zofingiensis*. It inhibits the effect of UV rays on host plant. It shows high efficiency in free-radical scavenging, hinder lipid peroxidation and oxidative degradation of LDL-cholesterol, damage of cells, cell membranes, and tissues (**Sastasivam et al., 2017**).

Canthaxanthin: It is mainly used as a dying agent in food. Chemically it is an important carotenoid, which provides colour to chicken skin and egg yolks. It plays a major role in increasing vitamin E content of liver, shows anti-inflammatory neuro protective and antioxidant effect **(Sastasivam et al., 2017)**.

2.4 Micro-Algal Ingredients in Functional Food Formulations

Microalgae are considered as a major substitute and potential food stuffs because of their enriched bioactive components, nutritional composition and are considered as an alternative source of protein for the future **(Caporgno et al., 2018)**. Various microalgae have been used in different functional food formation in order to produce healthier food stuffs **(García et al, 2017)**. In this section we will discuss about the products, which are designed by adding algae or algal bioactive compounds as a constituent for better results.

Enriched dairy products:

Dairy items contribute significant measures of numerous elements to the diet, such as magnesium, calcium, phosphorus, potassium, zinc and protein. Dairy items such as cheese have been reformulated by adding microalgae to enhance the nutritional value. These combined products are more beneficial from nutrition point of view. Milk and its derivatives are calcium rich substances, but in cheese it is locked into a protein called casein **(Singh et al, 2017).** Hence, in absence of casein degrading enzymes a hypocalcaemic condition develops. Therefore, by adding calcium rich microalgae to milk products, this problem can be solved. The algae rich cheese is more important from nutrition point of view as it has higher calcium and iron

concentration. **Wijesekara et al. (2014)** investigated the physical properties of processed cheese after adding *Chlorella* (0.5–1%). The algal rich cheese had a higher concentration of lactic acid bacteria than that of normally processed cheese **(Dominguez at al., 2013**).

Enriched cereal-based food products:

Cereals are used as a staple food in many countries and are well adopted by human population due to their cost effectiveness, versatility, nutritional quality, easy preparation and sensory attributes. But, various technologies can be applied in order to enhance its nutritional values, which include microalgae incorporation as ingredients **(Wells et al., 2017)**.

a) **Pasta**: Pasta is one of the most versatile terms in both nutritional and gastronomic field. According to the nutritionists pasta is considered as highly digestible, having good content of carbohydrates, vitamins and iron with low levels of total fat and sodium. But one disadvantage of pasta is it contain less protein and essential amino acids for which it is highly necessary to improve its nutritional properties by adding more supplements from protein rich sources. In this scenario algae play an important role, the algae rich pasta has more improved variety of amino acids, phenols, fucoxanthins and fatty acids (**Dominguez et al., 2013**).
b) **Noodles**- Noodles are used as diets in several countries of the world. They are considered as a major food source in Asia and represents about 40% of all wheat products. In the day to day life, it is quite easy to cook and time saving food product for which it is more preferred by a large number of consumers. Hence, the quality of noodles should be improved by incorporation of algae. Algae can be used by means of improving colour, flavour and functionality enhancing the nutritional value. Algae powder has the ability of increasing the water absorption (higher cooking yields) and crude fibre content leading to more soft and spongy textures in noodles (**Dominguez et al., 2013**).
c) **Bread-** Bread is a cereal-based item that provides different bioactive ingredients. Algae are used as nutritional components in breads and are frequently consumed by a wide sector of population all over the world **(Keservani et al., 2010).**
d) **Cookies-** *Arthrospira platensis* and *Chlorella vulgaris* are two novel strains those who enhance the functional properties of cookies. Cookies made from *C. vulgaris* and *A. Platensis* shows significant protein content. According to **Batista (2017)**, all microalgae-based cookies has showed higher amount of antioxidant capacity and phenolic content**.**

3. Challenges

The concerned interest of algae as supply of co-products can be utilized as functional food components or pharmaceutical merchandise **(Pooja et al., 2015)**. Algae are given as natural reactors with an enormous metabolic malleability which means that the assembly of certain metabolites will be somehow tuned by modifying the culture conditions or through metabolic engineering approaches. Alga have conjointly been conferred because the key actor in an exceedingly bio-refinery platform during which they will be used as property supply of mass and energy and a valuable supply of bioactive compounds **(Gillbert-lobez et al., 2015)**. An additional analysis is required for a complete selection of bioactive compounds made through a different marine organism. Hence, in order to have the ability of unravelling the metabolic pathways, the annotation and cistron sequencing should be followed. This creates a sensible use of all tie info towards a sustainable production of energy and healthy food.

3.1 Algae based bio refinery concept

Primarily, the use of algal biomass through its fractionation economically leads to many types of outputs. This can be supply of a huge number of algal based products like oil for bio fuel and food ingredients. The idea of combining the bio-refineries with industries will tend to financial and environmental profits. This helps in mitigating the problems associated with fossil fuels, food inadequacy. Such kind of platforms are ought to be optimized which are collected from biomass and then fractionised to several product retaining their bioactive compound characteristics **(Elena et al., 2012)**. Analysis of the life cycles, modifications of the strain through biotechnology are accepted in order to assure the economic and ecological viability of the technology **(Spicer et al., 2017)**.

3.2 Microalgal biotechnology

Microalgal biotechnology is an innovative sector of biotechnology that has developed exponentially in the last few decades using the potency of the organisms available in our environment. Microalgae are now a group of primary producer cluster in aquatic ecosystems. They can easily grow despite of all extreme environmental circumstances like high concentration of greenhouse gas, temperature, pH, contaminated waste material and heavy metals or high salinity **(Jara et al, 2016)**. They are always ready to adapt the environmental conditions by their specific metabolism of synthesising and accumulating some compounds. This property of microalgae accelerates the production of commercial products of interest which has cosmetics, food, feed, pharmaceuticals and some energy applications. For this purpose, the organism has to supply some desired compounds in cost effective manner to make the field profitable. Moreover, increasing the productivity, the optimisation of downstream processes and by planning some new merchandise, a new market can make the production lucrative. **(Grobbelaar et al., 2003)**.

4. Market Scenario and Future Prospects

Nutraceuticals are health foods or extracts which have been well established for the prevention or treatment of diseases and reduction of the risk of illness. These are supplied in the form of food supplements, functional food ingredients or functional foods. Moreover, diet plays a vital role in disease initiation and control. The intake of synthetic chemical treated fruits, vegetables, grains, fish, meat, and milk product are responsible for the occurrence of 70 per cent of all cancer cases. Similarly, the consumption of more saturated fats, salts, and trans-fatty acids create cardiovascular diseases **(Mozaffarian D, 2016)**. So the

consumers are now becoming more aware about the effect of diet and this leads to the revolution of nutraceutical market. Global market size in nutraceuticals is expected to attain $ 302,306 million by 2022. The algae products market was around USD 3.98 billion in 2018 and is expected to reach a value of USD 5.17 billion by 2023, at a CAGR of 5.4%. Major market share was dominated by Europe in 2017. Rising health concerns among people, increase in awareness about the health benefits of the algae based food supplements, the algal proteins, PUFA, pigments, antioxidants, vitamins, minerals, peptides, and their related products has drawn the attention of both pharmaceutical and health food industries **(Barkia et al., 2019)**. According to TMR, the nutraceuticals market in U.S is highly competitive. The nutraceutical market in North America is expected to grow in future because of the awareness of life quality and healthy life **(Nasri et al, 2014)**. The algal nutraceutical market in Asia Pacific region is expected to increase owing to the demand for nutraceuticals and food supplements. In this scenario market of developing countries like China and India could be the main focus for more revenue generation in future. Although a number of algae are studied for their nutraceutical potential, many more strains remain unexplored and could be studied in future. Additionally, some genetically modified strain need to be studied in future to meet some challenges like low biomass production, improvement in the concentration of bioactive compound per cell, and exploration of novel products.

5. Conclusion

Change in life style and the insufficiency of balance nutrition for the overwhelming world population make the way for the incidence of a number of chronic diseases. Microalgae are proved to be a renewable and sustainable source of nutrition with health assistances. These could be the future food basket of the world. The microalgal biomass are used as nutraceuticals and the metabolites produced by them are used as food additives to form formulated foods. They exhibited a lot of plasticity in their bioactive compound production that means modification of the algal culture condition or gene editing through genetic engineering can increase the productivity of the chemical compounds or bring about an alteration of the same. Global nutraceutical market is expanding. In this scenario economic feasibility and to make the efficacious use of the algal biomass and its process sustainability is vital. This can be achieved through the adoption of bio-refinery approaches**.**

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