ISSN: 2348-1900

Plant Science Today

http://www.plantsciencetoday.online

OPEN ACCESS

Mini Review

Diverse application and future prospects for commercial cultivation of microalgae species: A review

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Article history
Received: 25 May 2019
Accepted: 31 July 2019
Published: 01 October 2019

Publisher
Horizon e-Publishing Group

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Abstract

Industrial revolutions, advancements in health care, pharmaceuticals, transportation can be attributed to advancements made in the field of science and technology. Environment and natural resources has paid a heavy cost for most of industrial development. Rapid depletion of non-renewable sources of energy eventually leading towards the energy crisis, direct or indirect release of industrial effluents into soil and natural water bodies, global warming are among major consequences of industrialization. Ever since these environmental concerns have been recognized substantial studies have been conducted to minimize, control pollution and restore environment and natural resources. Among several measures cultivation of algae on large scale stands out to be a multipurpose solution. Inherent potential of microalgae species to accumulate lipids makes algae an efficient source of biofuel. Beside this ability of algae to detoxify polluted water and industrial effluent support utilization of algae for environment management and restoration. Efficient CO_2 fixation, ability to tolerate wide range of environmental conditions, minimal nutritional requirements further support commercial cultivation of algal species to achieve their widespread application. However, efforts are required to develop large scale cultivation protocols (beyond the range of photobioreactors) so as to achieve practical applicability of algae and their products. Alongwith, cultivation protocols there is simultaneous need of either selection of naturally occurring high yielding strains / species or genetic improvement. Standardization of optimum cultivation conditions along with harvesting procedure is equally important.

Keywords: Microalgae; Biofuel; Bioremediation; Bioplastic

Citation: Sharma N, Singh A, Lalremruati F, Vanlalmalsawmi, Sharma R. Diverse application and future prospects for commercial cultivation of microalgae species: A review. Plant Science Today 2019;6(4):427-432. https://doi.org/10.14719/pst.2019.6.4.581

Indexing: Plant Science Today is covered by Scopus, Web of Science, BIOSIS Previews, ESCI, CAS, AGRIS, CABI, Google Scholar, etc. Full list at http://www.plantsciencetoday.online

Introduction

Microalgae are unicellular photosynthetic eukaryotes occupying diverse range of habitats including different environmental and geographical regions. Microalgae possess diverse applications including biofuel production, bioremediation, utilization as biofertilizers and animal feed, bioplastic synthesis, waste water treatment, synthesis of compounds with industrial/pharmaceutical applications including pigments, anti-aging compounds (1, 2). Algal proteins and polysaccharides are of industrial and nutritional importance. The ability to convert solar energy to lipid renders microalgae as the most appropriate and potential alternate source of energy. Besides this, their inherent ability to produce oxygen and bioremediation potential is crucial to maintain ecological balance for sustained environment (3, 4). The above mentioned applications become more pronounced owing to advantages associated with microalgae cultivation. Ability to tolerate and survive in wide range of environmental conditions, minimal nutritional requirement and rapid growth rate, efficient CO_2 fixation makes cultivation of algae convenient and efficient. However, there are also certain factors which check or restrict algae growth. Presence of toxins, contamination and competitive microbes are primary concern during cultivation of algae. Studies are required to optimize large scale commercial cultivation practices alongwith optimization of cultivation conditions, screening / production of potential / improved strains, convenient and effective harvesting methods, etc.

Microalgae species have inherent potential to convert atmospheric carbon dioxide (CO_2) into lipids. (5, 6). Biofuel production from algae species have been recognized as an effective alternate of energy source (7). However, biofuel production from algae species encounters economical challenges in terms of biofuel production on commercial scale. Several methods including hydrothermal liquefaction, pyrolysis, gasification and direct combustion have been employed for biofuel production from different algal species (8,9). Hydrothermal liquefaction (HTL) plants have been established by industries for the large-scale production of bio-crude oils (black viscous oils). Biocrude / bio-oil production focusing on the conversion of just a single microalgae through HTL technique is an effective procedure for the production of bio-oil or bio-crude production from algae feedstock (10). Dalmas Neto *et al* (11) reported fast pyrolysis of algae to produce bio oil with high yield and low cost. Du *et al* (12) reported microwave assisted pyrolysis of *Chlorella* species to produce bio-oil. Du *et al* (12) and Kapoore *et al* 2018 (13) in their microwave assisted pyrolysis (MAP) of *Chlorella spp.* using a microwave oven resulted in the production of bio-oil yield of 28.6%. GC-MS results of the bio-oil product showed the presence of aliphatic, aromatic hydrocarbons, phenols and other compounds which are the desirable compounds present in crude oils, petroleum and diesel. Production of biofuel from algae species generally employ utilization of thermo chemical processes, due to which a large proportion of proteins undergo decomposition. Kumar *et al* (14) depicted a process in which proteins present in algae were separated out (through hydrolysis) before algal biomass was subjected to biofuel production. The study also reported synthesis of polyurethane from algal proteins.

Studies conducted have revealed variation in optimum light is important for lipid synthesis in algal species (5, 15-17). Ever since the potential of algae species to produce biofuel has been recognized, there has been efforts to optimize methods to enhance lipid synthesis. Reduction in antenna size of algae species has been reported to enhance photosynthesis efficiency. Several methods including UV mutagenesis (18), Insertional mutagenesis (19), RNAi mediated gene silencing (20), Random mutagenesis (21), EMS induced mutagenesis (22, 23) have been reported to enhance / improve photosynthetic efficiency of algae species.

With ever increasing industrialization, industrial effluents are directly or indirectly released into the natural resources results in environmental pollution. Effluents released from various industries are enriched with potential toxic components such as heavy metals, enhanced phosphate, sulphate and nitrate content, ammonia, dissolved solids, phenolic compounds. Due to the presence of these potentially toxic components release of industrial effluent into water bodies have gained concern.

Minimizing or treatment of polluted soil or water has become utmost important for maintaining sustainability of environment. Bioremediation techniques are not only effective and efficient but environment-friendly approach for treatment of polluted soil. Besides plants (phytoremediation); bacteria and algae reportedly possess inherent potential for bioremediation (24).

Several studies have indicated application of algal species in the treatment of waste water from various sources (Table 1). Among different algal species, *Chlorella vulgaris* is the most commonly utilized algae for waste water treatment (25-30). Kumar *et al* (31) reported *Chlorella minutissima* and *Scenedesmus* spp. to effectively reduce COD, TDS and phosphate content of sewage water. Similarly, Lim *et al* (25), Kassas and Mohammed (32) and Ramirez *et al* (33) treated textile industry effluent with different algae. All three studies reported that *Chlorella vulgaris* effectively reduced COD contents of effluent. Lim *et al* (25) also reported 33% reduction in the phosphate content with algal treatment. Kassas and Mohammed (31) simultaneously reported *Scenedesmus* spp., *C. vulgaris* and *Muriellopsis* spp. found equally effective for the treating textile industry effluent. Salgueiro *et al* (26) reported significant reduction in COD and removal of phosphate in domestic waste water treated with *C. vulgaris*. Acid mine drainage treated with *Chlorella* and *Scenedesmus* spp. resulted in the reduction of COD (34). Kumar *et al* (14) found that *C. marina* to possess potential to reduce phosphate, nitrate and ammonia from industrial effluent. Hammud *et al* (35) also reported *Spirulina platensis* to absorb copper ion from industrial waste water. The study also

ISSN: 2348-1900

Table 1. Summary of potential of different algae species utilized for treatment of effluents

S. No.	Water sample from various sources	Algae species employed for treatment	Parameters analyzed	Response / outcome	Author
1.	Sewage water	*Chlorella minutissima, Scenedesmus* spp.	COD, TDS, Phosphate content	Reduction in COD and TDS, removal (87.3%) of Phosphate	(31)
2	Textile industrial effluent	*Chlorella vulgaris*	COD, Phosphate content	Reduction in COD, removal (33%) of Phosphate	(25)
3.	Textile industrial effluent	*Chlorella* sp., *Scenedesmus* sp., *Muriellopsis* sp.	COD	Reduction in COD	(33)
4.	Textile industrial effluent	*Chlorella vulgaris*	COD	Reduction up to 17.5% COD	(32)
5.	Domestic, industrial, agro waste water	*Chlorella vulgaris*	COD, Phosphate content	Reduced COD Removal of Phosphate (97%)	(26)
6.	Acid mine drainage	*Chlorella, Scenedesmus* spp.	COD	Reduction in COD	(34)
7.	Electroplating, tanning industrial waste	*Chlorella vulgaris*	Chromium	Adsorbed Chromium (23.6 mg/g) by algae	(27)
8.	Olive mill waste water	*Chlorella vulgaris, Spirulina platensis*	COD, Phenolic compounds	Reduction in COD and Phenolic compounds	(36)
9.	Industrial effluent with heavy metal	*Chlorella vulgaris, Spirunera maxima*	Zinc and Copper	Reduced conc. of Cu upto 81% and Zn up to 94.1%	(37)
10.	Industrial effluent	*Chlorella marina*	Phosphorus, Nitrate, Ammonia	Reduced conc. of PO_4 (88%), NO_3 (64%), NH_3 (85%)	(14)
11.	Industrial waste water	*Spirulina platensis*	Copper	Adsorption of Cu ions increased with decrease in algae biomass concentration	(35)
12.	Industrial effluent	*Chlorella minutissima*	Phosphorus and Nitrate	Reduced conc. of P (4.47 ppm to 1.15ppm) and N (3.6ppm to 0.3ppm)	(39)
13.	Industrial effluent	*Chlorella vulgaris, Scenedesmus quadricauda*	Phosohorus, Nitrate, COD,BOD	Removal efficiency of P, N, BOD, COD increased	(29)
14.	Industrial effluent	*Scenedesmus obliquus, Chlorella vulgaris, Chlorella kessleri*	COD, Phosphate content	Reduction in COD, removal of phosphate 22%-62%	(40)
15.	Industrial effluent, sewage water	*Chlorella vulgaris, Scenedesmus dimorphus*	COD, TDS	Reduction in COD & TDS	(41)
16.	Industrial effluent	*Chlorella vulgaris*	COD, TDS	Reduction in COD & TDS	(28)
17.	Sewage and sea well samples	*Chlorella vulgaris, Chlorella salina*	COD, TDS, Phosphate content	Reduction in COD & TDS, removal of phosphate	(30)

reported increased absorption of copper ions with decrease in concentration of algal biomass.

C. vulgaris and *C. salina* have also been reported to reduce TDS, COD and phosphate content from sewage and sea water samples (30). Several other studies have also reported potential of *C. vulgaris, S. dimorphus, S. quadricauda, S. obliqus, C. kessleri* to reduce COD, TDS and phosphate content of industrial effluent (28-30, 40, 41). Waste water obtained from olive mills potentially possesses high COD along with phenolic compounds. Ismail *et al* (36) utilized *Chlorella vulgaris* and *Spirulina platensis* to treat waste water obtained from olive mill and achieved reduction in COD and phenolic compounds.

One of the major concern associated with release of industrial effluent into environment (soil, water) is presence of heavy metals. Jyoti and Awasthi (27) reported *Chlorella vulgaris* to absorb chromium from waste water obtained from electroplating and tanning industry. Chan *et al* (37) also reported *C. vulgaris* and *Spirulina maxima* to reduce the concentration of zinc and copper in industrial effluent containing heavy metals. Algae have the potential for biosorption/neutralization of heavy metals present in the industrial effluents (38). Microalgae are useful in biomonitoring and restoring the aquatic ecosystems, which make it easier to extract and degrade the various organic and inorganic pollutants (24).

Algal species exhibit antimicrobial, antioxidant activity, anti-inflammatory, hypolipidemic, antihelmenthic, anticancer, antiprotozoal (42) and pharmacological properties (Table 2). Hoseini *et al* (43) reported antibacterial and antiviral potential of *Sprirulina platensis*. Nicoletti (44) reported antibacterial activity of *S. platensis* and *Chlorella*. Antioxidant activity by *C. closterium* is also on record (45). Priyadarshani and Ratu (46) demonstrated antimicrobial and

Table 2. Biological activities of algae species

Sl No.	Microalgae species	Medicinal uses	Author
1	*Spirulina platensis*	Antibacterial, antiviral	43)
2	*Spirulina platensis* and *Chlorella*	Antibacterial, dietary supplement	(44)
3	*Chlorella closterium*	Antioxidant	(45)
4	*Isochrysis, Chaetoceros, Chlorella, Arthrospira, Dunaliella*	Antimicrobial, Antifungal	46)
5	*Phaeocystis pouchetii*	Antibiotic production	(47)
6	*Scenedesmus almeriensis, Chlorella protothecoides*	Reduce risk of retina damage by blue-light	(50)
7	*Arthrospira*	Antioxidant	(51)
8	*Phaeocystis pouchetii*	Antibiotic production	(48)
9	*Spirulina platensis*	Antioxidant, dietary supplement	(52)
10	*Chlorella sorokiniana*	Lowers the risk of premature death	(49)

antifungal activity of *Isochrysis, Chaetoceros, Chlorella, Arthrospira* and *Drenaniella.* Mostafa (47) and Sigmani *et al* (48) stated that *Phaeocystis pouchetii* produces antibiotic with potential antimicrobial action. Sathashivam *et al* (49) observed that, *Chlorella sorokiniana* lowers the risk of premature death. *Scenedesmus almeriensis* and *Chlorella protothecoides* are capable to reduce risk of retina damage caused by blue light (50). *Arthrospira* (51) and *S. platensis* (55) possess antioxidant potential.

Synthesis of bioplastics from algal polymers successfully serves as a field of growing interest for researchers. Proteins obtained from different sources have been utilized for synthesis of plastics. Wheat gluten, soy protein, peanut protein are most commonly utilized plant proteins whereas gelatin, keratin, collagen are animal proteins utilized for synthesis of plastics (53-55). However, utilization of plant material for production of plastic appears to be practically unfavourable since the same plant material can be better utilized in food industry, as animal fodder, etc. Hence, utilization of algae for synthesis of bioplastic appears to be an efficient and appropriate alternative. Utilization of algae proteins for synthesis of bioplastics has several advantages including high protein content with high algal biomass yield; comparatively cost effective cultivation in natural habitat makes algae species most suitable alternate for production of plastics (55). Zeller *et al* (56) revealed bioplastics synthesized from *Spirulina* and *Chlorella* species to be compatible with plastics synthesized from protein of plant or animal origin. Substantial technological development is required to make production of bioplastics from algae a cost effective process. There can be no debate that plastics of algae are environment friendly and biodegradable as compared to conventional plastics. Besides this increasing viability of algal bioplastics can prove to be an effective contribution to economic development. Commercialization of bioplastics will automatically aid in conservation of fossil resources.

Conclusion

Widespread distribution and application of algal species including production of biofuel, bioremediation potential, synthesis of phytocompounds with medicinal, pharmaceutical and other biological activities renders algae to be cultivated on commercial scale. Diverse application of algae becomes more pronounced owing to their minimal growth requirement. Studies are required to optimize cultivation protocol for mass propagation of algae on large scale. Along with development of efficient cultivation protocol efforts are required to genetically modify / improve existing strains / species followed by selection of high yielding varieties. Practical application is required while utilizing algae for various purposes. Separation of proteins from algae species before extraction of oil provides an alternate to synthesize bio polymers since algal proteins are degraded during thermal/chemical processes employed during extraction of biofuel. In the present scenario, algal species stands out to be most potential bioresource for the treatment of polluted water simultaneously being an extremely effective alternate source of energy along with medicinal importance of many algal species.

Authors' contribution

NS and AS contributed towards design and prepared the initial draft of the manuscript. FL, V and RS have worked on acquisition, collection, compilation of literature for the present review. NS and RS have revised the manuscript after review. All authors read and approved the final manuscript.

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