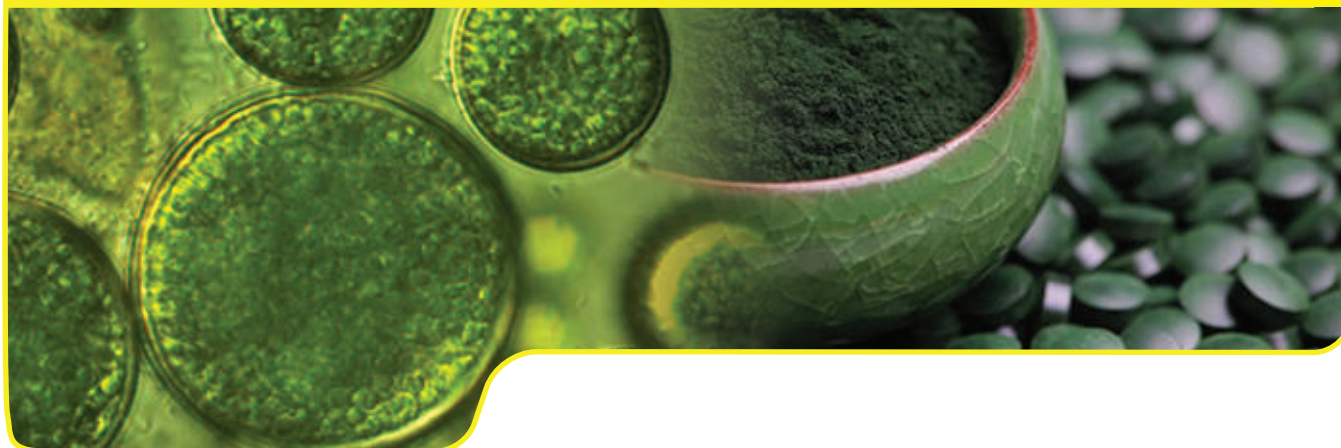


Microalgae, an underutilized microbial resource in Sri Lanka

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1. Introduction to microalgae

Microalgae are unicellular photosynthetic organisms found

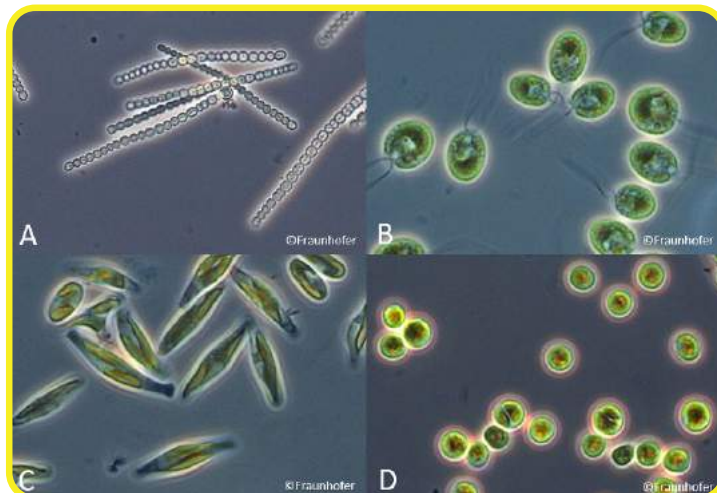


Figure 01: Diverse microalgae species (Source: Derwenskus and Holdmann, Microalgae – Underestimated All-Rounders, ChemViews Magazine, 2016)

in aquatic environments which include freshwater bodies, marine environments and brackish water zones. Although microalgae are photosynthetic organisms, they differ from higher plants in not having roots, leaves or stems. Scientists have estimated that there are approximately 1 million species of microalgae on earth. As shown in Figure 01, morphology of microalgae varies drastically with

the species, making them a highly diverse group of microorganisms.

Microalgae are considered as primary producers of aquatic eco-systems, where they provide energy for all the higher trophic levels. In addition, microalgae generate oxygen during photosynthesis, attributing to nearly 50% of the total oxygen in the atmosphere. Moreover, being photosynthetic organisms, microalgae consume carbon dioxide in the atmosphere which contributes to alleviate the effect of global warming.

Over the past few decades, microalgae have emerged as a natural resource with great industrial potential due to

their ability of accumulating commercially valuable metabolites in high quantities. For instance, microalgae can synthesize carotenoids, lipids, carbohydrates and vitamins which can be employed in the production of pharmaceuticals, nutraceuticals, food/feed supplements, cosmetics or bioenergy. The rapid growth rates, higher photosynthetic efficiency, shorter harvesting time and higher biomass productivities (as compared to terrestrial plants) make microalgae a potential raw material for bio-based industries. Additionally, the cultivation conditions of microalgae can be easily manipulated according to the requirements. Furthermore, microalgae do not require arable land or potable water to facilitate their growth. Thus, cultivation of microalgae can be more sustainable as compared to land-based crops.

2. Microalgae-based bioproducts

Metabolites synthesized by microalgae can be extracted from the biomass and subsequently processed into diverse bioproducts.

2.1. Biofuels and Bioenergy

Several microalgae species are capable of synthesizing lipids up to 60-70% of their dry cell weight. The final lipid content is substantially affected by microalgal species as well as the culture conditions. Following the harvesting of biomass from cultures, lipid extraction is conducted from dried or wet microalgal biomass. Solvent extraction methods are the most widely used techniques, whereas solvent-free technologies are currently gaining interest due to lower potential of product contamination. The extracted lipids are then subjected to a process called transesterification where triglycerides are converted into alkyl esters in the presence

of a strong acid/base catalyst. However, microalgae-based biodiesel production is currently not economically feasible. In order to compete with petroleum-based fuels, the production cost of microalgae-based biodiesel should be decreased significantly.

In addition to the production of biodiesel, microalgae can also be employed for the production of bioethanol. This involves the hydrolysis of microalgal carbohydrates, which converts them into fermentable sugars such as glucose. Depending on the species, carbohydrate content of microalgae can reach up to 65% of dry cell weight, which is comparatively higher than lignocellulosic biomass. Enzymatic hydrolysis is preferred over chemical hydrolysis, due to

higher conversion yields, minimal by-product formation, mild operating conditions, and low energy input. However, further studies on economic feasibility of production are required prior to large-scale implementation.

Anaerobic digestion allows the generation of biogas from microalgal biomass. In this process, microalgal biomass is broken down into methane, water, and carbon dioxide by the activity of anaerobic bacteria. In general, anaerobic digestion is considered to be more economically feasible than biodiesel and bioethanol production, and showcases higher net energy ratios (i.e. ratio between energy output and energy input in biofuel production). Anaerobic digestion process is capable of

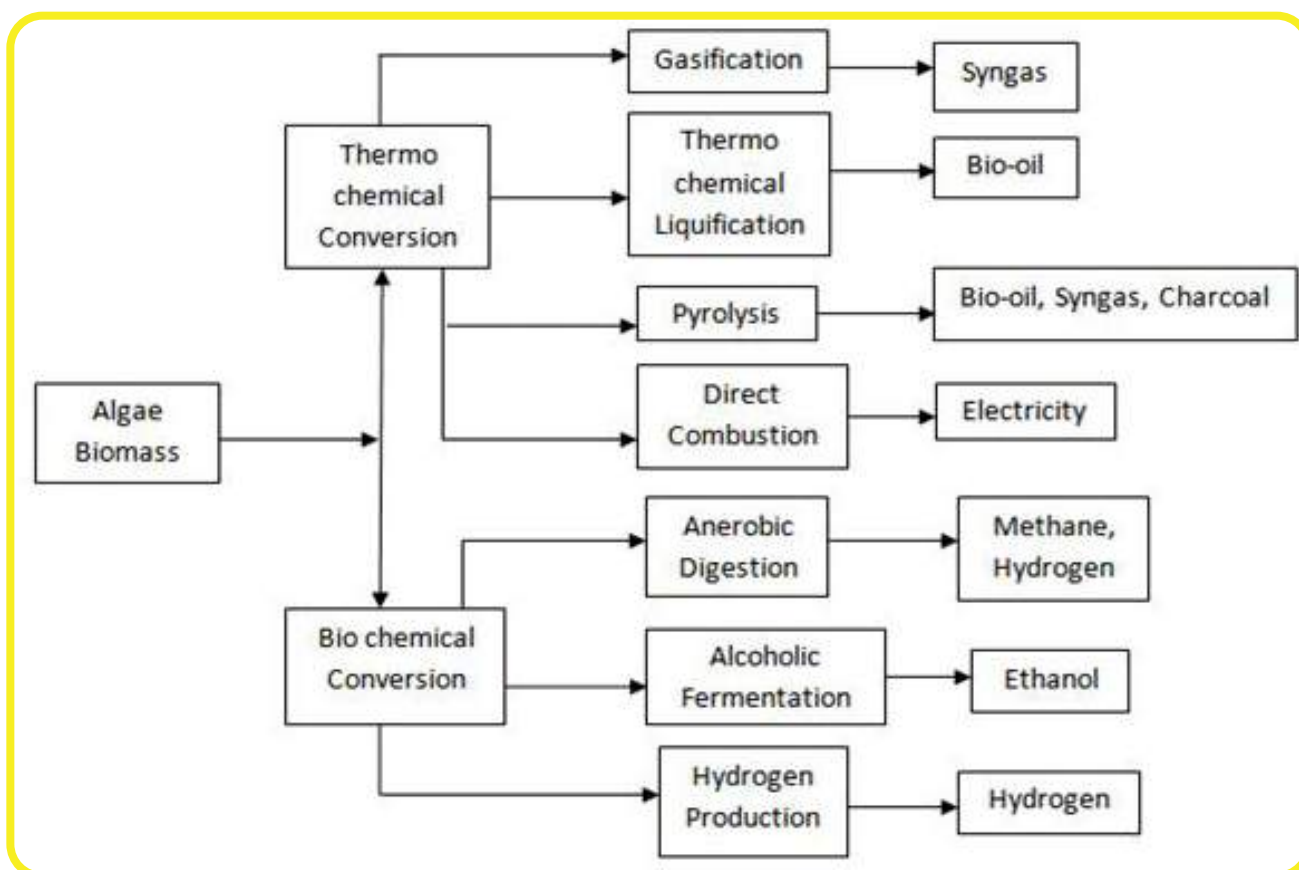


Figure 02: Biofuel and bioenergy from microalgae (Source: Chisti, Biodiesel from microalgae, Biotechnology Advances 25, 2007)



Figure 03: Spirulina as food supplement (Source: Leech, 10 Health Benefits of Spirulina, 2018. <https://www.healthline.com/nutrition/10-proven-benefits-of-spirulina>)

utilizing all the organic compounds in the microalgal biomass, whereas transesterification and fermentation utilize only lipids and carbohydrates respectively. Microalgal biomass can be co-digested with other substrates to enhance biogas yields.

Microalgal biomass can be subjected to thermochemical conversions which include pyrolysis, hydrothermal liquefaction and gasification. These processes generate biochar, biooil and syngas which can be utilized as energy sources. While existing facilities can be used for these processes, they involve elevated temperatures and pressures which can significantly increase the cost of energy. The different processes employed in the production of microalgae-based biofuel can be observed in Figure 02. Nonetheless, it is important to note that the most feasible conversion process for biofuel production from microalgae should be selected based on the biochemical composition of biomass, and a comprehensive techno-economic and life cycle analysis.

2.2. Pharmaceuticals, nutraceuticals and food/feed supplements

Microalgae can synthesize compounds such as carotenoids, proteins and vitamins which have high nutritional value. These compounds are either extracted from the microalgal biomass and encapsulated or consumed as whole

biomass. Carotenoids accumulated in microalgae with high nutritional value include astaxanthin, lutein, beta carotene and fucoxanthin. The biomass of microalgae such as *Spirulina platensis* (Figure 03) and *Chlorella vulgaris* are currently used as a human nutritional supplements due to their high protein content.

Considering the current state of technology, the use of microalgal biomass for pharmaceutical/nutraceutical applications is more economically feasible than the production of biofuels and bioenergy. This is due to the high market value of these compounds in comparison to the lower value of biofuels.

2.3. Biofertilizer

During their growth, microalgae can assimilate nitrogen, phosphorus, and carbon present in the growth media. Thus, the generated biomass is also rich in these elements, thereby making them a potential biofertilizer. By employing the microalgal biomass as biofertilizer, these elements are

introduced into the soil, which are subsequently absorbed by plants for their growth. In addition, microalgae biomass improves the texture of the soil. Furthermore, microalgae cultures can be added to soil as live inoculants instead of dried biomass. Live microalgae can secrete extracellular polymeric substances, produce plant growth hormones, fix atmospheric nitrogen and solubilize minerals in soil, which can substantially enhance plant growth.

2.4. Animal feed

Microalgae biomass is rich in essential fatty acids, proteins, vitamins and carbohydrates which are essential for the growth of living organisms. Hence, microalgae have been often used as animal feed and feed supplements to achieve enhanced quality of livestock as indicated by Figure 04. For instance, carotenoid-rich microalgae biomass has been used to improve the pigmentation of ornamental fish. In addition, use of carotenoid-rich microalgae in poultry feed has enhanced the nutritional value of hens' eggs and enhanced the color of egg yolk.

3. Microalgae in bioremediation

3.1. Carbon dioxide sequestration

Microalgae exhibit higher photosynthetic efficiencies than terrestrial plants, and hence showcase the ability to fix carbon dioxide from gas streams containing carbon dioxide concentrations far exceeding atmospheric levels (~0.04% v/v). Hence, numerous researchers have employed microalgae for

sequestration of carbon dioxide from industrial flue gas, which may contain the gas up to 3-30% v/v. Thus, the development of large-scale CO₂ sequestration processes would assist in the limitation of air pollution and global warming. Nonetheless, high temperature and potentially inhibitory constituents in flue gas can hinder microalgae growth, which necessitates further research and optimization of the growth conditions or pretreatment of flue gas.

3.2. Bioremediation of wastewater

Wastewater contains nitrogen, phosphorus and organic compounds which can be utilized by microalgae for biomass production. Thus, wastewater can be employed as an alternative growth media for microalgae. During their growth, microalgae assimilate these compounds, thereby removing them from wastewater. In addition, microalgae can remove heavy metals, dyes, and other toxic compounds from

wastewater through adsorption and biodegradation. Hence, numerous researchers have employed microalgae for wastewater bioremediation, and successfully achieved significant nutrient removal efficiencies. In addition to the effective treatment of wastewater, the integrated process is also advantageous in enhancing the sustainability and economics of microalgal biomass production. Accordingly, wastewater-based cultivation would result in the reduction of freshwater consumption and nutrient costs

incurred in the production of microalgae-based biofuels or bioproducts.

4. Microalgae as feedstock for biorefineries

One of the most significant challenges in the manufacture of microalgae-based bioproducts is the high costs in upstream and downstream processing steps. Because of this issue, it is currently not economical to produce low-value compounds such as biofuels. Nonetheless, the market value of microalgal metabolites used in pharmaceutical/

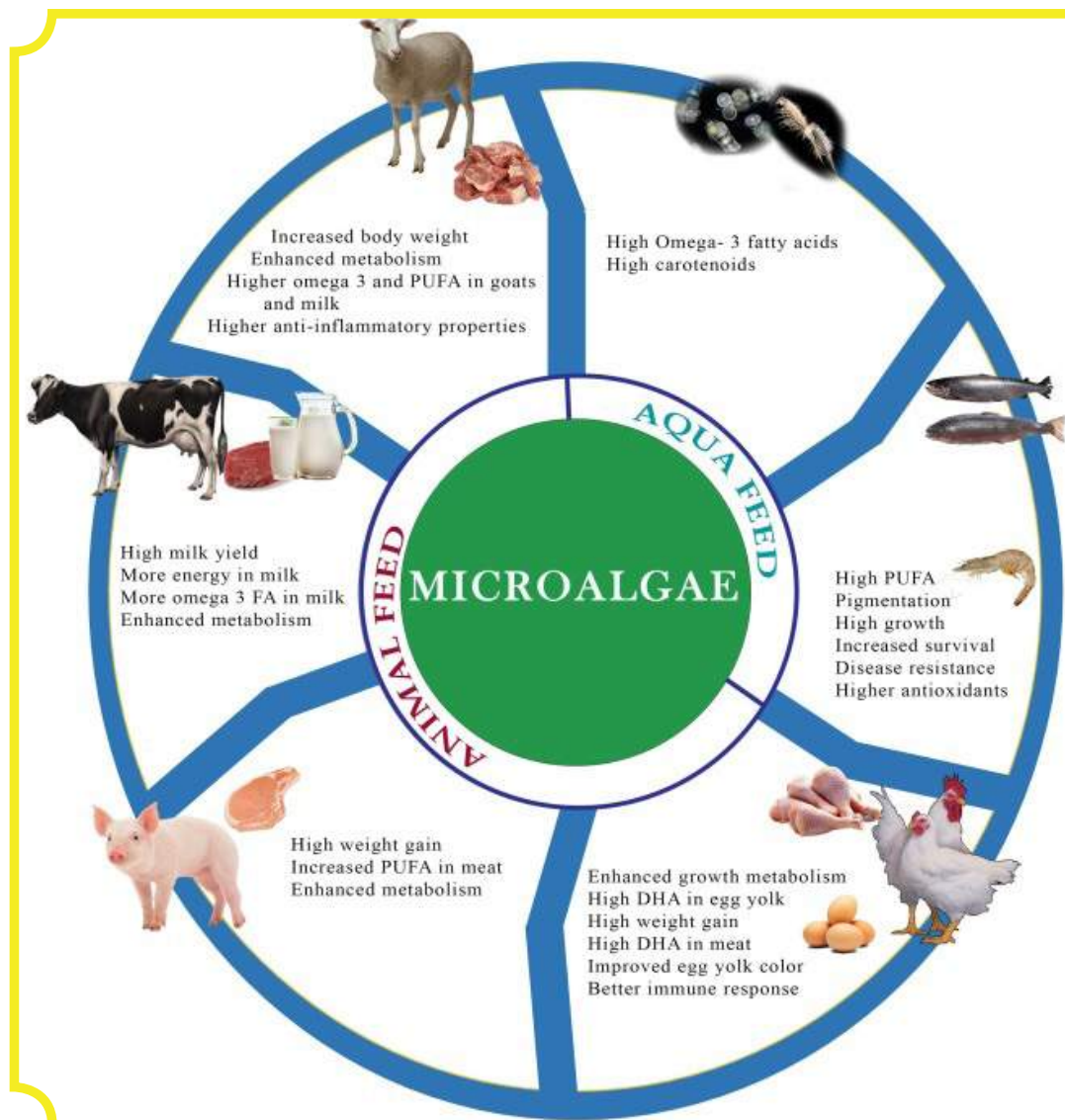


Figure 04: Microalgae as animal feed (Source: Dineshbabu et al., Microalgae–nutritious, sustainable aqua- and animal feed source, Journal of Functional Foods 62, 2019)

nutraceutical applications is markedly higher. Due to the lucrative nature of these metabolites, they are often termed as “high-value compounds”. Within recent years, the biorefinery concept has emerged as a potential method for holistic valorization of the microalgae biomass via the production of a diverse spectrum of bioproducts from a single biomass feedstock. In this scenario, the high-value compounds will be produced as primary products, whereas lower value compounds will be extracted from the residual biomass and converted to the desired bioproducts. Thus, the production cost attributed to lower value compounds would simply be the incremental costs incurred for processing of residual biomass, since bulk of the costs could be recovered from the revenue generated through the production of high-value compounds.

5. Microalgae-based research: the Sri Lankan scenario

Sri Lanka is an island surrounded by the ocean, which is rich in marine microalgal species. In addition, the inland surface waters of Sri Lanka include a large number of rivers and lakes. Despite the presence of different local microalgae species, Sri Lanka has barely tapped this valuable aquatic resource. Thus, the foundation for developing bio-based industries in Sri Lanka could be established by the exploitation of the diverse microalgae species within the country.

In order to identify microalgae species with biotechnological potential, sampling of inland and marine water bodies should be conducted, followed by

the isolation of species and subsequent identification. Thereafter, the isolated strains should be screened for their ability to synthesize metabolites of interest. Thereafter, extensive research should be performed to maximize the productivity of valuable compounds. This could be achieved through laboratory scale experiments for the identification of optimum culture parameters, which are highly dependent on

the field of microalgae because of the high biotechnological potential of these microbes. Currently, the microalgae research group at the Department of Chemical and Process Engineering, University of Moratuwa, are engaged in harnessing the underutilized national wealth of microalgae. The research group is currently working on isolation and identification of local microalgae species, screening of strains for target metabolite production, optimization of culture conditions, microalgae-based bioremediation, microalgal biorefineries and pilot-scale microalgae cultivation systems. Their ultimate goal is to contribute to the establishment of microalgae-based industries within the country.

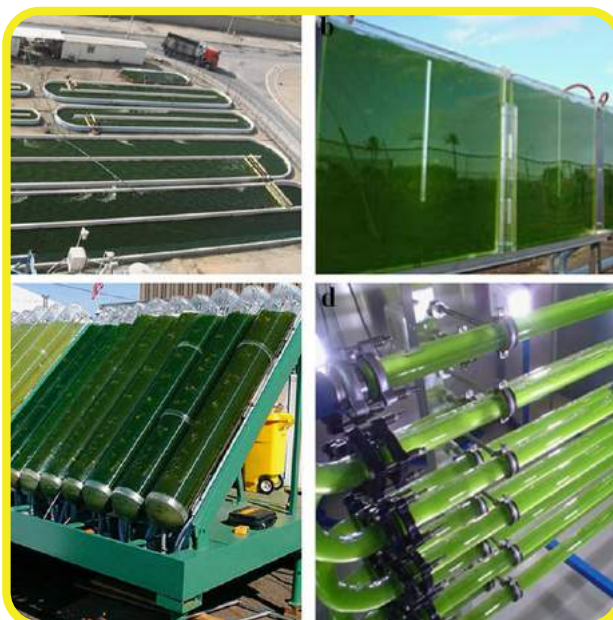


Figure 05: Outdoor microalgae cultivation systems (Application of computational fluid dynamics for modeling and designing photobioreactors for microalgae production)

the microalgal species. Following laboratory scale optimization, microalgae cultivation systems should be scaled up to increase the production of target metabolites. Being a country without any drastic seasonal variations and abundance of sunlight throughout the year, Sri Lanka could be an ideal location for the establishment of outdoor microalgae cultivation systems.

Hence, it is evident that Sri Lankan researchers should venture into



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