**Microalgae- A promising tool for sustainable future**

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1. Introduction:

Algae are a diverse group of autotrophic members of aquatic microorganisms, which are primary producers in the aquatic ecosystem that can fix CO2 into carbohydrates by photosynthesis (Haddad et al., 2014**).**They may be simplest like unicellular, microscopic, motile, or non-motile cells to complex branched macroscopic in form. Algae are ubiquitous in distribution and can be found in every possible habitat including marine and fresh water bodies (Desikachary, 1959). They play a vital role in functioning of both freshwater and marine ecosystems. Between 30,000 to more than 1 million algal species are thought to exist in this world (Guiry, 2012). Among them, microalgae are diverse algal community that can be found to exist in a broad variety of forms, size and shapes. Despite being microscopic, microalgae can play several inherent roles in a number of scientific disciplines.

            The broad adaptability and potential advantages of microalgae have led to a surge in recent years in the field of research and sustainable development. Due to their occurrence in diverse habitats, these organisms are excellent materials for investigation by ecologists, phycologists, biochemists, microbiologists, and bacteriologists. Thereby researchers are constantly looking for new beneficial uses for these microscopic organisms and to develop novel technology to harness their potential for a healthier and more sustainable future.

1. **Potential microalgal species for mankind:**

As a result of their numerous inherent benefits, algae have recently attracted a lot of attention for bioprospecting (Teronpi and Baruah 2017). Algae are one of the primary natural suppliers of a wide variety of beneficial substances, including antibiotics, proteins, carbohydrates, lipids, chlorophylls, carotenoids, phycobilins, glycolipids, phenolics, terpenes, β-diketone, polyols and indole alkaloids (Pratt *et al*., 1944; Ördög *et al*., 2004; Del Campo *et al*., 2007; Subudhi, 2017; Karkala *et al*., 2021). For which algae has been widely used in fish and animal feedstock, agriculture industry, human nutrition, medical treatments, cosmetic industry, biodiesel production as well as for environmental management (Soletto *et al*., 2005, Apt and Bahrens, 1999; Spolaore *et al*., 2006; Milledge, 2011; De Jesus *et al*., 2013: Mullue *et al*., 2023). Algal species of genera like *Anabaena*, *Nonstoc*, *Botryococcus*, *Chlamydomonas*, *Chlorella*, *Haematococcus*, *Scenedesmus* have been known as the potent source of vitamin precursors, antioxidants, immune system boosters, anti-inflammatory agents, beta-carotene, lutein, astaxanthin and polyunsaturated fatty acids and are already utilized for production of commercial products (Stranska-Zachariasova *et al*., 2016; Mullue *et al*., 2023). The lectin cyanovirin-N, which is isolated from the cyanobacterium *Nostoc ellipsosporum*, has been shown to have antiviral action against the Ebola, influenza, and HIV viruses (Mullue *et al*., 2023). Astaxanthin is a potent antioxidant which is extracted from the green alga *Haematococcus pluvialis* (Plaza *et al*., 2009) which was report abundantly in Deepor beel of Assam. Short chain fatty acids extracted from *Haematococcus pluvialis* have strong antibacterial property against *Vibrio* strains (Subudhi, 2017). Another Freshwater green microalgal genus *Chlorella* produce chlorellin, an antibacterial substance that can prevent the growth of both Gram-positive and Gram-negative bacteria (Little *et al*., 2021). *Chlorella vulgaris,* a common green alga can be utilised for extraction of antibiotic. Calothrixin A, an alkaloid isolated from the cyanobacteria *Calothrix*, has been demonstrated to possess antibacterial property against *Bacillus subtilis*(Doan*et al*.,2001). *Spirulina* and *Chlorella vulgaris* are primarily used and exploited in the market for the manufacture of SCPs (Karkala *et al*., 2021). The green alga *Botryococcus braunii* has been shown to produce allopathic substances viz. mixture of free fatty acids including α-linolenic, oleic, linoleic, and palmitic acids, which favours its dominance in its natural habitat. These fatty acids can become hazardous to other group of phytoplankton (Mendes and Vermelho 2013). *Scytonema*, a cyanobacterial genus commonly available as many as 5 waterbodies could also be exploited for production of cyanobacterin, a chlorinated γ-lactone that specifically inhibits a variety of microalgae, including cyanobacteria and green algae, at micromolar concentrations (Mason *et al*., 1982). For many industrial uses, microalgae-based biofuels are acknowledged as a feasible substitute for fossil fuels (Gong and Jiang 2011). Researchers recommend that *Botryococcus braunii* and *Scenedesmus dimorphus* can be used as raw material for production of biofuels (Nagaraja *et al*., 2014; Arone Sou raj *et al*., 2016; Tasic *et al*., 2016; Prathima and Karthikeyan 2017; Dilia *et al*., 2018). It has been demonstrated that *Botryococcus braunii* is a potential candidate for bioremediation of domestic waste water as it can reduce ammonia, potassium, electrical conductivity and TDS from waste water (Arone Sou raj *et al*., 2016).



**Fig1: Bioprospects of microalgae in different field.**

1. **Emerging Bio prospects of microalgae:**
   1. **Heavy metal remediation:**

Microalgae are found to grow in harsh environment and they adsorb the noxious substances available therein. One of the toxic elements present in such environment is the HMs like Cd, As, Pb, Hg, Zn, Cu, Fe, Mn, Ni, Cr etc which are increasing in nature day by day. These HMs effects the aquatic and land ecosystem by incorporating in the food web.

Microalgae are the ecofriendly tool to remediate these harmful substance for better and healthier future. Microalgal members like *Oscillatoria princeps, Spirulina maxima, Aulosira fertilissima, Chlorella vulgaris, Scenedesmus obliquus, Microcystis* sp, *Pithophora odeogonia, Spirogyra hyaline,* couldremove a number of toxic heavy metals from the environment in a variable pH and temperature ranges (Kumar et al., 2015).

* 1. **Biofuel Production:**

Microalgae are abundant in lipids content and can be used to make biofuels like biodiesel, which are more eco-friendly substitutes for fossil fuels. Particularly,Triglyceride content in microalgae is the main source for the production of biofuel. On the other hand, biomass can be thermochemically transformed into biofuel oil (Lestari et al., 2009). Production of biofuel from microalgae has the potential to lower greenhouse gas emissions and lessen reliance on limited fossil fuel supplies. Among all the members of the microalgal group, chlorophycean members are rich in lipid content (Patidar et al., 2015) and it could be attributed to the production of biofuels. *Chlorella emersonii, Chlorella protothecoides Schizochytrium limacinum, Scenedesmus obliquus* are the few members of chlorophycean members which are known for their rich lipid content (Suali and Sarbatly, 2012).

* 1. **Plastic degradation:**

In general, plastics are regarded as synthetic or semi-synthetic materials or polymers, which are easy to use but pose a threat to the environment. PVC (polyvinyl chloride), PE (polyethylene), PP(Polypropylene) PET(Polyethylene Terephthalate ), LDPE (Low-Density Polyethylene), HDPE (High Density Polyethylene) are the most commonly used plastic compound in recent years.

Nowadays these plastic compounds enhance threats to the environment and their degradation process is quite complex. Researchers have introduced a number of microbes including a few microalgae for the degradation of this polymeric substance. Algal species like [*Scenedesmus*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/scenedesmus) dimorphus, [*Oscillatoria*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/oscillatoria) subbrevis, [*Phormidium*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/phormidium) lucidum, [*Navicula*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/navicula) pupula, and [*Anabaena spiroides*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/anabaena-spiroides)   are known for the degradation of PE (Sarma and Rout, 2019). Amongst those aforementioned species [*Anabaena spiroides*](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/anabaena-spiroides), *[Scenedesmus](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/scenedesmus" \o "Learn more about Scenedesmus from ScienceDirect's AI-generated Topic Pages)* dimorphus, *[Navicula](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/navicula" \o "Learn more about Navicula from ScienceDirect's AI-generated Topic Pages)* pupula are known to degrade both HDPE and LDPE. Recently, Nostoc carneum has gained attention for the degradation mechanism of LDPE (Sarma and Rout, 2020).

* 1. **Bioplastic production:**

In order to reduce the plastic pollution researchers have developed bioplastics from different natural sources including microalgae. Certain microalgae species have the potential to replace the synthetic polymers with biodegradable bioplastics as an ecofriendly substance. Microalgae are rich in carbohydrate and protein content, which actually serve as a core agent for production of bioplastics (Chia et al., 2020). Cellulose, Starch, PE, PVC,PHA, PHB, PLA and polymers based on protein are a few examples of chemicals from algal biomass that are being used to create biodegradable plastics . PHA is the polymer that is most frequently suggested for use in the production of bioplastics since it can be broken down by enzymatic action. Additionally, PHB, a subtype of PHA, has recently become a novel polymer for the production of bioplastics due to its effective oxygen barrier (Karan et al., 2019).

**Table1: Potential use of different microalgal members**

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| --- | --- | --- | --- |
| **Name of the species** | **Algal group** | **Uses** | **References** |
| *Nostoc linckia* | Cyanobacteria | HM (Cr,Cu,Fe,Ni,Zn) removal | Cepoi et al. ( 2021) |
| *Anabaena oryzae* | Cyanobacteria | HM (Cu, Zn) removal | El-Bestawy (2008) |
| *Anabaena* sp. | Cyanobacteria | Biofertilizer | Chittora et al. (2020) |
| *Anabaena spiroides* | Cyanobacteria | Plastic degradation | Kumar et al. (2017) |
| *Anabaena variabilis* | Cyanobacteria | HM (Cd) removal | El-Hameed *et al.*(2021) |
| *Calothrix marchica* | Cyanobacteria | HM (Cd, Hg, Pb) removal | Inthorn et al. (2002) |
| *Chlamydomonas reinhardtii* | Green alga | HM (Co, Cd) removal | Macfie and welbourn (2000) |
| *Chlorella vulgaris* | Green alga | HM (Ni) removal | Mehta and Gaur (2001) |
| *Chlorella vulgaris* | Green alga | Plastic degradation | Falah et al. ( 1964) |
| Chlorella sp. | Green alga | Food | Spolaore et al. (2006) |
| *Chlorococcum humicola* | Green alga | Antimicrobial activity | Bhagavathy et al. (2011) |
| *Dolichospermum crassum* | Cyanobacteria | Anticancer activity against prostrate and colon cancer | Senousy et al. (2020) |
| Dolichospermum spiroides | Cyanobacteria | Anticancer activity against hepatic cancer | Senousy et al. (2020) |
| Dunaliella  sp. | Green alga | Food | Spolaore et al. (2006) |
| *Nannochloropsis* sp. | Green alga | Biofuel | Wang and wang, (2012) |
| *Nostoc carneum* | Cyanobacteria | Plastic degradation | Sarmah and Rout, (2019) |
| Nostoc muscorum . | Cyanobacteria | Anticancer activity | Shanab et al. (2012) |
| *Nostoc* sp. | Cyanobacteria | biofertilizer | Chittora et al. (2020) |
| Oscillatoria sancta | Cyanobacteria | Anticancer activity against breast cancer | Senousy et al. (2020) |
| Oscillatoria sp. | Cyanobacteria | Anticancer activity | Shanab et al. (2012) |
| *Scenedesmus dimorphus* | Green alga | Plastic degradation | Kumar et al. ( 2017) |
| *Scenedesmus obliquus* | Green alga | HM (Cd) removal | Monteiro et al. (2009) |
| *Schizochytrium* sp. | Green alga | Biofuel | Wang and wang, 2012 |
| *Spirulina platensis* | Cyanobacteria | Food | Marzieh Hosseini et al. (2013) |

1. **Conclusion:**

Even while microalgae exhibit enormous promising features, there are still issues to be solved, including identification of a greater number of potential species for industrial uses, improving cultivation methods to produce higher amount of biomass and ensuring economic sustainability. In spite of these, continued research and technological development are steadily enhancing microalgae's bio prospects and broadening their range of industrial use which in turn will lead to a better and sustainable future.

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