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Review Article

THE ROLE OF MICROALGAE IN DIFFERENT BIOTECHNOLOGY APPLICATIONS

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Abstract: *Microalgae's role as an energy source has indeed been extensively studied. However, due to the high cost of producing microalgae biomass, its use as an energy source in the feedstock cannot guarantee its scalability or economic sustainability. Microalgae biomass can be co-processed with other bio-refinery applications to reduce costs and increase sustainability. As a result, it raises the need to evaluate the role of microalgae-biomass beyond its current use. Microalgae have unique characteristics that make them suitable as alternate feedstock for various bio-refinery applications. Microalgae have a one-of-a-kind ability to be used in industrial as well as environmental applications. As a result, this review aims to broaden the area of incorporating microalgae with the other biotechnology applications to improve their long-term viability. Microalgae as just a feed for animals & aquaculture, cosmetics, environmental, fertilizers and medicine, and other biotechnological applications are thoroughly examined. It also discusses the challenges, opportunities, advances, and prospects for microalgae. According to the findings, study funding and a change in microalgae concentration from biofuels produced to biorefinery byproducts can identify microalgae as a potential feedstock. Furthermore, to cover the costs of microalgae-biomass-processing, technology integration is unavoidable. It is expected that even this review would've been beneficial in explaining the future role of microalgae in biorefinery applications. Microalgae have special features that can be used in environmental and industrial applications. Animal & aqua-culture-feed, fertilizer, pharmaceuticals, or cosmetic items are all possible uses for microalgae. Therefore, it necessitates that researchers concentrate on algae co-processing. A unified bio-refinery strategy could be used to increase the value of microalgae-biomass.*

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Introduction

Microalgae are microscopic microorganisms found not just in the water but also on the land. Not just in the aquatic ecology but also in the terrestrial ecosystem. Consequently, they significantly impact many animals that can exist in various environments. For microalgae to grow, they require three key components (Nigam et al., 2011). Sources of light, water, & carbon; get their nourishment from aquatic environments, absorb sunlight, consume carbon dioxide from the atmosphere, and create roughly half of the O_2 in the atmosphere (Singh et al., 2011). Microalgae have an extremely effective biological system that can use sunlight to produce chemical molecules(Richmond, 2004). Microalgae have distinct features that make them commercially valuable. Microalgae species with different biochemical & physiological properties have been found. Microalgae can produce stable isotopes like 13C, 15N, and 2H, which have become a component of the algal biomass used to make various products. Microalgae are a large and undiscovered category of microorganisms and, thus, an untapped source of a variety of vital goods. Microalgae produces several critical biochemicals that are employed as a source of food, fuel, as well as other high-value goods. Microalgae, on the other hand, contain several important biochemical that have yet to be found (Gavrilescu and Chisti, 2005; Raja et al., 2008). Microalgae are economically utilized for nutrition, animal and aquatic feed, cosmetics, and biofertilizers for an increase in available compounds, stable isotope biochemical, & antibiotic, antiviral, antibacterial, or anticancer medication synthesis (Suganya et al., 2016). Anti-oxidants, carotenoids, lipids, enzyme polymers, natural colors, poly-unsaturated fatty acids, toxins, and sterols are all produced by microalgae species that are used in a wide range of industrial goods (Moreno-Garcia et al., 2017)(Oh et al., 2003). They can also make natural colors and a variety of chemicals that can be employed in the pharma industry Acetylic-acids and carotene(Del Campo et al., 2007), agars, carrageenans, agarose, alginates and poly-unsaturated fatty acids (Wen and Chen, 2003) are some of the elevated bioactive substances formed by microalgae. Lutein (He et al., 2005), vitamin B, and keto-carotenoid astaxanthin (Ip and Chen, 2005).

Microalgae can improve the nutritional value of both human & animal diets and play an important role in aquaculture. The processing of microalgae-biomass differs significantly from that of normal bio-refinery feedstocks. Because microalgae develop in liquids, obtaining a substrate for chemical extraction involves many processes. Cultivation, harvesting, & extraction are the three main phases of microalgae-biomass. Bio-refinery is the manufacture of biofuels and high-value co-products from microalgal biomass resources using environmentally friendly bio-processing & chemical techniques (Radmer, 1996). Microalgae can create various chemical compounds employed in food and medicine. Microalgae organic matter has a higher protein quality than vegetables (rice) and wheat, but it is lower than animal products like milk & meat. Sterols are produced by microalgae and are used to treat cardiovascular disorders. Microalgal substances are commonly found in cosmetics for the face & skin. They also make hair care as well as sun protection solutions. Microalgae can be utilized to make a variety of industrial goods, including pharmaceuticals, aquatic feed, pet food, as well as biofertilizers, to name a few. Environmental biotechnology uses microalgae for environmental-toxicant monitoring and bioremediation, including bioassays. Carbon dioxide emissions reduction and sewage treatment are two of the most popular application areas. They are one of the most important sources of bioactive chemicals. Antiviral, antimicrobial, nutritional, anti-cancer, and anti-HIV properties are found in microalgae (Apt and Behrens, 1999).

Biomass extraction from microalgae

The processing of microalgae biomass differs significantly from that of normal bio-refinery feedstocks. Because microalgae develop in liquids, obtaining material for biochemical separation requires many processes. Cultivation, harvesting, & extraction are the three main phases in producing microalgae-biomass(Babu and economy, 2008; Boateng et al., 2008). In agriculture, species selection is perhaps the most fundamental yet crucial phase in determining the system's long-term vitality and sustainability. Robust microalgae species have been reported in this area. Microalgae that are robust are vulnerable to natural stress and can thrive in various environments. The next step in the species selection process is to produce microalgae in a continuous and batch system. Microalgae are grown in open- ponds and lakes, as well as in closed (PBRs) with a tightly controlled environment. Compared to closed growth systems, open cultivation systems' initial and maintenance costs are often lower. Open-system longevity is greater than closed-system longevity, with a maximum biomass output. Closed reactors, however, have a significant benefit over open reactors in terms of flexibility. Closed systems' optimal growing parameters enable the development of microalgae that would not develop in open ponds. It's tough to distinguish the efficiency of PBRs and open ponds since numerous elements must be considered, mostly during the assessment. One of the most significant aspects is the micro-algal organism to be grown and the productivity calculation method utilized. For the monitoring of microalgae productive factors, 3 parameters are usually utilized (Richmond, 2004).

Volumetric production (VP) is assessed in grams per liter per day, agricultural production (AP) is assessed in grams per square meter per day, as well as illuminated-surface-productivity (ISP) is calculated in grams per square meter per day. The type of microalgae species, nutrients available, environment, production mode autotrophic and heterotrophic, but, most crucially, the final application of biomass all influence the cultivation system used(Maxwell et al., 1985). The doubling time & biomass production of microalgae are used to gauge their progress. The production of biomass is inversely related to the density of the culture. Optical density is used to stabilize cultural density. The wavelength of absorbance varies with the color of various microalgae species. Most of the absorption range of microalga is between (600 to 700 nm). Total cell counting and particle analysis can also determine the growth rate. These techniques are not very accurate. Poor growth rates and, as a result, low biomass production hamper microalgae culture. Various factors influence biomass productivity, including microalgae species, nutrients, sunlight, temperature, pH, mix, concentration, and culture purity. The growth conditions must be tuned to produce optimal biomass productivity. Microalgae can explore their surroundings to conserve resources and efficiently use them. Photosynthesis necessitates an adequate amount of carbon source and light for microalgae cultivation(Moheimani, 2005)**.** Microalgae require carbon sources (such as sugar, protein, and fat), salts, nitrogen, vitamins, and phosphorous. Balance operational parameters (like molecular O2, Carbon dioxide, pH level, temp, sunlight intensity, and product or by-product removal) are also critical. Operating conditions' influence and interrelationships are critical to understanding when producing biofuels using microalgae. Even at an industrial level, it is critical to successfully control the mixture of microalgal strains (De Pauw et al., 1984).

Micro-algae cultures treated properly resist biological infection(Chisti, 2007). Microalgae may grow in various metabolic environments, including autotrophic, microtrophic, photo-heterotrophic, and heterotrophic. Strains include *Arthrospira platensis*, (Chlorella-Vulgaris) or *Haemato-coccuspluvialis* can develop in photo-autotrophic, mixotrophic, and as heterotrophic environments. Other microalgal species, such as *Scenedesmus acutus* and *Selenastrum capricornutum*, can develop in photo-autotrophic, phototrophic, or heterotrophic environments (Chojnacka and Marquez-Rocha, 2004). Metabolic shifts occur in microalgae as a response to changes in environmental parameters. The algal metabolic process is also affected by changes in pH, which is determined by the stoichiometry of microalgal growth. The harvest is the next phase of the production cycle.

Microalgal biomass is isolated first from growth media during harvest. It is among the most expensive phases in manufacturing micro-algal bio-diesel, accounting for 20–30% of the total cost (Grima et al., 2003). A suitable harvesting procedure is necessary to extract significant amounts of water and handle huge microalgal biomass. Filtration, ultra-filtration (centrifugation), and sedimentation are among the primary procedures for harvesting, which are occasionally combined with flocculation and flocculation–flotation. Product quality, as per Richmond, is among the most important factors to consider when choosing a good harvesting technique. Cultivation of low-value gravity deposition is accompanied by flocculation of the products. Conversely, to recover higher-value items, such as those utilized in the food industry. Constantly operational centrifuges are suitable for aquaculture because they can extract high amounts of biomass (Grima et al., 2003). Another significant factor to consider when choosing a harvesting process is its ability to optimize the biomass concentration or required moisture level in the final concentrate. Gravity-sedimentation creates more dilute waste than biomass collected by centrifugation which considerably impacts downstream processing costs. Because thermally dry is much more costly than manual dewatering, an end concentrate with a larger solids content is required to reduce total production costs. Dehydrating (biomass) is a typical procedure used to extend the shelf-life of the finished product (Richmond, 2004).

Sun drying is not regarded as an efficient drying technique for micro-algal biomass due to increased water levels, and spray drying is not even an economical option for low-value goods. Drying the microalgae is followed by cell disruption, which releases the compounds in the cells. Various approaches can be used to break microalgal cells based on the cell wall's characteristics and the intended products' nature. Non-mechanical procedures include acidic, basic, and enzyme reactions, organic compounds, freezing, osmotic shock, and mechanical processes such as autoclaves, bead mills, spray drying, ultrasounds and cell homogenizers. Separation is a major commercial barrier in the production of biofuel, meals, & feed, as well as high-value goods, including polysaccharides & -carotenes. Extraction is difficult to generalize since it is a highly particular process that depends on the desired results. Solvent extraction is often used to extract (lyophilized) biomass since it is a quick and efficient approach that reduces deterioration. A variety of solvents such as 96%, hexane, or a combination of hexane–96% can be utilized to get pure fatty acids. (Richmond, 2004)

Microalgae have a wide range of applications.

Microalgae can produce a wide range of biochemical employed in culinary and medical studies (See Figure 1 and Table 1). Microalgae can also produce a variety of critical biochemicals that have yet to be identified (Brennan et al., 2010)**.** Microalgae are a valuable renewable source that can be used for various commercial purposes, including sewage treatment and CO_2 mitigation. Human diet, animal as well as aquatic life feeding. Cosmetic items high value chemicals. Astaxanthin, carotene, and phycobiliproteins are pigments (Raja et al., 2008)**.** Antimicrobial, antibacterial, anticancer, and antiviral medicines are synthesized. Arthrospira, Dunaliella, Iisochrysis, Chaetoceros and Chlorella are some of the most common microalgae used to make commercial products (Lee, 1997).

Products for human health or nutrition

The health advantages of microbial communities like microalgae have been extensively researched in recent years, particularly since the introduction of probiotics. Microalgae mass has a higher protein value than wheat, vegetables and rice, but it is lower in animal protein, like milk and meat. Sterols are produced by microalgae and are used to treat cardiovascular disorders. Spirulina spp. is thought to produce clionasterol, which aids vascular cells in avoiding illness (Barrow and Shahidi, 2007). Microalgae also create several antioxidant chemicals, including astaxanthin, -carotene, and mycosporines, as well as a few additional carotenoids. These antioxidant substances can help protect against oxidative damage. Spirulina-platens and Spirulina-maxima are the most common Spirulina species found in human food, a dietary source that boosts immune function and is farmed commercially. It also boosts the number of lactic acid microbes, which helps the body's hormones. Other disorders treated with spirulina include arthritis, anemia, diabetes, cancer, and cardiovascular disease. It has been suggested that chlorella can be used as a food source. Chlorella has a lot of nutrients. Carotenoids, and several vitamins, are abundant in proteins (51 to 58 percent dry weight)(Becker, 2004). Microalgae also include glucan, an immune system booster.

Free radicals as well as blood lipids are reduced by this stimulator (Iwamoto and phycology, 2004). Chlorella is also a type of algae. Chlorella is a type of algae used to make a product named 'Chlorella Growth-Factor, which promotes lactic growth of bacteria in the system. According to them, Chlorella has numerous health benefits (Laliberte et al., 1997). Increased haemoglobin levels, for example, can lead to lower blood - sugar levels. It acts as a hepato-protective agent, protects against kidney failure, and increases the development of intestinal flora during hunger as well as ethionine intoxication. Chlorella species create metabolic products that boost the immune system, inhibiting Candida albicans and Listeria mono-cytogenes growth. In animals, chlorella compounds stimulate the generation of splenocytes & cytokines, as well as other immunological responses (Barrow and Shahidi, 2007).

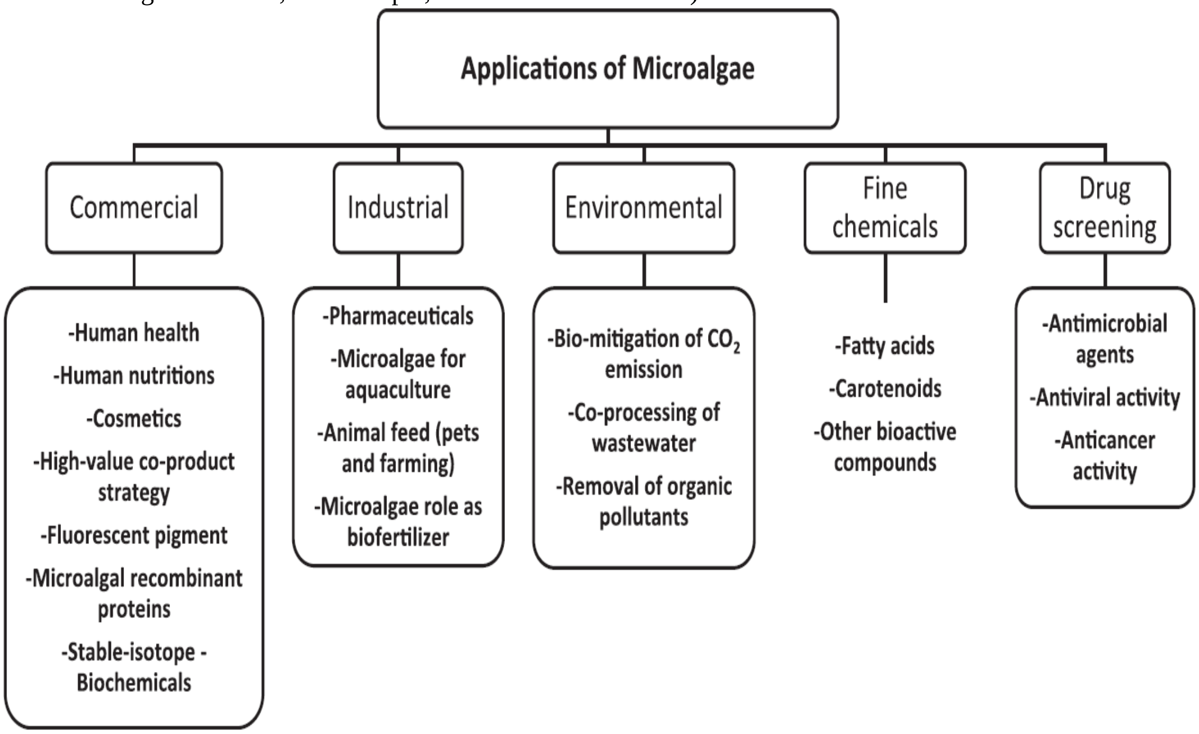

Figure 1: Flow chart depicting microalgae applications in several fields (Priyadarshani and Rath, 2012; Suganya et al., 2016)

C. ellipsoidea was used by Japanese scientists. Food goods, such as bread, rolls, ice cream, powdered milk, noodles, green tea, soaps, cookies & soy sauce, are among the items on the menu. Dunaliella sp. is a kind of Dunaliella. (Particularly, *D. salina* is also regarded as a food source. They are abundant in lipids & proteins, as well as glycerol & carotene, and have unique abilities. Starting to grow brackish, Dunaliella-carotenoids are a type of carotene made by the bacteria Dunaliella. Sp. as well as Spirulina sp. Compared to cancer cells, they are much more effective than β – carotene (Canela et al., 2002). *Nostoc sphaeroides* have already been utilized in creating traditional Chinese medicine to treat hypertension. Diarrhea, hepatitis, and Nostoc sphaeroides are common components of pharmaceuticals(Barsanti and Gualtieri, 2014). Muriellopsis sp., on the other hand, generates a high quantity of carotenoids, such as lutein, that are utilized to treat degenerative illnesses (Del Campo et al., 2007). Protein, fibre, enzymes, and carbohydrates make up the mass of microalgae. Microalgae can also produce vitamins (A-B1-B2-B6, & C) and minerals (iodine, potassium, calcium, magnesium, iron, and niacin). Because it contains all of the necessary nutrients, microalgae is a key dietary source in parts of Asia, particularly China and Japan. The nutritional supplements supplied by microalgae are the focus of microalgae - based biotechnology. Only a few microalga sp are used for human consumption due to strict food safety laws, consumer preferences, and commercial variables (Pulz et al., 2004)

Tablets containing microalgae for nutrition are available liquids as well as capsules. It's also found in various snack foods(Liang et al., 2004). Foods, candies like gum, pasta, or beverages. Microalgae are microscopic algae. They have a variety of chemical properties that allow them to be employed in a variety of applications. Natural food flavour enhancers and nutritional supplements(Borowitzka, 1999; Soletto et al., 2005). The following are the most important microalgae species consumed by humans: *Chlorella*, *Aphanizomenon*, *Spirulina*, *Dunaliella*, and *Nostoc* are all examples of algae. *Dunaliella*, *Spirulina* (Vonshak, 1997) and other algae are commonly used to make commercial goods. These microalgae-based products can be employed as a multivitamin or a food source, and they have the potential to generate hundreds of millions of dollars(Apt and Behrens, 1999). Vitamins and vitamin intermediates, such as tocopherol, ascorbic acid & riboflavin, are also found in microalgae. Protein makes up 55 to 70% of the dry biomass in Arthrospira, giving these microalgae a significant nutrient benefit. And it is used as a source of food in Asia & South America because of its great nutritional content. Most businesses in Israel and Australia cultivate Algae sp. and *Dunaliella* sp. as vitamin A and C-rich food supplements, including powders(Brown et al., 1997). *Spirulina-platensis* is often regarded as the most nutrient-dense food on the planet. Polyunsaturated fatty acids, proteins, vitamins, phenolic (Colla et al., 2007; Ogbonda et al., 2007), or pigments are all abundant(de Oliveira Rangel-Yagui et al., 2004).

Chlorella can also be used as a source of food. Chlorella is primarily promoted as seafood and a nutritious supplement. Chlorella's co-products are employed for fruit as well as vegetable preservation. *Dunaliella-salina*, on the other hand, is an important microalga. It's mostly utilized to make photosynthetic pigments as well as beta-carotene. Vitamin C supplements & orange dye are two of the most common uses for beta-carotene. The *Scenedesmus* species is a nutritious source of food as well. They aren't, however, commercially produced. Their extraction can be used in various dishes, including desserts, ravioli, fruit puddings, noodles, and soups**.** The cyano-bacterium *Nostoc* is also other microalgae utilized as a source of food. It has been a food source in China for over 2000 years (Sigamani et al., 2016). These algae are considered a healthy food because they are high in protein and pigment.

Table: 1 Microalga and their habitat

Microalgae	Habitat	References
Spirulina platensis	fresh	(Chu et al., 2002)
Dunaliellasalina	marine	(Ben-Amotz and Avron, 1992)
Nostocpunctiforme	fresh	(Priyadarshani and Rath, 2012)
Spirulinaplatensis	marine	(Chu et al., 2002)
Parietochloris incise	fresh	(Cohen and Cohen, 1991)
Protothecamoriformis	Fresh-marine	(Apt and Behrens, 1999)
***Cylindrospermum* sp.**	Marine	(Hills and Nakamura, 1978)
Nostocmuscorum	fresh-marine	(Barsanti and Gualtieri, 2014)
Porphyridiumcruentum	fresh	(Cohen and Cohen, 1991)
Chlorella vulgaris	Fresh-marine	(Apt and Behrens, 1999)
***Spirulina* sp.**	Marine	(Sajilata et al., 2008)

Cosmetics

The algae Arthrospira & Chlorella are used to make skincare. LVMH or Daniel Jouvance, for example, have their microalgae-based production technology. Microalgal extract is commonly found in cosmetics for the face & skin. Hair care, as well as sun protection solutions, are also made with them. Sun protection, skin care, & hair care are all made with *Arthrospira* & *Chlorella*. *Ascophyllumnodosum*, *Alaria-esculenta*, *Chondrus crispus*, *Spirulina platensis*, *Mastocarpus stellatus*, *Dunaliella salina*, *Chlorella vulgaris*, and *Nannochloropsis oculata* are among the most common algae used in cosmetics manufacture. Antioxidants, thickening agents, and water-binding agents are frequently used for microalgal constituents in cosmetics. This substance has outstanding skin-tightening qualities and was used. The ingredient from *D. salina* was used in another product called Pepha-Ctive, which can accelerate cell growth and improve the skin's energy metabolism (Stolz et al., 2005).

Microalgae bio-refinery

Bio-refinery is the manufacture of biofuels and high-value co-products from microalgae-based biomasses using environmentally friendly bio-processing & chemical methods. (Shin et al., 2016). Compared to energy-crop and petroleum technology and enterprises, microalgae bio-refinery is very recent. However, genetically modification, the inclusion of novel solvent combinations (Shin et al., 2016), the employment of nano-technologies(Seo et al., 2016), the utilization of numerous useful microalga bio-products (Chew et al., 2017), and the adaptation and dissemination of cell biology knowledge can help (Praveenkumar et al., 2015) Microalgal-pigments, which are found in microalgae biomass photosynthetic systems, are employed for commercial purposes. The most frequent pigmentation is phycobiliproteins. Microalgae pigments could be utilized in cosmetics, food, medicines, and natural dyes. Protein can also be found in algae biomass. C-phycocyanin, carotene and astaxanthin are three of the most valuable co-products. There are various uses for -carotene. They're utilized in food dye, as a supply of pro-vitamin A, and so as a cosmetic ingredient (Suganya et al., 2016)

Another protein, astaxanthin, is widely employed in the cosmetics, nutraceutical, food, and feeding industries. It also has anti-oxidant characteristics(Waldenstedt et al., 2003). Protects against UV rays, strengthens the immune system, is a hormone precursor, a provitamin A supply, and acts as an anti-inflammatory agent (Cheng et al., 2016). It could be used to dye fish muscles because it is a powerful coloring agent. *H. pluvialis* is a key source of astaxanthin (Guerin et al., 2003), accounting for 1–8% of its mass (Hejazi and Wijffels, 2004). Due to increased deposits of natural dyes, customer demand, and regulatory standards, natural astaxanthin has an advantage over synthetic astaxanthin. The price of natural astaxanthin per kilogram is €7150 (Rosenberg et al., 2008)**.** Novel transformation approaches for Chlorella (Dawson et al., 1997) and diatoms (Apt et al., 1996). Microalgae biomass produces polyunsaturated fatty acids, which are crucial for human nutrition & health (Wang et al., 2015). Until now, recombination approaches have played no significant role in the manufacture of commercial products. The significance of recombinant technology will be expanded due to public and government awareness of innovation and continued advances in technology development for algae systems. Algae, in addition to glycerol & glucose, can produce stable isotopically labelled chemicals, which are utilized to study macromolecular connections and reveal metabolic processes (He et al., 2005). When 13C glucose is added to algal growth media, tri-glycerides containing 13C-DHA can be produced(Brossard et al., 1994). Based on its nature, (13C) galactose is recommended over liver biopsy in assessing liver functions (BEHRENS and KYLE, 1996). Another viable iso-topically labelled molecule generated by (*Chlamydomonas*) is 13C-xylose, which accounts for 25% of its biomass. Commercially, (13C) xylose is utilized to detect microbial growth in the intestine (Dellert et al., 1997). Stable isotopically labelled microalgal products are also employed in breathalyzer tests and the diagnosis of medical disease & dysfunction. Likewise, *Neochloris* produces 13C-labeled blended triglycerides, also known as Hiolein, which is then used to diagnose fat malabsorption (Lembcke et al., 1996).

Industrial applications

Pharmaceuticals

Microalgae have gained prominence as a natural source of bioactive molecules due to their ability to manufacture bioactive chemicals via biological processes that are difficult to synthesize utilizing chemical methods. Antibiotics, toxins, growth regulators, algicides, and pharmacologically active chemicals could all be produced by microalgae (Borowitzka, 1995). Some microalgae can produce chemically varied antibiotics (alcohols, bromophenols, polysaccharides, and terpenoids). Microalgae, too, create several hepatotoxic as well as neurotoxic chemicals. These molecules could also be useful in pharmacy (Metting, 1996). Many blue-green microalgae, including *Ochromonas* sp, (*Prymnesium parvum*), and Ochromonas sp, can create toxins that can be exploited in the pharmaceutical business. *Chlorella*, (*Spirulina*) and *Scenedesmus* are the most common microalgae-based species utilized as human supplementation. Microalgae increase immunological response, weight control, skin, fertility and coat lustre. However, prolonged use at high doses, particularly when using cyanobacteria, could be detrimental(Spolaore et al., 2006).

Aquaculture microalgae

For aquaculture species, the food supply is an essential nutrient. Microalgae are the primary producer in the food supply chain. Microalgae contain nutrients that are necessary for larval as well as adult mammal development and sustainability. Microalgae are important for aquatic creatures' physiological growth & outward appearance(Certik et al., 1999). Chlorella, Tetraselmis, Phaeodactylum, Chaetoceros, Skeletonema, Isochrysis, Pavlova, and Thalassiosira seem to be the most commonly utilized genera for aquatic livestock feed (Muller-Feuga, 2000). As well as for enhancing the immune responses of fish (Brown et al., 1997). Algae is also used to culture several zooplankton species. Brine shrimp and rotifers are two examples of food sources in crustacean and finfish aquaculture (Brown et al., 1997). Rotifer Brachionus is cultivated using food & Chlorella spp. Dunaliella salina and Haemato-coccus are similar. Pluvialis is often used in cell culture as a group of energy pigments. Salmonids, prawns, & ornamental fish are some of the most common types of fish. There have been significant efforts to have food sources. On the other hand, high production costs and the possibility of toxic contamination have challenged employing algae for food production.

Animal nutrition (pets and farming)

Microalgae have been demonstrated to be effective as a food supplement in many studies (Becker, 2004). Aquarium fish, cats, horses, dogs and decorative birds are just a few of the creatures that eat Arthrospira. Microalgae have a beneficial effect on the physiology of animals. The liver can also be used as a source of protein in chicken feed at a rate of 5–10%. But, feeding microalgae to chickens for an extended period and at larger concentrations will also have negative consequences. Microalgae mostly negatively impact the coloring of broiler skin, shanks, and egg yolk. Some algae species have been used as livestock feed supplements, particularly in Japan. And over 50% of Arthrospira is farmed for the manufacturing of feed additives, and 30% of current algae production is being used to produce animal feed (Becker, 2004)

Microalgae's uses as a bio-fertilizer

Pyrolysis at 350–700 °C in the inert atmosphere can transform microalgae into biogas, micro, and charcoal (Goyal et al., 2008). As a result of this procedure, biochar is produced. Biochar can be utilized as a biofertilizer and a carbon-sequestering material (Marris, 2006). It can also be utilized as a source of processing fuel for biofuel conversion. Reducing carbon emissions by 84% is possible by employing biochar in the carbon capture process. As a result of this sequestration, emission biofuels can be produced(Lehmann, 2007)**.** Microalgae are utilized as synthetic fertilizers as well as biofertilizers in farming. Blue-green microalgae may enhance soil physicochemical characteristics while also increasing biomass yield & reducing nitrogen fertilizer consumption. Biomass can also boost residual nitrogen as well as carbon in the ground, as well as enhance pH & electrochemical performance. Microalgae can also improve wheat quality by increasing protein content. Microalgae belonging to the genera Nostoc, Tolpothrix, Aulosira and Anabaena may fix nitrogen and thus are utilized for paddy plant growth in upland and lowland environments. According to some algologists, the technique utilized to produce algae is quite simple to operate & adaptable. The sales of algae bio-fertilizer provide additional revenue for the technology. Algal production is often done in four ways: a) in a pit, b) in a tank or trough, c) in a nursery, and d) in the field. The first two are mostly used for small-scale farming, whereas the latter are utilized for large-scale commercial output (Lehmann, 2007).

Applications in the Environment

Environmental biotechnology uses algae for environmental toxicant monitoring, phytoremediation, or bioassays. Pollutants released into waste without adequate treatment would pose a significant public health risk. HRAPs (high-rate algae ponds) are thought to be a cost-effective technique for water treatment (Phang et al., 2001). Moreover, the biomass produced by HRAP could be used for both animal feed and biofuel generation. *Spirulina platens* is cultured in HRAP removed 99% of the phosphorus from an-aerobically digested starch plant waste(Phang et al., 2000). Chlorella effectively cleaned wastewater in HRAP (Lim et al., 2010). Some research has investigated using mixed algae species to clean waste. A group of five microalgae has demonstrated wastewater treatment in HRAP (Mustafa et al., 2012). Using immobile microalgae can improve the elimination effectiveness of toxic compounds(De-Bashan and Bashan, 2010). *Chlorella vulgaris* trapped in alginate beads was shown to be effective in removing colors from textile colors (Chu et al., 2009). It was discovered that immobile *Chlorella vulgaris* and *Scenedesmus-obliquus* were effective in the continuous elimination of nitrogen & phosphate from home waste (Ruiz-Marin et al., 2010). Compared to immobile algae alone, immobilized algae and bacteria remove greater ammonium (De-Bashan et al., 2002). nitrate, or phosphate from sewage (De-Bashan et al., 2002).

Table: 2 Microalgae and their Applications

Microalgae	Applications	References
Aphanizomenon flos aquae	Human nutrition	(Yamaguchi, 1996)
Spirulina sp	Infant formulas and Nutritional supplements	(Sajilata et al., 2008)
Isochrysis galbana	Animal Nutrition	(Cohen and Cohen, 1991)
Chlorella vulgaris	Health food and food supplement	(Apt and Behrens, 1999; He et al., 2005)
Porphyridium cruentum	Pharmaceuticals, cosmetics and nutrition	(Cohen and Cohen, 1991)
Spirulina platensis	Health foods	(Chu et al., 2002)
Parietochloris incise	Food additives and nutraceuticals	(Borowitzka, 1988; Cohen and Cohen, 1991)
Prototheca moriformis	Human nutrition	(Apt and Behrens, 1999)
Cylindrospermum sp.	Growth promoting	(Hills and Nakamura, 1978)
Nostoc muscorum	Growth promoting	(Barsanti and Gualtieri, 2014)
Nostoc punctiforme	UV-Screening	(Priyadarshani and Rath, 2012)
Dunaliella salina	Human nutrition	(Ben-Amotz and Avron, 1992)
Spirulina platensis	Health food and cosmetics	(Chu et al., 2002)

Microalgae are frequently utilized in environmental contaminant bioassays. *Pseudokirchneriella subcapitata*, *Isochrysis galbana*, *Chlorella* species and *Dunailella tertiolecta*, are examples of microalgae that can be used for this (Ismail, 2004; Vannini et al., 2011). Microalgae can also determine whether nutrients (phosphorus & nitrogen) are present in freshwater habitats. The greatest instances are the tropic algae *Ankistrodemsus convolutes*, *Scenedesmus quadricauda*, and *Chlorella vulgaris* (Vannini et al., 2011).

CO_2 emission bio-mitigation in algal-cultivation

The release of CO_2, a green-house-gas into the atmospheric environment by burning fossil fuels is a severe environmental concern. To retain CO_2, many strategies (such as filtering and other mechanical and chemical procedures) have been explored. Therefore, biological methods are being explored as a viable option for reducing CO_2 emissions. Algae fix CO_2 photosynthesis ally (Huntley et al., 2007; Sheehan et al., 1998). Algae to collect CO_2 from power-plant exhaust appears to be an effective technique for avoiding greenhouse-gas emissions into the atmosphere. When microalgae are used for biofuels, CO_2 emissions from energy plants may be offset by carbon fixation through photosynthetic activity, resulting in a net carbon dioxide release of zero. As a result, it will depend on the technology to convert it into a biofuel efficiently. Typically, the more carbon-consuming a process is, the more CO_2 is produced during the fuel's life cycle. Microalgae can withstand high CO_2 concentrations in the environment. One of the key advantages of using algae for biofuel is that it feeds air stream production (Chang and Yang, 2003). It provides more efficient Carbon dioxide content capture (5 to 15%) from flue and flaring gasses (Hsueh et al., 2007) than terrestrial sources. Plants ordinarily absorbed only 0.03 to 0.06% of Carbon dioxide from the environment. As a result, the benefit of employing microalgae is clear. CO_2 abatement (Li et al., 2008). Microalgae are generally capable of digesting a variety of nutrients. CO_2 from the environment, Carbon dioxide from power plants, and soluble carbonates are all sources of CO_2.

Many microalgae are capable of absorbing carbon dioxide from soluble carbonates. Microalgae Mono-ruphidium-minutum produced substantial energy by utilizing existing flue gas containing high levels of carbon dioxide and sulfur or nitrogen oxides. Compared to plant species, Chlorophyta, and green algae, has a 10 to 50 times superior solar power absorption efficiency and CO_2 fixation (Wang et al., 2008). *Chlorococcum littorale*, a marine alga, showed a noteworthy resistance to high CO_2 concentrations of up to 40% (Iwasaki et al., 1998). Chlorella strains from hot springs are also resistant to high CO_2 concentrations (40%) and temperatures of 42 °C (Sakai et al., 1995). Certain Chlorella species have been shown to flourish in environments with CO2 levels as high as 40% (v/v). Chlorella sp. removed 10–50% carbon dioxide, and increased flue gas input into algae lowered the efficiency of carbon dioxide absorption. On something like a regular basis, *Spirulina* species fixed 53.3% of Carbon dioxide for 6% Carbon dioxide (v/v) as well as 45.6% for 12 CO_2 (v/v) from the supplied flue gas, with the highest possible bio fixation rate of 37.9 percentage points for 6% CO_2 (v/v) (Doucha et al., 2005)**.** *C. kessleri* & *S. obliquus*, 2 algae species, can develop in a mixture with up to 18% CO_2 (v/v). In contrast, *S. obliquus* exhibited fixation rates of 28.1% and 13.6% for 6% and 12% CO_2 (v/v), respectively (De Morais and Costa, 2007). The potential benefits of reusing CO_2 for algal plant growth through coal & microalgae are to minimize the overall consequences of energy production, such as decreases in dioxide, methane, SOx, and NOx particles (Kadam, 2002).

The treatment of waste and the cultivation of microalgae

Algae can treat sewage water. Small-to-municipal sewage treatment systems on a medium scale and maturation ponds could be used to do this. One instance of this is the innovative Inactive Integrated Sewage Pond Systems is the name of system (AIWPS) (Oswald and Technology, 1991) technology (Oswald and Green, LLC). Microalgae can be utilized to recycle animal waste because they are microalgae. Wastewater is accustomed to having a fantastic personality (Ogbonna et al., 2000; Olguín, 2003). Anaerobic treatment of organic waste; usually, the microbiological makeup of sewage treatment ponds isn't known specific. As a result, specific disease-prone species can also be used. Not just for phytoremediation, as well as for microalgae cultivation, but for using algae for aquatic environments and wastewater treatment, which may be the best solution. Microalgae may consume organic substances like nitrogen and phosphorus commonly found in industrial waste. Biomass can also help to mitigate the detrimental effects of sewage as well as industrial effluent containing metabolic wastes from water purification or fish farming. By eliminating nitrogen and phosphate from sewage, algae can also help to prevent eutrophication. Microalgae can be grown as heterotrophic allies for cleaning food industry effluent, a promising approach to producing microalgae and cleaning the environment(Mata et al., 2010)**.** Nutrient-rich sewage for microalgae development and sewage treatment holds a lot of promise. Organic pollutants, chemicals, heavy metals, and pathogens can be removed from wastewater and biofuel production due to something like these heavy metals, and contaminants can be successfully removed from waste by microalgae. *Chlorella*, *Scendsmus* and *Ankistrodesmus densus*, can be used to remove organic contaminants from the pulp & paper sectors and

Furthermore, microorganisms in heterotrophic microalgae can grow out of control due to their rapid growth rate. Algae and bacteria can be joined to generate consortia that can be used to treat sewage to solve this problem. Microalgae can generate photo-synthetic oxygen, reducing the need for external sewage aeration. This oxygen is needed in the anaerobic bio-degradation of VOC pollutants, which must be volatilized aerobically because mechanical aeration cannot evaporate these volatile contaminants (Munoz and Guieysse, 2006). Microorganisms can aid bacteria in the breakdown of harmful organic contaminants by producing oxygen. The algae biomass generated during water treatment is not utilized for human or animal use. This can, therefore, be utilized to produce high-value compounds. Most significantly, the algal-bacterial consortium can be used to reduce CO2 emissions and produce biomethane. Microalgae are utilized as a low-cost bioremediation agent for heavy metals. Brown algae, including alginate fucoid, is the best substrate for removing heavy-metal toxicity. (Perales-Vela et al., 2006)Toxic substances are also removed from wastewater using microalgae (Perales-Vela et al., 2006).

By-products with added value

Microalgae may also produce a variety of slightly elevated chemical compounds, like antioxidants, fatty acids, -carotenes, polysaccharides, pigments and triglycerides, which are utilized in various industries, including biofuels, cosmetics, medicines, nutraceuticals, as well as functional foods. Agar & carrageenan are all produced by microalgae and thus are widely applied as viscosity modifiers in the food and pharmaceutical industry. Marine algae generate poly-unsaturated fatty acids such as arachidonic acid, linolenic acid, and docosahexaenoic acid (Borowitzka, 1988; Cohen and Cohen, 1991). these important fatty acids are utilized to cure a variety of ailments as well as provide nutrition for humans (Okuyama and Medicine, 1992). Many microalgae spp. can create large amounts of long-chain (omega-3 & omega-6 fatty acids) in their oils and lipids. LC-PUFA is essential for human health as well as nutrition. Certain LC-PUFA is vital for newborns' mental, physical, including visual development. Microalgae-based extracts could not be utilized for the commercially synthesizing EPA and AA against other sources. DHA is currently only one algal PUFA that's also manufactured at a commercial level. And over 40 kinds of carotenoids and xanthophyll can be produced by microalgae(Jin et al., 2003).

Table: 3 Microalgae and their products

Microalgae	Products	References
Spirulinasp	γ -Linolenic acid (GLA)	(Sajilata et al., 2008)
Chlorella vulgaris	Biomass, Ascorbic acid	(Apt and Behrens, 1999)
Porphyridium cruentum	Polysaccharides	(Cohen and Cohen, 1991)
Spirulina platensis	Phycocyanin	(Chu et al., 2002)
Parietochloris incise	Arachidonic acid (AA)	(Borowitzka, 1988; Cohen and Cohen, 1991)
Prototheca moriformis	ascorbic acid (Vitamin C)	(Apt and Behrens, 1999)
Cylindrospermum spp.	Vitamin B12	(Hills and Nakamura, 1978)
Nostocmuscorum	Vitamin B12	(Barsanti and Gualtieri, 2014)
Nostoc punctiforme	Scytonemin	(Priyadarshani and Rath, 2012)
Dunaliella salina	powders β-carotene	(Ben-Amotz and Avron, 1992)
Spirulina platensis	Phycocyanin, biomass	(Chu et al., 2002)

All microalga spp. and crops contain -carotene, the most basic carotenoid. Another form of carotenoid generated from algae is astaxanthin. It's utilized in agriculture, animal health, cosmetics, pharmaceuticals, and nutraceuticals(Smidt, 2000). Phycobiliproteins are water-soluble photosynthesis pigments found in microalgae such as red algae, cryptophytes, glaucophytes and cyanobacteria. These are proteinaceous, complicated, water-soluble, red and blue in color, & complex. They're mostly utilized as food colorants, but they're used in the cosmetic as well as pharmaceutical industries. Phycobiliproteins in algae capture light energy inside the (495 to 650 nm) range and transport it to the photosynthesis respiratory chain cell. Phycobiliproteins are divided into 3 categories: allophycocyanin, phycoerythrin and phycocyanin. The levels of phycobiliproteins can be affected by environmental factors such as light quality as well as intensity. For example, the phycocyanin content of Spirulina-platensis can range from 0.11% to 12.7% by dry weight, depending on light intensity (Chu et al., 2002).

Drug screening by using microalgae

Microalgae are varied micro-organisms that can be widely distributed range of ecological environments. They are one of the most important sources of bioactive chemicals. Microalgae have antiviral, anti-HIV, and antibodies, Din-flagellates and blue-green-algae, for example, produce highly toxic toxins (Codd and Technology, 1995). Microcystins are a type of toxin. A collection of circular peptides produced by blue-green algae has an LD50 of 50 grams/kilogram (Rinehart et al., 1994). Similarly, dino-flagellates make brevetoxins as well as saxitoxins. Humans & fish are both affected by these toxins(de Souza Berlinck, 1995).

Antimicrobial activity of microalgae

Many microalga extracts and extracellular products, have antimicrobial properties because they create antifungal, antibacterial, antibacterial and antiprotozoal compounds in nature. These anti-microbial chemicals can be utilized in agriculture as well as for the development of novel antibiotics. Indole (2,3-a) carbazoles generated by Tolypothrix-tjipanensis are comparable to those made by actinomycetes and slime-moulds, but without the pyrrole 3,4-c ring (Bonjouklian et al., 1991). Microalga toxins can be involved in managing the environment. Scytonemahofmanni, for example, an algaecide (Fernández et al., 2003), *Fischerella muscicola* releases fischerellinis (Gross et al., 1991), Oscillatoria species. Produces an unidentified extracellular product (Chauhan et al., 1992). all of which can be used to reduce algal blooms. Cyanobacteria, too, have herbicidal properties. The microalga cell, as previously stated, has antimicrobial activities against both gram-positive and gram negative bacteria. Antifungal properties can also be found in dinoflagellates, green algae, and diatoms. *Prymnesium parvum*, blue-green-algae and Ochromonas species produce microalga toxins that are utilized in pharmaceutical goods(Katircioglu et al., 2006).

Microalgae used for antiviral activity

Microalgae's ability as an anti-viral agent has yet to be completely realized. Microalgae, however, have only recently been discovered to have anti-viral properties. Anti-respiratory-syncytia virus, as well as HIV-1 infections, were all suppressed by cyanobacteria. Cyanobacteria also developed cyanovirin-N, a new chemical that blocks the interaction between viral glycoprotein gp120 & CD4(Dey et al., 2000). Making it possible antiviral agents for HIV. The anti-viral activity of cyano-bacteria isolates surpasses 5% of Herpes simplex-virus type-II. However, less than 5% of the extract displays antiviral activity towards (RSV)(Lau et al., 1993) discovered that cyanobacteria suppressed avian myeloblastosis viral reversed transcription as well as human immunodeficiency virus type 1. Sulfo-lipid active-anti-AIDS chemicals are yet to be discovered. *Spirulina-platensis* generates calcium spirulina, as well as a sulfated-polysaccharide with antiviral properties. They prevent enveloped viruses, including Herpes simplex, human cytomegalovirus and measles, from entering the cell(Ayehunie et al., 1998). Similarly, red algae, including Porphyridium, produce a sulfated polysaccharide that inhibits the adhesion of HSV-1, HSV-2, and Varicella-zoster viruses to the surface (Huleihel et al., 2001).

Anti-cancer activity of microalgae

Bioactive chemicals found in microalgae have anticancer properties. Anticancer properties of cyanobacteria isolated from various environments. *Poteriochromonas-malhamensis*, for example, creates a chlorosulfonic lipid that suppresses tyrosine kinase function. Similarly, *cyanobacteria* produce anti-cancer bioactive chemicals; these chemicals induce apoptosis or alter cell signaling by activating protein-kinase C group signaling enzymes (Sithranga Boopathy and Kathiresan, 2010). *Scytonema-pseudo-hofmanni* produces scytophycins, polyketide-derived macrolides that suppress various mammalian cells, especially epidermoid carcinoma cell lines. These chemicals can protect against lung cancer and lymphocytic leukemia if injected intra-peritoneal. *Scytonemapseudo-hofmanni* also produced anti-cancer chemicals such as *toyoca-mycin* and *tubericidin*, and *Scytophycin B. Nostoc* (ATCC 53789) is another algae that produce cryptophytes. This compound is efficient at killing cancer cells (Schwartz et al., 1990).

Future perspective

Microalga biofuel synthesis can be more cost-effective by incorporating a high-value coproduct approach. Future advancements in biofuel technologies' micro-algal production and market conditions, may make biofuels more economically viable(Stephens et al., 2010). Microalgal lipids tend to turn into biofuel. In contrast, microalgae-based biomass is used to produce useful products, including carbohydrates, polyunsaturated fatty acids, and proteins, which can all be processed for a variety of uses (Lammens et al., 2012). Microalgae are thus a significant source of biofuels as well as bio-based compounds. The issues that algae bio-refinery technology faces must be addressed. High installation, as well as operation expenses, are among the most significant issues. Maintaining cultural control. Contamination of the media by microbes. An uneven supply of light as well as unfavorable weather. Isolation or selection of microalgae and cyanobacteria strains that can survive in thermal stress & grow easily throughout the growth media based on desired products. Choosing appropriate culture media can boost desired product output, and using an efficient and cost-effective microalgae growth system can boost biomass production(Chen et al., 2011).

Conclusions

Microalgae cannot be considered for large-scale applications unless their biomass yield is improved or combined with other technology. Microalgae have unique characteristics that make them suitable as an alternative feedstock for various bio-refinery applications. Microalgae have special features that can be used in environmental and industrial applications. Animal & aqua-culture-feed, fertilizer, pharmaceuticals, or cosmetic items are all possible uses for microalgae. Therefore, it necessitates that researchers concentrate on algae co-processing. A unified bio-refinery strategy could be used to increase the value of microalgae-biomass. This change in research topics necessitates the provision of logistics, the establishment of new research centres, and the development of necessary infrastructure. Microalgae's role as a potential biotechnology feedstock must be evaluated through systematic research. To verify the economic viability and the sustainable development of co-processing technologies, techno-economic analyses, including life cycle analysis studies, must be carried out.

Conflict of interest

The authors declared the absence of a conflict of interest.

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