Microalgae Culture Techniques: From Culture to Harvesting and Drying

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ABSTRACT

Microalgae as an emerging multipurpose biological resource can be used in sectors including aquaculture, food, feed, cosmetics, pharmaceuticals, and biofuels. It is able to synthesize a variety of active substances, such as proteins and lipids. Further, various techniques for mass culture are available, and hence, it is an attractive option for large scale production. Good biomass production is possible by choosing suitable cultivation conditions and systems of culture according to characteristics of the species and target application. Equally important are the downstream steps of biomass harvesting and drying that impact the quality, cost, and usability of the final products.

INTRODUCTION:

Microalgae are tiny photosynthetic organisms that have attracted significant interest due to their nutritional and commercial value. They have rich contents of valuable components such as highly unsaturated fatty acids (HUFA), polyunsaturated fatty acids (PUFA), sterols, pigments, proteins, carbohydrates, and various bioactive compounds. The components of microalgae constitute a promising resource for a wide range of applications. Microalgae are an important source of nutrition and of essential fatty acids, particularly in aquaculture. The presence of pigments such as carotenoids and chlorophylls provides antioxidant and natural colouring properties,

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which further increase its value. Apart from aquaculture, microalgal biomass is attracting more and more attention for food, animal feed, nutraceuticals, biofuel, and other high-value applications (Volkman *et al*. 1989). These wide applications have stimulated increasing interest in the efficient cultivation and utilization of microalgae.

Mode of culture

Microalgae need light (naturally or artificially), nutrients (carbon, nitrogen, and phosphorus), carbon dioxide, suitable temperature, and pH for healthy growth (Menegazzo and Fonseca 2019). Depending on their energy and carbon sources, they can be cultivated by three methods: autotrophic, mixotrophic, and heterotrophic.

In autotrophic cultivation, microalgae use light and CO_2 for photosynthesis. However, growth can vary with changes in sunlight and day-night cycles. Mixotrophic cultivation combines photosynthesis with the use of organic carbon, allowing microalgae to use both light and organic nutrients for growth and improving biomass production. In heterotrophic cultivation, some species can grow without light by using organic carbon sources such as glucose, acetate, or waste water (Tan *et al*. 2018).

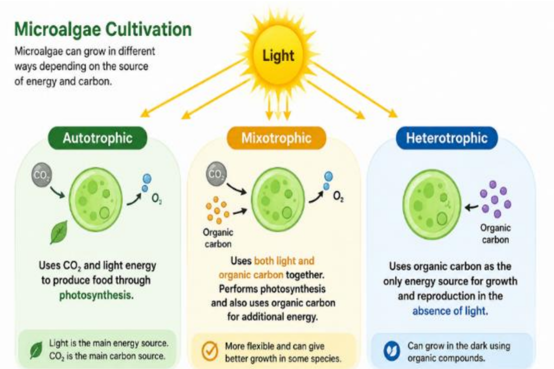

Fig. 1. Mode of microalgal cultivation

Types of culture systems

Microalgae are generally cultivated by two main approaches: open systems such as raceway ponds and closed systems such as photobioreactors (Tan *et al*., 2018).

1. **Raceway culture system:** Raceway ponds are typically shallow and employ a paddle wheel to continuously mix and circulate the algal culture, thus preventing cell sedimentation and enhancing light exposures (Chisti, 2007). These ponds are usually built up in concrete or are lined with suitable plastic materials. The culture medium is added to the pond and continuously circulated, and part of the algal biomass can be harvested after the circulation cycle is completed. But the main disadvantage is the growth and the final biomass production of microalgae are affected by water evaporation, temperature variations, seasonal changes, inefficient utilization of CO_2, and contamination by unwanted microorganisms.

2. **Closed Photobioreactor:** Photobioreactors are closed systems for culturing microalgae using light as an energy source. They provide better control conditions for culturing microalgae and also can produce a high quantity of algal biomass. The system is fully enclosed, so the risk of contamination is very low compared with a raceway culture system. However, their higher construction and operating costs can limit large-scale applications. The closed photobioreactor is costly compared to the open raceway pond. On the other hand, less land is required for closed photobioreactors to cultivate microalgae. A closed bioreactor requires less land and can be designed in different configurations, including flat-plate reactors, tubular airlift and bubble column bioreactors, helical tubular bioreactors, and alpha-shaped bioreactors, depending on the production requirements.

Types of Photobioreactors

Types of photobioreactor	Features	Advantage
Tubular Photobioreactors	Tubular photobioreactors are closed systems made up of long glass or plastic tubes in which microalgae grow under controlled conditions. The tubes can be arranged either vertically or horizontally and are connected to a central system that supplies essential nutrients and carbon dioxide. Sensors and pumps help maintain suitable conditions for algal growth. These systems can be used at different scales, ranging from small laboratory experiments to large commercial production units.	High light exposure, good control of culture conditions relatively high biomass concentration, and reduced contamination compare with open systems.
Flat Photobioreactors	Flat plate photobioreactors use shallow, transparent panels made of glass or plastic. The thin culture layer allows light to penetrate efficiently into the culture. Mixing and CO_2 supply are generally achieved by bubbling air through the culture or using mechanical circulation	Simple construction, good light penetration, high surface area to volume ratio, and suitability for solar cultivation.
Bubble column reactors	Bubble columns reactors are vertically cylindrical vessels in which air or CO_2 enriched gas is introduced from the bottom through a sparger. The rising bubbles mix the culture and simultaneously supply CO_2 needed for photosynthesis. Light is generally supplied from outside the reactor.	Simple design. Low construction and operating costs, no moving mechanical parts, and effective gas and heat transfer.
Airlift photobioreactor	Airlift reactors contain (downcomer) zones. Gas is introduced into the riser, causing the culture to move upward, while the culture returns through the downcomer. They may be designed as internal or external loop systems.	Good mixing and gas transfer, no mechanical stirrer, relatively low energyconsumption, and reduced mechanical stress on algal cells

Fig. 2. Different methods of microalgal cultivation

Important commercial microalgae and their major applications

Microalgae	Characteristics	Major commercial important / Applications
Arthospira sp. (Spirulina)	➢ High growth rate ➢ Growth well under alkaline conditions also ➢ Rich in C-phycocyanin	➢ Aquaculture feed ➢ Nutritional products ➢ C-phycocyanin production
Chlorella sp.	➢ High growth rate ➢ Can grow under mixotrophic conditions ➢ Produce valuable lipids	➢ Biodesel production ➢ Bio-oil production ➢ Aquaculture feed and nutritional applications
Dunaliella salina	➢ High β-carotene content under stress conditions ➢ Tolerate high salinity	➢ Natural β-carotene production ➢ Vitamin A source ➢ Antioxidant products
Eugelenagracilis	➢ High growth rate ➢ Can grow in mixotrophic conditions ➢ Tolerate relatively low pH conditions	➢ Production of valuable biomass and bioactive compounds ➢ Nutraceutical and biotechnology application's
Nannochloropsis sphaeroides	➢ Rapid cell population growth ➢ Suitable for biomass production	➢ Aquaculture feed ➢ Production of valuable lipids and biomass

Harvesting of Microalgae Biomass

Once microalgae have reached the desired concentration, the biomass must be separated from the culture medium. Harvesting is an important downstream step because it can significantly influence the cost, energy requirement, and quality of the final biomass. Common harvesting approaches include centrifugation, sedimentation, and filtration.

1. **Centrifugation:** Centrifugation is the rapid and highly efficient technique for recovering microalgal biomass. The separation is primarily based on differences in cell density and particles using centrifugal force. It provides high recovery efficiency without chemical flocculants and is suitable for high-value applications such as food, cosmetics, and pharmaceuticals. However, its high energy consumption and equipment cost can limit its use for large-scale production. (Grima *et al.*, 2003; Alam*et al.*, 2019)

2. **Sedimentation:** Sedimentation is a simple and low-cost harvesting method in which algal cells settle under gravity. It requires little energy and simple equipment, making it suitable for low-cost biomass recovery. However, the process is slow and is less effective for small, low-density, or buoyant microalgae (Pragya *et al*. 2013).

3. **Filtration:** Filtration separates microalgal cells from the culture medium using a porous filter or membrane. Techniques such as microfiltration, vacuum filtration, dead-end filtration, and tangential-flow filtrationcan be used depending on the algal species and culture conditions. Although filtration can provide effective biomass recovery, membrane fouling, filter blockage, and cleaning and replacement costs can restrict its large-scale application.

4. **Flocculation:** Flocculation is a simple and widely used method for harvesting microalgae by joining individual algal cells into larger clusters called flocs, which can then be easily separated from the culture medium. Different types of flocculation are used depending on the harvesting requirement.

   a) **Chemical flocculation:** Chemical flocculants, such as organic compounds and inorganic metal salts, destabilize algal cells and promote their aggregation and settling. It is effective for many microalgal species but may introduce chemical residues into the harvested biomass (Wan *et al*. 2015).

   b) **Bio-flocculation:** Microorganisms or natural substances such as extracellular polysaccharides and proteins help aggregate algal cells. It is considered an environmentally friendly, low-cost, and sustainable approach because it reduces the use of chemical flocculants. (Alam *et al*. 2017)

   c) **Electrolytic flocculation:** An electric current is used to neutralize the charge of algal cells, causing them to aggregate. (Mubarak *et al*., 2019). This method does not require chemical flocculants and can provide high harvesting efficiency, although electrode replacement and equipment costs can be limitations.

5. **Flotation:** In this method, fine gas bubbles attach to algal cells and carry them to the water surface, where the concentrated biomass can be collected. It is particularly useful for small and low-density microalgae and can be more effective than gravity sedimentation. (Singh *et al*. 2011; Menegazzo and Fonseca 2019).

Drying of microalgae biomass

After harvesting, microalgal biomass contains a large amount of water and is usually dried before further processing of lipids, carbohydrates, pigments, proteins, and other valuable products. Drying methods depend on the intended application, cost, and required product quality.

1. **Solar Drying:** Solar drying is a simple and inexpensive method that uses sunlight to dry large quantities of biomass. Uncontrolled temperature and exposure, however, can lead to loss of nutrients and microbial contamination, while traditional sun-drying takes more time and space. Closed solar dryers improve the process by maintaining temperatures between 35 and 60 degrees Celsius and removing almost all of the moisture in a few hours. It is especially suitable when the biomass is to be used as animal feed. (Brennan and Owende 2010).

2. **Spray Drying:** The algal suspension is spray-dried, which is to atomize it into a fine mist of droplets ad then rapidly dry these droplets by hot air to give a dry powder within seconds. It can be used to produce premium microalgal powders for food and other high-value applications. However, this process requires a lot of energy, and high temperatures can harm heat-sensitive materials such as pigments. (Zhang*et al*. 2022).

3. **Rotary Drying:** Rotary and drum drying is the use of a revolving heated surface or cylinder to remove moisture from biomass (Chen *et al*., 2015). These methods are very simple and can be useful for large-scale drying. Drum drying also has the advantage of cell wall rupture and partial sterilization, which can improve intracellular component accessibility.

4. **Freeze Drying:** Freeze-drying, also called lyophilization, is a process in which the biomass is frozen and then the water is removed at low pressure. It is widely used when the preservation of proteins, pigments, and other delicate compounds is important. Freeze-drying is more expensive than spray-drying but often leads to lower protein losses (Chen *et al*., 2015).

CONCLUSION

Microalgae are attractive biological resources with diverse applications in aquaculture, food, animal feed, nutraceuticals, medicine, cosmetics, and biofuel. Their successful cultivation depends on adopting a suitable culture mode and production system according to the requirements of the series and the desired result. Raceway ponds are desirable due of their simple form and lower cost, while closed photobioreactors give better control of culture conditions and reduced contamination. Similarly, the choice of harvesting and drying procedures plays an essential role in maintaining biomass quality and decreasing processing costs. Therefore, an efficient microalgal production system should include species characteristics, growing conditions, biomass yield, energy utilization, cost, and the intended end product. Selecting optimal culture, harvesting, and drying processes can increase biomass quality and assist the sustainable and economical usage of microalgae for diverse commercial purposes.

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