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Review Article

Potential Applications Of Microalgae In Bioproduct Production: A Review

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ABSTRACT

The present review addresses the versatile industrial applications of unicellular photosynthetic microalgae which play a pivotal role in the field of petrochemical, biopharmaceutical, and nutraceutical, cosmetics and food industries. They can be used for third generation biofuels production as they are renewable source of energy and better alternative to living fossil fuels. Besides, they also decipher significant potential as value added products such as bioactive medicinal products, and food ingredients, proteins, lipids, carbohydrates, pigments, carotenoids, antioxidants, (poly un saturated fatty acids) and biofuels. Thus, they are paving considerable attention throughout the world.

INTRODUCTION

About 3 billion years ago at the time of earth's environment formation, microalgae were one of the first microorganism that came into existence in the oceans of earth and they can also be named as phytoplankton and by utilizing carbon-dioxide these unicellular phytoplankton (microalgae) produce oxygen in the atmosphere by the process of photosynthesis. These microalgae are microscopic organisms with a large group of single celled eukaryotic and prokaryotic micro-organisms. They generally use autotrophic mode of nutrition, but there are also some microalgae present like *Polytoma* sp., *Protothecawickerhamii*, *Polytomella* sp. which use heterotrophic mode of nutrition having degenerated chloroplasts (Tartar et al.,2003; Ueno et al.,2003). Regardless of the reason that there is increase in the number of new species reckoned every year, but there is a very small amount of those has been examined till date. In reality, only a small number of microscopic microalgae can be grown in a large amount, namely *Chlamydomonas, Chlorella, Haematococcus, Isocrysis, Nannochloris, Nannochloropsis, Dunaliella* and *Spirulina* etc (Proksch et al., 2002; Tartar et al.,2002).Microalgae which produces required specificquantity of oil content and biomass, can be utilisedasa source of raw material for theproduction of biodiesel and is suggested as a potential energy source (renewal). In addition to it, the residual biomass of microalgae is also used for the productionof bio-hydrogen by utilizing anaerobic digestion, bio-methanol,bio-ethanol, bio-fertilizer,biogas,bio-plastics,animalfoodand medicinal value products (Tong et al.,2014; Gebreslassie et al.,2013).

By using microalgae we can produce a variety of therapeutically affective bio-active compounds which can be eitherreleased extracellular into the mediumor can either beproduced from the biomass (Bhagavathy et al.,2011). These microorganismshave many biologically active compounds likelipids, proteins,enzymes, polysaccharides,sterols,vitamins and other high-value compounds with nutritional and pharmaceutical importance that can be used commercially (Priyadarshani et al.,2012).

Some major products being produced commercially now a daysor under considerationto beproduced commercially are phycoboilins, carotenoids, polysaccharides,sterols, fatty acids, vitamins and biologically active molecules for use in animal and human health (Bhattacharjee et al.,2016). A bioactive compound is a physiologically active substance which has some functional properties in the human body. Therefore, there is a great enthusiasm for the manufacture and development of various bio-active compounds that can be used as functional ingredients such as poly-phenols,phycosynins,fatty acid, carotenoids, and polyunsaturated compounds (Plaza et al., 2010).

Microalgae grow rapidly even when given little quantity of nutrients and moisture in comparison with the plants that develop insoil. For example, 333 litres of water is needed for the production of 1 kilogram micro-algal biomass, whereas; soy requires 2,204 litres of water for producing the same amount of biomass (Schenk, et al., 2008). Micro-algal growth is affected by numerous factors that are enlisted as follow ; biotic factors (i.e., competition from other viruses, algae and fungi, bacterial presence), abiotic factors (i.e., light, toxic chemicals, temperature, dissolved oxygen content, pH,CO2 concentration, salinity, and nutrients in the growth media), and operational factors (i.e., shear forces generated by mixing, harvest method and dilution rate and frequency) (Renaud et al., 1994; Hu et al.,2006; Chiu et al., 2009). However, it is not easy to find out which of these factors has maximum effect in microalgalgrowth,as it may also be a possibility that different factors may collectively affect algal growth at the same period(Rezqet al., 1999; Zittelliet al., 1999).

The chances of finding out new value added products with high commercial value are high because of the development of new algal growth techniques. There are many products which are previously identified and marketed (Borowitzka et al., 2013).

Commercial uses of microalgae

Microalgae have been used for many purposes such as human nutrition as a functional food and nutraceuticals, pigments extracted are used in various industries such as pharmaceuticals, cosmetics, aquaculture and food and beverages. Others use of microalgae are in the field of bioremediation, cosmeceutical, as an animal feed and clinical and diagnostic research reagents.

Proteins

By the process of photosynthesis microalgae use sun light, carbon dioxide (CO_2)and nutrients for producing valuable organic compounds like lipids,carbohydrates, proteins, carotenoids etc.(Mendes et al., 2003; Batista et al.,2013). Proteins (amino acids biopolymers) cannot be obtained without having food, as there is a deficiency in synthesizing them in adequate amount, this is the reason they are essential for human beings. Some proteins, amino acids and smaller peptides besides their nutritional benefits also have functions that contribute to health benefits(Hemalathaet al.,2016). The reason behind considering micro algae to be a non conventional wellspring of proteins is there elevated protein content level. For example, *Spirulina* and *Chlorella* were the first commercialized micro algal species; they were used as a nutritional food in Japan, Mexico and Taiwan (Sánchez et al., 2003; Borowitzka et al., 2013) (Table 1). Due to the favourable essential amino acid composition and high content of protein (50%–58% DW) of Chlorella vulgaris, it is the most common industrially exploited species (Becker et al., 2007).The quality of protein produced by microalgae is better than plant sources of protein such as rice, wheat or beans but good as not as animal sources of protein such as meat and milk etc. (Mendes et al., 2007).

Lipids

Microalgae cultivation for producing lipids is the main interest in research. They are used for formation of compounds like methyl or ethyl esters by the process of esterification from fatty acids and then they are

Table-1: Microalgae species and their application

Microalgae species	Application and Product	Reference
Spirulina	Human and animal nutrition, phycobiliproteins, cosmetics	Pulz*et al.,* 2004; Spolaore *et al.,* 2006
Nostoc	Human nutrition	Pulz*et al.,* 2004; Spolaore *et al.,* 2006
Chlorococum sp.	Bio ethanol	Ike *et al.,*997
Haematococcus	Aquaculture, astaxanthin	Pulz*et al.,* 2004; Spolaor *et al.,* 2006
Chlorella	Human nutrition, aquaculture, cosmetics	Pulz*et al.,* 2004; Spolaore *et al.,* 2006
Muriellopsis sp.	Pigments, cosmetics and human nutrition	Dufossé *et al.,* 2005; Del Campo *et al.,* 2007
Botryococcusbraunii	Bioenergy	Orpez *et al.,* 2009
Dunaliellatertiolecta	Carbohydrates	Brown *et al.,*1991
Coelastrella sp.	Pigments, carotenoids	Hu *et al.,* 2013
Oscillatoria sp.	Flavonoids	Baviskar *et al.,* 2015
Tetraselmissp	Polyunsaturated fatty acid	Oviyaasri *et al.,*2017

Table-2: Microalgal species and compounds extracted from them.

Microalgae Species	Compounds	Reference
Chlorella vulgaris	Cantaxanthin, astaxanthin	(Demming*et al.,* 2002; El - Bakyet *al.,* 2011)
Haematococcuspluvialis	Astaxanthin, cantaxanthin, lutein	(El-Bakyet *al.,* 2003; Demming*et al.,* 2002)
Dunaliellasalina	β-carotene	(Demming*et al.,* 2002; Rabbani *et al.,* 1998)
Scenedesmusalmeriensis	Lutein, β-carotene	(Macaís*et al.,* 2010)
Coelastrellastriolata var. multistriata	Canthaxanthin, astaxanthin, β-carotene	(Abe *et al.,* 2005)
Galdierasuphuraria	Phycocyanin	(Bermudez *et al.,* 2015)
Phaedactylumtricornutum	Lipids, eicosapentaenoic acid, fatty acids	(Bermudez *et al.,* 2015)
Nannochloropsis sp.	n-3 fatty acids	(Sharma *et al.,* 2015)
Sargassumsiliquastrum	Fucoxanthin	(Heo*et al.,*2009)

ued for producing bio-diesels. Present focus in microalgae research is on the technologies of cultivation to optimize the quantity of lipid in microalgal biomass (Demirbas et al.,2011). The classification of lipids present in microalgae can be done primarily on the basis of their polarity (polar and nonpolar). The long-chain of polyunsaturated fatty acids (PUFAs), from the lipids class,areone of the most important ones because they impart good health to humans if taken regularly. Sometimes PUFAs are believed to have risk reduction and potential prevention against arthritis, coronary thrombosis and other immunological disorders, psoriasis, inflammation, cancer andhigh blood pressure (Lands et al.,2014).Waxes,sterols,fatty acids,ketones,pigmentsand hydrocarbons (phycobilins, carotenoids, and chlorophylls) are the major compounds found in micro algal lipids (Halim et al.,2011). The variation in the quantity oflipid in micro algae variesfrom 20% to 50% of dry biomass produced after harvesting algae which can vary species to species(Spolaore et al.,2006). For extracting pigments andlipids, mainly fatty acids from microalgae; the primary step is cell disruption, after that lipid is recovered using organic solvents. The choice of solvent for the efficient recovery of fatty acids must be appropriate for both the tasks of cell disruption and extraction from the algal bio mass. (Natarajan et al., 2015). The lipid extraction is an extremely important process for the production of microalgal biodiesel.

Poly Unsaturated Fatty Acids

In early 20thcentuary,omega-3 fatty acids were termed as 'VITAMIN F', this attracted research attention (Cannon, 2009). In the food products PUFA's Incorporation is dominated bydocosahexaenoic acid (DHA) C22:6n-3), eicosapentaenoic acid (EPA)C20:5n-3 and omega-3 fatty acids (α-linolenic acid)(ALA) C18:3n-3, (Augustinet al.,2003). SomePolyunsaturated fatty acids (PUFAs) play a major role in providing in healthy life as a part of their health and diets,eg:- EPA and DHA. These (EPA and DHA) are obtained mainly from Fish Oil that has been extracted successfully with maximum productionworld-wide(Winwoodet al., 2013). It has been noted that there was an increment in the use of microalgae for producing oils rich in EPA and DHA in the food processing industries. Some commonly known algae like Schizochytrium,Isochrysisgalbana,Ulkenia, Chlorella ellipsoidea, Chlorella pyrenoidosa andCrypthecodinium are used for producing algal biomass oil rich in DHA. Temperature and salinity are major micro algal growth factors that influence the production of EPA and DHA(Winwoodet al., 2013). Marine microalgae having largepolyunsaturated fatty acids (PUFA) content are an important and recognised renewable source of bioactive lipids, are proved effective for the preventionor treatment ofnumerous diseases. Polyunsaturated fatty acids (PUFA), mainly n-3 PUFA such aseicosapentaenoic acid(EPA, C20:5n-3),docosahexaenoic acid (DHA, C22:6n-3),alinolenic acid (ALA, C18:3n-3), and docosapentaenoic acid (DPA, C22:5n-3)are proved to be effective in the prevention or treatment of numerous diseases likeasthma,CVD, arthritis, adult onset diabetes (type 2),cancer, inflammatory bowel disorders, skin and kidney disorders, schizophrenia and anxietydisorders (Priyadarshaniet al., 2012).

Carbohydrates

Carbohydrate production in algae helps it in the storage of components inside the cell and they also behaveas abasic component of the cell wall. As storage constituents,they help in the metabolic processes of the organisms providing required energy and also helps ustaining temporarily without sunlight (Geideret al.,2002). Microalgae the synthesis of starch, hemicelluloses, cellulose and other polysaccharides is done by microalgae from simple monomeric sugars (glucose). Algal cells are important food source as they have good source of carbohydrates. Producing biofuels (e.g. bioethanol) from microalgae carbohydrate production is investigated by the process of successive fermentation.Aftertheextractionof lipid there was an increment in purity of carbohydrate.The presence of carbohydrate in the biomass depends not only on different varieties of microalgaebut also on the environmental conditions and the cultivation method. Some examples of species having high carbohydrate content are Spirogyra sp. (35-65 %), Porphyridiumcruentum (40-60%) etc (Harun et al.,2010). For producing biofuels microalgal carbohydrates can be used with the help of several biomass conversion techniques. Some techniques used for conversion of carbohydrates for producing biofuels are (a) anaerobic digestion, (b)biological biohydrogen production and (c) anaerobic fermentation (Markou et al.,2012).

Vitamins

Microalgae produce a wide variety of valuable and commercially important products. The vitamins produced by microalgae increase their value as a nutritional food for animals as well as humans beings (Borowitzkaet al., 1998)., A blue pigment called Marennine is the reason behind green colour of diatom Haslea (Navicula) ostrearia and oysters which are rich in Tocopherols. P. Cruentum (microalgae) has high quantity ofprovitamin A (β-carotene), E (tocopherols) and vitamin C. Another microalgae, Dunaliella salina produces β-carotene along with thiamine, riboflavin, pyridoxine, nicotinic acid, tocopherols and biotin (Hemalathaet al., 2016).

Antioxidants

Antioxidants, lipids, nucleic acidsandproteinsgetoxidative damage byreactive oxygen species; this mayaccelerate variousdisorders, like coronary artery disease,cancer, artherosclerosisand ageing (Finkelet al., 2000). Loss of life from ageing disorders, likecancerandcoronary artery disease, and consumption of vegetables and fruits are inversely associated with each other according to the demonstrations given by Epidemiological studieswhichimplies their antioxidant property. Microalgae show adaptive responses whenever exposed to oxidative stresses, by stimulating their antioxidant defence mechanism (Hong et al., 2008; Srivastava et al., 2005).Some substances, like butylated hydroxyl toluene (BHT), vitamins E and C or carotenoids present in microalgae have such antioxidative effects (Skjånes et al.,2013). The microalgal biomass of Spirulina platensis is good source of vitamins (such as pro-vitamin B1, B2, A,E, B12, D, and B6), proteins, essential fatty acids, minerals as well as in other components having antioxidant properties (Babadzhanovet al., 2004; Wanget al., 2007).

Pigments

We can obtain natural pigments from insects (such as aphids and cochineals), fruits, vegetables, flowers and from microscopic species like microalgae (Farré et al.,2010;Vilchezet al.,2011).These microscopic species (Microalgae) are important pigment source from a biotechnological point of view because they contain molecules, including phycobili proteins (red and blue), carotenoids (red, orange and yellow) and chlorophylls (green).

Carotenoids

The presence of carotenoids is mainly in orange-coloured fruits and yellow coloured and green leafy vegetables. Carotenoids on the basis of their chemical composition are classified into carotenes and xanthophylls and also they are lipophilic in nature. Xanthophylls are more polar than the carotenes because they have oxygenated functional groups where as carotenes are just hydrocarbons(Stahl et al., 2012; Sainiet al., 2015).Natural carotenoids are combination of cis-isomer plustrans-isomers and they show anti-carcinogenic property where as synthetic carotenoids only form trans isomers therefore in comparison to synthetic carotenoids natural carotenoids are used more frequently. The combination of the algal beta-carotene isomerof natural carotenoid has 10 times higher accumulation in comparison with the all-trans-beta-carotene synthetic compounds (Ben-Amotzet al., 1989)., Carotenoids (β-carotene, lutein, as taxanthin, zeaxanthin, and fucoxanthin) takes part in the process of photosynthesis like chlorophylls (Anon, 2014) by absorbing blue, violet and green light of the visible spectrum and reflecting yellow, orange and red . Recently, these compounds have been given more importance, but their commercial use is still low on pilot scale because of their high extraction and purification cost. (G€unerken et al., 2015).

β-Carotene

β-carotene which is also called pro-vitamin A carotenoid, can be converted into retinol and it also helps in reducing the risk of macular degeneration (Table 2) (Siemset al.,2005; Jaswiret al.,2011). β-carotene is an important type of carotenoid and is used commercially as a colouring pigment, as a vitamin-A supplement and as an antioxidant. In addition to this, it also has anti-cancerand anti-ageing properties. Carrots are the naturally occurring source of β-carotene. But now a days algae is up for consideration as a new source for producing natural β-carotene (Pisalet al., 2005).β-carotene is believed to have mechanisms of preventive action against cancer including inhibiting the growth of carcinogenic cells , possible augmentation of carcinogen-metabolizing enzymes, hindrance of oxidative DNA damage and induction of differentiation by modulation of cell cycle regulatory proteins (Cooper et al.,2004). Some examples of microalgae species used for producing β-carotene are Scenedes musalmeriensis, Dunaliell abardawil and Dunaliellasalina (D. salina) (Guedes et al., 2011).

Lycopene

Lycopene is also known as non-provitamin-A carotenoid, have a widerange of natural processes (Singh et al., 2008). Lycopene have anti-atherogenic and anti-carcinogenic properties which are very beneficial for good health of human beings. The intake of lycopene in human diet decreases the oxidative stress because of its anti-oxidative properties and therefore decreases the risk of severe disorders like cardiovascular diseases and cancer (Agarwal et al., 2000). The major natural source of lycopene extraction is tomatoes and is considered as an important antioxidants and cannot be obtained from animals (Agarwal et al., 2000).It prevents the harmful solar radiation from causing any damage to skin if applied as a sunblock (Mourelle et al.,2017). In comparison with standard drugs like trans-lycopene and lovastatin, which are generated from tomatoes are higher in algal lycopene producing species Chlorella marina having higher anti-inflammatory and antioxidant effect in high cholesterol fed rats ; reveals a study (Renju et al., 2014).

Lutien

Lutein is a carotenoid that contains oxygen and has antioxidative properties and also it is relatedto good eye health of human beings (Bhattacharyya et al., 2010).The quantity of lutein obtained from microalgae gets affected by different factors such as pH, irradiance temperature, amount of nitrogen present and salinity (Guedes et al.,2011).The lutien production from the microalga species like Chlorella protothecoides (Shi et al.,2002; Shi et al.,2000), Scenedesmus almeriensis (Sánchez et al.,2008), Dunaliellasalina (González et al.,2003) and Galdieria sulphuraria (Graziani et al., 2013) is widely studied and the most successful microalgal biotechnology.

Astaxanthin

Some researchers have revealed that astaxanthin has remarkable anti-carcinogenic effects on prostatic cancers and prostatic hyperplasias. The enzyme 5-α-reductasewhich is responsible for the abnormal prostate growth is inhibited by Astaxanthin(Guerin et al., 2003; Andersonet al., 2001). Astaxanthin have several other properties likeAnti–inflammatory properties anti-oxidative properties and helps in dealing with Cardio-vascular diseases (CVD). Besides these properties it also has anti-cancer properties against benign prostatic hyperplasia and prostate cancer and liver tumors(Lemoineet al., 2010). Astaxanthin is produced on industrial scale by Haematococcussp. With the help of two step mechanism which involves production of green biomass in proper growth conditions/environment after that it is exposed to adverse environment conditions so that astaxanthin accumulation is induced. Some companies producing astaxanthin by this species are Cyanotech and Aquasearch(Guerin et al., 2003). Astaxanthin production is mainly done with the help of members of Chlorophyceae family like Chlamydomonas, Chlorella, Haematococcus sp. and Dunaliella, etc. (Pulzet al.,2004).

Zeaxanthin

Zeaxanthin is a yellow coloured carotenoid mainly found in corn, gulmohr, eggyolk, berries, orange and marigold flowers. It is generally used in pharmaceutical, food industry applications and cosmetics (Sajilata et al.,2008). Zeaxanthin helps in prevention of chronic andacute coronary syndromes and Helps in maintaining normal visual function by preventing cataracts and it also prevents macular degeneration which is associated with age (Lidebjeret al.,2007; Raposo et al.,2015).Some common examples of microalgae producing zeaxanthin are Nannochloropsis oculata and Scenedesmus almeriensis (Granado et al.,2009; Guillerme et al., 2017).

Phycobili protien

Phycobili proteins are important in algae and are present in of rhodophytes, cyanobacteria, glaucophytes and cryptomonads and are water-soluble and light harvesting proteins in nature (Sekaret al.,2008; Eriksen et al., 2008). Theycan absorb the light in a range (495 –650nm) in which even carotenoids and chlorophyll do not absorb the light (Apt et al., 1999). More commercial applications of Phycobiliproteins are as follows food colourants, natural dyes (Phycocyanin), cosmetics (phycoerythrin) and in food industry. Phycocyaninis the most versatile natural food colorant of blue colour such as indigo and gardenia but it is less stable in high temperature (heat) and when exposed to light (Sekar et al.,2008). It is used in cosmetic industries for making lipsticks and eye liners and in the food industry it is used for making ice cream, candies, soft-drinks, milkshakes, chewing gum, cake decorations, desserts, icings and frostings (Sekar et al.,2008; Eriksen et al.,2008). Some other industrial applications of Phycobiliproteins are fluorescent agents, natural dyes, cosmetic industries (perfumes and eye-make up powders) and pharmaceuticals (antioxidant, heap toprotectiveagents, neuro-protective and anti-inflammatory). Amphanizomenonfloa-aquae, Arthrospira platensis and Spirulina sp. are some of the most important sources of Phycobili proteins (Odjadjare et al.,2017; Raposo et al., 2013).

Biofuel

T To deal with the problem of earth's rising temperature(global warming) some other sources are being searched and biofuel (3rd generation fuel) produced from microalgae is considered as an potential option for energy production (Chistiet al.,2012). Efficiency of Microalgae is many times more efficient than plants in photosynthetic activity and the rate of producing bio-oil from microalgae (Kumar et al., 2018; Richardson et al., 2012).Microalgae are produced from the naturalre sources (sunlight, O2/CO2 and water) which make it a renewable energy source. Using microalgal based bioethanol and biodiesel is economic as well as sustainable and also it helps in reducing Green House Gases emission in the environment (Najafi et al.,2011; Kumar et al., 2017). Microalgae are exceptionally good for producing biofuel, producing biomass (nearly 77% ofdry cell mass) and photosynthesis process for lipid fabrication (Singh et al., 2010; hu et al.,2013; Nanda et al.,2019). Microalgal biomass is being used for producing a wide variety of valuable by products as well as biofuel. For producing a good amount of microalgal biomass to enhance the production of biodiesel a two reactor system is being used 1st an open pond system and 2nd the close type photobioreactor (Richardson et al.,2012). Prior to mass scale cultivation of microalgal-based biofuel, it is important to check its impact on the environment and also its economic feasibility.

Human Food and Pharmaceutical

Now a days, Microalgae is frequently used in the food and pharmaceutical industries in the form of tablets, liquids, capsules and can be incorporated into candy, gums, pasta, food bar, snack and beverages etc.(lianget al., 2004; Yamaguchi et al.,1996). Microalgae are good source of health supplements and can also be used as colorants (Apt et al., 1999; Soletto et al., 2005). The most common species used for industrial purpose are Anthrospira, Aphanizomenon flo saquae , Chlorella and Dunaliella salina (Liang et al., 2004; Yamaguchi et al., 1996) Microalgae (mainly Chlorella sp. and Spirulina sp.) are commercialized traditionally for animal feed or human food and have a market worth of $80 million turnover per annum (Vigani et al., 2015). There are numerous high-value products in the market produced from microalgae with specific applications in the nutritional industry(Plaza et al., 2008).Carotenoids being the most interesting microalgal bioproduct is used for producing asthaxanthin (mainly from H. pluvialis) and β-carotene (mainly from D. salina) and the less exploredlycopene, zeaxanthin and lutein. These are one of the most important class of bioactive compounds because they are potential competitors of carotenoids synthesized from chemicals (Spolaore et al., 2006).In pharmaceutical applications the PUFA DHA extracted from microalgal biomass has an annual $10 billion market value and also it is recommended for infants in their daily diet (Ward et al., 2005).

CONCLUSION

The main focus of this review is to provide insights on the potential applications of microalgae tiny factories for the renewable, sustainable and economical production of third generation biofuel, bio-active therapeutic compounds and food supplementsas their biomass are rich source of high value-added products and biodiesel. The pilot to large scale cultivation of these photosynthetic organisms would be beneficial for the commercialization of biofuel and high value added products like proteins, lipids, carotenoids, lutein, β-carotene, astaxanthin, zeaxanthin, antioxidants, pigments, biofuel carbohydrates and phycobili proteins. In addition to this, these unicellular organisms would be useful in the mitigation of elevated environmental CO2 levelat global scale. Thus, microalgae are safe feedstock which offersan arsenal of valuable commercial products in the field of pharmaceutical, neutraceutical and bioenergy.

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REFERENCES

1. Abe, K.; Hattor, H.; Hiran, M. (2005) Accumulation and antioxidant activity of secondary carotenoids in the aerial microalga Coelastrellastriolata var. multistriata. Food Chem., 100; 656–661.
2. Abu Rezq, T. S., L. AlMusallam, J. AlShimmari, and P. Dias. (1999). Optimum production conditions for different high quality marine algae. Hydrobiologia 403; 97107.
3. Agarwal S, Rao AV. (2000) Tomato lycopene and its role in human health and chronic diseases. Can. Med. Assoc. J., 163; 739-744.
4. Anderson, M. (2001) Method of Inhibiting 5α-Reductase with Astaxanthin to Prevent and Treat Benign Prostate Hyperplasia (BPH) and Prostate Cancer in Human Males. U.S. Patent 6277417, 21 August 2001.
5. Apt KE, Behrens PW (1999) Commercial developments in microalgalbiotechnology. Journal of Phycology, 35(2); 215–226.
6. Augustin, M.A., and L. Sanguansri. (2003). Polyunsaturated fatty acids: delivery, innovation and incorporation into foods. Food Australia 55;294-296.
7. Babadzhanov, A. S., Abdusamatova, N., Yusupova, F. M., Faizullaeva, N., Mezhlumyan, L. G., &Malikova, M. K. (2004). Chemical composition of Spirulina platensis cultivated in Uzbekistan. Chemistry of Natural Compounds, 40; 276–279.
8. Batista, A.P., Gouveia, L., Bandarra, N.M., Franco, J.M., and Raymundo, A. (2013) Comparison of microalgal biomass profiles as novel functional ingredient for food products. Algal Res 2; 164–173.
9. BaviskarJ.W. and Khandelwal S.R. (2015) Extraction, Detection and Identification of Flavonoids from Microalgae: An Emerging Secondary MetaboliteInt.J.Curr.Microbiol.App.SciSpecial Issue-2; 110-117.
10. Becker, E. (2007) Micro-algae as a source of protein. Biotechnol. Adv., 25; 207–210.
11. Ben-Amotz, A., Mokady, S., Edelstein, S., &Avron, M. (1989). Bioavailability of a natural isomer mixture as compared with synthetic all-trans-β-carotene in rats and chicks. Journal of Nutrition, 119; 1013–1019.
12. Bhagavathy S, Sumathi P, Jancy I, Bell S. (2011) Green algae Chlorococcumhumicola - A new source of bioactive compounds with antimicrobial activity. Asian Pac J Trop Biomed., 1: S1-7.
13. Bhattacharjee M (2016)pharmasutically valuable bioactive compounds of algae. Asian J Pharm Clin Res, 9(6).
14. Bhattacharyya, S., Datta, S., Mallick, B., Dhar, P. and Ghosh, S. (2010), "Lutein Content and in Vitro Antioxidant Activity of Different Cultivars of Indian Marigold Flower (Tagetespatula L.) Extracts", Journal of Agricultural and Food Chemistry, 58 (14); 8259-8264
15. Borowitzka MA. (1998) Vitamins and fine chemicals from microalgae. In: Borowitzka MA, Borowitzka LJ, editors. Micro-algal biotechnology. Cambridge: Cambridge University Press, 153–96.
16. Borowitzka MA. (2013) High-value products from microalgae – Their development and commercialisation. J. Appl. Phycol., 25; 743-756.
17. Brown MR (1991) The amino-acid and sugar composition of 16 species of microalgae used in mariculture. J Exp Mar BiolEcol 145(1);79–99. doi:10.1016/0022-0981(91)90007-j
18. Cannon,D. (2009). From Fish Oil to Microalgae Oil ... A Win-Win Shift for Humans and Our Habitat. Explore-the Journal of Science and Healing, 5:299-303.
19. Che-Wei Hu, Lu-Te Chuang, Po-Chiea Yu, ChingNen Nathan Chen (2013) Pigment production by new thermotolerant microalgae coelastrella sp. F50 , food chemistry 138: 2071-2078.
20. Chisti Y (2012) Raceways-based production of algal crude oil. In: Posten C, Walter C (eds) Microalgal biotechnology: potential and production. deGruyter, Berlin, 113–146.
21. Chiu, S., C. Kao, M. Tsai, S. Ong, C. Chen, and C. Lin. (2009). Lipid accumulation and CO2 utilization of Nannochloropsis oculata in response to CO2 aeration. Bioresource Tech., 100(2); 833-838.
22. Cooper D, (2004) Carotenoids in health and disease: recent scientific evaluation, research recommendation and the consumer. J. Nutr., 134: 221S–224S.
23. Cuellar-Bermudez SP, Aguilar-Hernandez I, Cardenas-Chavez DL, Ornelas-Soto N, Romero-Ogawa MA, Parra-Saldivar R. (2015) Extraction and purification of high-value metabolites from microalgae: essential lipids, astaxanthin and phycobiliproteins. MicrobBiotechnol.; 8; 190–209.
24. De Jesus Raposo MF, de Morais RMSC, de Morais AMMB. (2013) Health applications of bioactive compounds from marine microalgae. Life Sci.,93; 479-486.
25. Del Campo, J.A, Garcia-González, M., and Guerrero, M.G.(2007) Outdoor cultivation of microalgae for carotenoid production: current state and perspectives. Applied Microbiology and Biotechnology;74; 1163–1174.

26. Demirbas A, FatihDemirbas M (2011) Importance of algae oil as a source of biodiesel. Energ Convers Manage 52(1); 163–170. doi:10.1016/j.enconman.2010.06.055
27. Demming-Adams, B.; Adams, W.W. (2002) Antioxidants in photosynthesis and human nutrition. Science, 298; 2149–2153.
28. Dufossé, L., Galaup, P., Yaron, A., Arad, S.M., Blanc, P., Chidambara Murthy, K.N., and Ravishankar, G.A.(2005) Microorganisms and microalgae as pigments for food use: A scientific oddity or an industrial reality? Trends in Food Science and Technology;16; 389–406.
29. El-Baky, H.H.A.; El-Baroty, G.S. (2011) Enhancement of carotenoids in Dunaliellasalina for use as dietary supplements and in the preservation of foods. Food Chem. Toxicol., in press.
30. El-Baky, H.H.A.; El-Baz, F.K.; El-Baroty, G.S. (2003) Spirulina species as a source of carotenoids and α-tocopherol and its anticarcinoma factors. Biotechnology, 2: 22–240.
31. Eriksen NT (2008) Production of Phycocyanin - a pigment with applications in biology, biotechnology, foods and medicine. Applied microbiology and biotechnology 80; 1-14.
32. Farré G, Sanahuja G, Naqvi S, Bai C, Capell T, Zhu C, Christou P (2010) Travel advice on the road to carotenoids in plants. Plant Science 179; 28-48.
33. Finkel, T., & Holbrook, N. J. (2000). Oxidants, oxidative stress and the biology of ageing. Nature, 408; 239–247.
34. G€unerken, E., D'Hondt, E., Eppink, M.H.M., Garcia-Gonzalez, L., Elst, K., Wijffels, R.H., (2015). Cell disruption for microalgae biorefineries. Biotechnol. Adv. 33; 243–260.
35. Gebreslassie BH, Waymire R, You F (2013) Sustainable design and synthesis of algae-based biorefinery for simultaneous hydrocarbon biofuel production and carbon sequestration. AIChE J 59(5):1599–1621.
36. Geider RJ, La Roche J (2002) Redfield revisited: variability of C:N:P in marine microalgae and its biochemical basis. Eur J Phycol 37 (01);1–17. doi:doi:10.1017/S0967026201003456.
37. González S, Astner S, An W, Goukassian D, Pathak MA (2003) Dietary lutein/zeaxanthin decreases ultraviolet B-induced epidermal hyperproliferation and acute inflammation in hairless mice. J Invest Dermatol 121;399–405
38. Granado-Lorencio F, Herrero-Barbudo C, Acién-Fernández G, et al. (2009) In vitro bio accesibility of lutein and zeaxanthin from the microalgae Scenedesmus almeriensis. Food Chem,114; 747-752.
39. Graziani G, Schiavo S, Nicolai MA, Buono S, Fogliano V et al (2013) Microalgae as human food: chemical and nutritional characteristics of the thermo-acidophilic microalga Galdieriasulphuraria. Food Funct 4;144–152.
40. Guedes AC, Amaro HM, Malcata X. (2011) Microalgae as sources of carotenoids. Mar. Drugs, 9; 625-644.
41. Guerin, M.; Huntley, M.E.; Olaizola, M. (2003)Haematococcus astaxanthin: applications for human health and nutrition. Trends Biotechnol., 21; 210–216.
42. Guil-Guerrero JL, Navarro-Juarez R, Lopez-Martinez JC, Campra-Madrid P, Rebolloso-Fuentes MM. (2004) Functional properties of the biomass of three microalgal species. J Food Eng. 65; 511–7.
43. Guillerme JB, Couteau C, Coiffard L. (2017) Applications for marine resources in cosmetics. Cosmetics:4:1-15.
44. Guschina, I.A., and Harwood, J.L. (2006) Lipids and lipid metabolism in eukaryotic algae. Prog Lipid Res 45: 160– 186.
45. Halim, R., Gladman, B., Danquah, M.K., and Webley, P.A. (2011) Oil extraction from microalgae for biodiesel production. BioresourTechnol 102; 178–185.
46. Han, F., Pei, H., Hu, W., Jiang, L., Cheng, J., Zhang, L., (2016). Beneficial changes in biomass and lipid of microalgae Anabaena variabilis facing the ultrasonic stress environment. Bioresour. Technol. 209; 16–22.
47. Harun R, Jason WSY, Cherrington T, Danquah MK (2010) Microalgal biomass as a cellulosic fermentation feedstock for, bioethanol production. Renew SustEnerg Rev. doi:10.1016/j.rser.2010. 07.071.
48. HemalathaN., SanthoshS. andDhandapani R.(2016) Bioactive compounds from Microalgae and its different applications- a review Adv. Appl. Sci. Res., 7(4);153-158.
49. Heo, S.-J.; Jeon, Y.-J. (2009) Protective effect of fucoxanthin isolated from Sargassumsiliquastrum on UV-B induced cell damage. J. Photochem. Photobiol. B, 95; 101–107.
50. Hong, Y., H.Y. Hu, X. Xie and F.M. Li, (2008). Responses of enzymatic antioxidants and non-enzymatic antioxidants in the cyanobacteriumMicrocystisaeruginosa to the allelochemical Ethyl 2-Methyl Acetoacetate (EMA) isolated from reed (Phragmitescommunis). J. Plant Physiol., 165; 1264-1273.
51. Hu Z, Zheng Y, Yan F, Xiao B, Liu S, (2013) Energy, 52,119-25.
52. Hu, H., and K. Gao. (2006). Response of growth and fatty acid compositions of Nannochloropsis sp. to environmental factors under elevated CO2 concentration. Biotech. Lett. 28(13); 987 992.
53. Ike N, Toda N, Tsuji K, Hirata K, Miyamoto K (1997) Hydrogen photo production from CO2-fixing microalgal biomass: application of halotolerant photosynthetic bacteria. J Ferment Bioeng 84;606–609.
54 Jaswir I, Noviendri D, Hasrini RF &Octavianti F (2011), J. Med. Plants, 5; 7119–7131.
55. Kumar V, Kumar A, Nanda M. (2018) Pretreated animal and human waste as a substantial nutrient source for cultivation of microalgae for biodiesel production.Environmental Science and Pollution Research. 25(22); 22052-22059doi: 10.1007/s11356-018-2339-x.
56. Kumar V, Nanda M, Verma M.(2017) Application of agar liquid-gel transition in cultivation and harvesting of microalgae for biodiesel production. BioresourceTechnology. 243; 163–168. http://dx.doi.org/10.1016/j.biortech.2017.06.080
57. Lands, B., (2014). Historical perspectives on the impact of n-3 and n-6 nutrients on health. Prog. Lipid Res. 55; 17–29.
58. Lemoine, Y.; Schoefs, B. (2010) Secondary keto carotenoid astaxanthin biosynthesis in algae: A multifunctional response to stress. Photosynth. Res., 106; 155–177.
59. Liang S, Liu X, Chen F et al. (2004) Current microalgal health food R & D activities in China. Asian Pacefic Phycology in the 21st Century: Prospects and Challenges. Dordrecht: Springer Netherlands; 45-48.
60. Lidebjer, C.; Leanderson, P.; Ernerudh, J.; Jonasson, L. (2007) Low plasma levels of oxygenated carotenoids in patients with coronary artery disease. Nutr. Metab. Cardiovasc. Dis., 17; 448–456.
61. Macaís-Sánchez, M.D.; Fernandez-Sevilla, M.; Acién-Fernández, F.G.; Cerón-Garcia, M.C.; Molina-Grima, E. (2010) Supercritical fluid extraction of carotenoids from Scenedesmusalmeriensis. Food Chem., 123; 928–935.
62. MarkouG &Angelidaki I&Georgakakis D (2012) Microalgal carbohydrates: an overview of the factors influencing carbohydrates production, and of main bioconversion technologies for production of biofuels ApplMicrobiolBiotechnol DOI 10.1007/s00253-012-4398-0.
63. Matos J, Cardoso C, Bandarra N. M, Afonso C. (2017) Microalgae as healthy ingredients for functional food: A review. Food Funct.; 8:2672-2685.
64. Mendes, A.,Lopes da Silva, T., & Reis, A. (2007).DHA concentration and purification from the marine heterotrophic microalga Crypthecodiniumcohnii CCMP 316 by winterization and urea complexation. Food Technology and Biotechnology, 45(1); 38-44.
65. Mendes, R.L., Nobre, B.P., Cardoso, M.T., Pereira, A.P., and Palavra, A.F. (2003) Supercritical carbon dioxide extraction of compounds with pharmaceutical importance from microalgae. InorganicaChimActa 356; 328–334.
66. Mourelle ML, Gómez CP, Legido JL. (2017) The potential use of marine microalgae and cyanobacteria in cosmetics and thalassotherapy. Cosmetics, 4; 1-14.
67. Najafi G, Ghobadian B, Yusaf TF. (2011) Algae as a source of sustainable energy source for bio fuel production in Iran : a case study ,Renew Sust Energy Rev;15(8); 3870-6.
68. Nanda M, Kumar V, Fatima N, Pruthi V, Verma M,ChauhanP.K,Vlaskin M S., Grigorenko A V. (2019) Detoxification mechanism of organophosphorus pesticide via carboxylestrase pathway that triggers de novo TAG biosynthesis in oleaginous microalgae. Aquatic Toxicology 209; 49–55. https://doi.org/10.1016/j.aquatox.2019.01.019
69. Natarajan, R., Chen, X., Lau, R., (2015). Ultrasound applications in lipid extractions from microalgae. Production of Biofuels and Chemicals with Ultrasound. Springer, Netherlands, pp. 117–139.
70. Odjadjare EC, Mutanda T, Olaniran O. (2017) Potential biotechnological application of microalgae: A critical review. Crit. Rev. Biotechnol.37; 37-52.
71. Orpez R, MartÍ ´nez ME, Hodaifa G, El Yousfi F, Jbari N, Sa ´nchez S (2009) Growth of the microalga Botryococcusbraunii in secondarily treated sewage. Desalination 246; 625–630.
72. Oviyaasri M., Manjuladevi M., Anitha R., NarmathaM., KavithaJ. (2017)Extraction and Isolation of Polyunsaturated Fatty Acids from Microalgae Tetraselmis.Sp International Journal of Innovative Research in Science, Engineering and Technology 6(3) DOI:10.15680/IJIRSET.2017.0603273 .
73. Pisal DS, Lele SS. (2005) Carotenoid production from microalga, Dunaliellasalina. Ind. J. Biotechnol.4; 476-483.
74. Plaza M, Santoyo S, Jaime L, García-Blairsy Reina G, Herrero M, Señoráns FJ, et al. (2010) Screening for bioactive compounds from algae. J Pharm Biomed Anal, 51(2); 450-5.
75. Plaza, M., Cifuentes, A., Iba ´nez, E., (2008). In the search of new functional food ingredients from algae. Trends Food Sci. Technol. 19; 31–39.
76. Priyadarshani I. and Rath. B. (2012) Commercial and industrial applications of micro algae – A review. J. Algal Biomass Utln. , 3 (4); 89–100.
78. Proksch, P.; Edrada, R.A.; Ebel, R. (2002) Drugs from the seas—Current status and microbiological implications. Appl. Microbiol. Biotechnol., 59, 125–134.
79. Pulz O, Gross O, (2004) ApplMicrobiolBiotechnol, 65; 635-648.
80. Rabbani, S.; Beyer, P.; von Lintig, J.; Hugueney, P.; Kleinig, H. (1998) Induced β-carotene synthesis driven by triacylglycerol deposition in the unicellular alga Dunaliellabardawil. Plant Physiol., 116; 1239–1248.
81. Raposo, M.F.D.J.; Morais, A.M.M.B.D.; Morais, R.M.S.C.D. (2015) Carotenoids from marine microalgae: A valuable natural source for the prevention of chronic diseases. Mar. Drugs, 13, 5128–5155.
82. Renaud, S. M., and D. L. Parry. (1994). Microalgae for use in tropical aquaculture: II. Effect of salinity on growth, gross chemical composition, and fatty acid composition of three species of marine microalgae. J. Appl. Phycol. 6(3); 347 356.
83. Renju G, Kurup GM, Kumari CS. (2014) Effect of lycopene from Chlorella marina on high cholesterol-induced oxidative damage and inflammation in rats. Inflammopharmacology, 22; 45-54.
84. Richardson JW, Johnson MD, Outlaw JL (2012) Economic comparison of open pond raceways to photo bio-reactors for profitable production of algae for transportation fuels in the Southwest. Algal Res 1; 93–100.
85. Richmond, A. (2004) Handbook of Microalgal Culture. Oxford, UK: Blackwell Publishing Ltd. pp. 83–90.
86. Saini, R. K., &Keum, Y.-S. (2017). Progress in microbial carotenoids production. Indian Journal of Microbiology, 57(1); 129–130. http://dx.doi.org/10.1007/s12088-0160637-x.
87. Sajilata M, Singhal R, Kamat M. (2008) The carotenoid pigment zeaxanthin – A review. Compr. Rev. Food Sci. Food Safe. 7; 29-49.
88. Sánchez JF, Fernández JM, Acién FG, Rueda A, Pérez-Parra J (2008) Influence of culture conditions on the productivity and lutein content of the new strain Scenedesmus almeriensis. Process Biochem 43;398–405.
89. Sánchez, M., Bernal-Castillo, J., Rozo, C., and Rodríguez, I. (2003) Spirulina (arthrospira): an edible microorganism: a review. UnivSci 8; 7–24.
90. Sathasivam R. ID and Ki J. S. (2018) A Review of the Biological Activities of Microalgal Carotenoids and Their Potential Use in Healthcare and Cosmetic Industries Mar. Drugs, 16(26); doi:10.3390/md16010026
91. Schenk P M, Thomas-Hall SR, Stephens E, et al. (2008) Second generation biofuels: High-efficiency microalgae for biodiesel production. Bioenergy Res.; 1:20-43.
92. Sekar S, Chandramohan M (2008) Phycobiliproteins as a commodity:trends in applied research, patent and commercialization journal of applied psycology 20; 113-136.
93. Sharma, K.; Schenk, P.M. (2015) Rapid induction of omega-3 fatty acids (EPA) in Nannochloropsis sp. by UV-C radiation. Biotechnol. Bioeng., 112; 1243–1249.
94.Shi X, Zhang X, Chen F (2000) Heterotrophic production of biomass and lutein by Chlorella protothecoides on various nitrogen sources. Enzyme MicrobTechnol 27; 312–318.
95. Shi XM, Jiang Y, Chen F (2002) High-yield production of lutein by the green microalga Chlorella protothecoides in heterotrophic fed-batch culture. BiotechnolProg 18; 723–727.
96. Siems W, Wiswedel I, Sommerburg O, Langhans CD, Salerno C, Crif C, Capuozzo E, Alija A, Bresgen N, Grune T &Eckl P, (2005) Clinical use of carotenoids – antioxidative protection versus prooxidative side effects. In: Free Radicals and Diseases: Gene Expression, Cellular Metabolism and Pathophysiology, NATO Science Series, I: Life and Behavioural Sciences, 367; 177–192.
97. Singh J, Gu S, (2010) Commercialiization potential of microalgae for biofuel production, Renew SustEnerg Rev, 14(9); 2596-610.
98. Singh P &Goyal GK, (2008),Dietary lycopene its properties and anticarcinogenic effects. Comp. Rev. Food Sci. Food Saf. 7; 255–270.
99. Skjånes K, Rebours C, Lindblad P. (2013) Potential for green microalgae to produce hydrogen, pharmaceuticals and other high value products in a combined process. Critical Reviews in Biotechnology. 33; 172-215.
100. Soletto D, Binaghi L, Lodi A, et al. (2005) Batch and fed batch cultivations of Spirulina platensis using ammonium sulphate and urea as nitrogen source. Aquaculture, 243; 217-224.
101. Spolaore, P., Joannis-Cassan, C., Duran, E., and Isambert, A. (2006) Commercial applications of microalgae. J BiosciBioeng 101; 87–96.
102. Srivastava, A.K.,Bhargava P. and RaiL.C., (2005). Salinity and copper-induced oxidative damage and changes in the antioxidative defence systems of Anabaena doliolum. World J. Microbiol. Biotechnol., 21; 1291-1298.
103. Stahl, W., &Sies, H. (2012). Photoprotection by dietary carotenoids: Concept, mechanisms, evidence and future development. Molecular Nutrition and Food Research, 56(2); 287–295.
104. Tartar, A.; Boucias, D.G.; Adams, B.J.; Becnel, J.J. (2002) Phylogenetic analysis identifies the invertebrate pathogen Helicosporidium sp. as a green alga (Chlorophyta). Int. J. Syst. Evol. Microbiol., 52;273–279.
105. Tartar, A.; Boucias, D.G.; Becnel, J.J.; Adams, B.J. (2003) Comparison of plastid 16S rRNA (rrn16) genes from Helicosporidium sp.: Evidence supporting the reclassification of Helicosporidia as green algae (Chlorophyta). Int. J. Syst. Evol. Microbiol., 53; 1719–1723.
106. Tong KL, You FQ, Rong G (2014) Robust design and operations of hydrocarbon biofuel supply chain integrating with existing petroleum refineries considering unit cost objective. ComputChemEng 68;128–139.
107. Ueno, R.; Urano, N.; Suzuki, M. (2003) Phylogeny of the non photosynthetic green micro-algal genus Prototheca (Trebouxiophyceae, Chlorophyta) and related taxa inferred from SSU and LSU ribosomal DNA partial sequence data. FEMS Microbiol. Lett., 223; 275–280.
108. Vigani, M., Parisi, C., RodrÍ´guez-Cerezo, E., Barbosa, M.J., Sijtsma, L., Ploeg, M., Enzing, C., (2015). Food and feed products from micro-algae: market opportunities and challenges for the EU. Trends Food Sci. Technol. 42; 81–92.
109. Vilchez C, Forjan E, Cuaresma M, Bedmar F, Garbayo I, Vega, JM (2011) Marine carotenoids: biological functions and commercial applications. Mar Drugs 9; 319-333.
110. Wang, L., Pan, B., Sheng, J., Xu, J., & Hu, Q. (2007). Antioxidant activity of Spirulinaplatensis extracts by supercritical carbon dioxide extraction. Food Chemistry, 105; 36–41.
111. Ward, O.P., Singh, A., (2005). Omega-3/6 fatty acids: alternative sources of production. Process Biochem. 40; 3627–3652.
112. Winwood RJ. (2013) Recent developments in the commercial production of DHA and EPA rich oils from micro-algae. OCL;20:1-5.
113. Yamaguchi K. (1996) Recentanvances in microalgal biosciences in Japan, with special reference to utilization of biomass and metabolites: a review. J. Appl. Pycol,8;487-502.
114. Zittelli, G. C., F. Lavista, A. Bastianini, L. Rodolfi, M. Vincenzini, and M. R. Tredici. (1999). Production of eicosapentaenoic acid by Nannochloropsis sp. cultures in outdoor tubular photobioreactors. J. Biotech. 70; 299 312.
115. Yamaguchi K. (1996) Recentanvances in microalgal biosciences in Japan, with special reference to utilization of biomass and metabolites: a review. J. Appl. Pycol,8;487-502.
116. Zittelli, G. C., F. Lavista, A. Bastianini, L. Rodolfi, M. Vincenzini, and M. R. Tredici. (1999). Production of eicosapentaenoic acid by Nannochloropsis sp. cultures in outdoor tubular photobioreactors. J. Biotech. 70; 299-312.