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A Mini Review on Microalgae Biomass Production: Recent Progress in Cultivation Systems

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ABSTRACT: Single-celled photosynthetic microscopic algae (microalgae) have numerous significances for human wellbeing. From medicine to fuel industry these tiny organisms have tremendous potentials and in future they would be game changer to mitigate global warming and environmental pollutions. The current production cost is a matter of consideration during its applications. Scientists all over the world are trying to reduce the production costs as well as to develop new or improve the existing culturing methodologies and techniques. Open pond and closed pond (PBRs) culturing system are two most prominent ways to culture microalgae. Open pond culturing techniques for microalgae have several advantages over closed pond system such as low operational costs and easy to make. However, the main drawback of this system is contamination by other microorganisms, which is possible to control in closed pond system. Among the many types of PBRs systems, the advanced tubular PBRs presently considered as more useful than open pond culture system. To meet the minimum production costs, more research is needed on both the culturing systems.

Keywords: Microalgae, Open Pond, PBRs, Algae biomass.

A group of single-celled microscopic autotrophs are generally called microalgae in biology, which commonly produces atmospheric oxygen via photosynthesis using CO_2 and water in the presence of sun light (1). They are considered as the most primitive form of plants because of their very simple cellular structures. They usually grow in suspension of a surface water of any aquatic environments and can double every few hours during their exponential growth time (2-4). Their motile and non-motile features make them versatile, and they can consume organic material for their energy requirements (5,6). Within the cell, they can synthesize all essential amino acids, and can possesses high levels of proteins, carbohydrates as well as lipids. Algal species containing high protein contents could be used as an ideal source of functional foods, food additives and nutraceuticals precursor in commercial industries (7,9). Besides, it is also used as human foods, food supplements, pharmaceuticals, cosmetic industry, immune-modulating, anti-cancer products (10-12). Furthermore, C- sequestrations to abate global warming, bioremediation of heavy metals from wastewater, biotransformation, and treatment of sewage and municipal wastes are also considered as the potential usages of microalgae nowadays (13).

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The worldwide need for energy usage is surprisingly increasing day by day. It is estimated that the demands will be much more than 85% by 2040 (14). Currently, most the energy demands in the globe are met by fossil fuel, although the resources which reducing gradually. Thus, the additional sources of renewable energy, particularly biofuels, must be considered for sustainable energy management (15). At present, plants and plants parts have been used as biofuel feedstock in many parts of the world with some limitations that pose new challenges for humankind. For example, the amount of arable lands is reducing which would contribute to food crises in near future. Microalgae have been considered as a suitable source for biofuels production due to their higher growth rates, higher photosynthetic efficiency as well as higher biomass productivity, as compared to other terrestrial plants or plants parts (16,17). According to a report, it is estimated that the produced algal oil per acre is almost 30 times higher than oil crops (15). Although microalgae biomass is regarded as the most suitable renewable feedstock for high-energy production, its pilot-scale economic utilization is still challenging due to its production costs along with other associated limitations. As only a small land area can support to produce biomass several times higher than currently used energy crops, microalgae still now attractive for bioenergy production purposes and regarded as a best competitor in this field for future utilization (18).

However, presently microalgae can be cultivated adopting different techniques and methodologies to make an expectable amount of biomass. Open pond systems, closed systems, and hybrid systems are the most prominent cultivating systems (19,20). However, open pond system is very easy to make and possible to install for pilot scale production purposes, although contamination by other unwanted microorganisms is a major disadvantage of open pond culturing system. A closed system, also called a photobioreactor (PBR), is now widely studied due to the facility of controlled growth and less contamination. It gives a higher ratio of biomass to substrate conversion with economic efficiency than an open system (21). However, the high cost of construction and maintenance of PBR systems restricted the use of the system mostly for research purposes till now (22). Construction of PBR systems, formulation of the growth medium, and maintaining the turbulent flow continuously is also a very high-cost process that outweighs its other advantages (23). This high cost can be checked by the use some low-cost materials as PBRs unit and uses the wastewater or industrial surplus products as a growth medium and also possible to use an energy-efficient pumps with the system (24). Commercial application of microalgae is still a dream.

Moreover, microalgae have the huge scopes to use in biotechnology industry targeting different demands in the future (25). As production cost is the major problem in microalgae biomass industry, there has been seen many improvements achieved during the last decades by the hard efforts of scientists (26-30). They are trying to develop new strategies to produce microalgae with minimum costs, which will be commercially viable to cultivate and to apply. Therefore, the main aim of the review was to study the recent findings developed by researchers under different type's affordable culturing techniques to produce microalgae biomass as cheap as possible.

MATERIALS AND METHODS

To collect the information, different open access journals were scrutinized to find out recent research progress on microalgae cultivation. Besides, other paid articles also were downloaded with topic relevance. Most of the keywords that wrote in search engine are- microalgae culture, recent progress in microalgae culture, open pond culture, open pond culture for microalgae, closed cultivation of microalgae, photobioreactors, low cost culturing, and cost reduction approaches, so on. The collected articles were shorted based on the publishing year. Then the collected articles were arranged according to two types of major cultivation- open pond and photobioreactors (PBRs) systems.

MICROALGAE CULTURING TECHNIQUES

Various types of cultivation techniques for algae biomass productions are being practiced for different purposes and based on algae types. Nevertheless, most of them are mainly based either on open ponds or closed pond culturing system. Moreover, hybrid type is also getting attention for coast lowering approach. In the following, there are presented the recent findings under open pond and closed pond culturing techniques for microalgae biomass production.

Open pond culture systems

The oldest, conventional, and commonly used systems for microalgae cultivation are open pond systems. Researchers follow this system mainly due to its maintenance. At the same time, open ponds are

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mostly preferred because of their lower energy consumption, easy construction procedures, and low operational costs (31,32). The size and shape of these types of ponds are variable; usually depth between 1 and 100 cm, and the area consists of about one to several acres. In terms of pond shape, circular and shallow big ponds are very common nowadays along with thin and multilayer configurations to increase the production efficiency (33-35). Although cost is a factor, that's why scientists designed the size and shape of the pond based on algal species and geographical conditions (36). There are a lot of open pond systems available; however, scientist prefers the most common type is the paddle-wheel raceway pond, which has comparatively more advantages than traditional open pond systems. The shape of a typical raceway pond has resembled that of a race track with a paddle wheel. The paddle wheel mixes and circulates the liquid around the entire pond which makes this cultivation system mostly used for microalgae culture at industrial scales (4,31). Not only that, for treating wastewater by microalgae, these ponds looking more perspective than the others (37). According to Marchetti et al., different microalgae species shows the different biochemical composition due to variations in culture and geographical conditions that meant the placement of open pond system also should be considered during pilot-scale productions (38). However, this raceway open pond system also has some limitations. For example, mixing of nutrients, CO2 transfer, and light availability equally is not almost the same (39).

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However, although this type of pond has the limitations mentioned above, an open raceway cultivation system is widely used in different parts of the world due to its low energy requirements (32). Moreover, multilayer system incorporation into open pond raceway systems, consisting of a combination of several open tanks placed at different heights, recently makes it more attractive for microalgae cultivation (35,40). Recently, Min et al. (2013) tested a pilot-scale multilayer system of microalgae cultivation, which gave promising results for *Chlorella* biomass production that would be usable for other types of microalgae (35). Most of the conventional open pond systems face major disadvantages including high land requirements, contamination issues, and CO_2 discharge to the atmosphere, poor light utilization, and continuous evaporation to loss water (39). Therefore, these limitations make the open pond system of microalgae cultivation less preferable by scientists for research purposes. As microalgae has correlation with its surroundings in natural water bodies, there would be needed to study species specific growth environmental set up for open pond cultivation system prior to start any commercial productions (40). To maintain the research homogeneity, closed photobioreactors (PBR) are preferred for the cultivation of microalgae over the open pond system. Microalgae cultivation using biofilm in liquid suspension is a prospective very recent finding. However, there are many more recent findings have been made, which make this cultivation system promising for future research to make it profitable (Table1).

Closed system photobioreactors (PBRs)

The closed photobioreactors are made of glass or transparent PVC with varying size and shape. They can be located both in outdoors and indoors environmental conditions. The tubular shaped PBRs systems are very popular during microalgae cultivation, although helical, flat panel like and airlift PBRs systems are being improving for different purposes. Not only that, more other shaped PBRs systems has been developed nowadays. Vertical tubular shaped photobioreactors, horizontal tubular photobioreactors, tank photobioreactors and hybrid type PBRs have been developed and trying to improve more for better results (33). However, the tubular PBRs installing horizontally or vertically has been taken in most cases, due to more advantages than limitations and presently considered as more helpful than open pond culture system (42).

However, the Photobioreactor systems seems more advantageous than open pond system, they have some drawbacks also. For example, algae biomass must settled in the bottom if there lack high turbulent flow (4). To overcome this associated problems scientists use pump to lift air within the reactors. Moreover, scientists find out that the outcome of PBRs would be limiting if there arise any design flaws, which can make a large scale productions abortive economically (43,44). Scientists also reported that suitable material selections for construction, relevant shape, size and spacing along with the optimum operational modes could reduce the production costs more than the present (45,46). To overcome the situations related with design flows there need to design effective as much as possible (47). However, these should be very effective based on geographical conditions and microalgae species specific growth environments (48). Chakraborty et al. (2021) investigate the growth rate of several microalgae in PBR system along with different environment conditions set up and found significant findings (49). They reported different microalgae species responses differently in a same given conditions. Besides, report found that the *C. vulgaris* gave much more good results in biomass yield growing in a modified soil extract medium at a pH of 7.2 and 12:12 light: dark conditions (50). However, there are found several reports emphasizing the similar findings for different microalgae species rather than *C. vulgaris* (42,43,51).

Therefore, researchers recently propose hybrid designs, which particularly is being developed combining both tubular and flat panel PBRs systems. Not only had those hybrid systems, Suh and Lee listed some other prospective designs to make it profitable and promising for microalgae cultivation in large scale (52). Recently, the results found in biomass yield and lipid content perspective culturing with helicoidally and horizontal PBRs systems was lucrative for some algae species, but the horizontal PBRs have a lower biomass yield by other report (53). Consequently, the combination of efficient modeling and design of PBRs along with a better understanding of the growth parameters will be helpful to chase the such types of challenges (42,43). Hopefully, outdoor mass cultivation by large PBRs systems along with media alterations to change the biochemical compositions of microalgae would be attractive in future (54,48).

Table 1. Some of recent progress in microalgae cultivation systems (Open pond and PBRs system).

Method	Findings	Ref
OP	1. Using biofilm in liquid suspension	(55)
	2. Alternative media in raceway system	(56)
	3. Using wastewater as nutrient source	(57)
	4. Mixed culture in a same system	(58)
	5. Paddle wheel raceway system	(31)
PBR	1. Outdoor mass cultivation	(54)
	2. Media alterations	(48)
	3. Algal biofilm membrane	(59)
	4. Industrial gas use as byproduct	(60)
	5. New protocol for high yielding	(50)

Industrial flu gas also could reduce the production costs in closed PBRs system that is considering because of its direct environmental benefits (50).

However, different types open ponds and photobioreactors are being commonly used for *C. vulgaris* culturing suitable but photobioreactors comparatively expensive due to its sophisticated design and controlled operations. Recently other scientists found some limitations of this system (28,61). Open pond and PBRs system considered as mostly used cultivation techniques for microalgae biomass production. However, co-culture of microalgae with fungi or other microorganisms also gaining popularity (62). Moreover, co-culture with bacteria are also getting attention for higher biomass yield nowadays (63,64). This co-culture, either fungi or bacteria, provides synergistic effects on microalgae biomass yields (64). In present, the improvement on co-culture methods of microalgae culturing are being regarded as research advancement in microalgae cultivation process, which is being investigated for further development worldwide.

CONCLUSION

Open pond cultivation systems for microalgae biomass production are very common for large scale demands, although the system has some limitations yet. The PBRs systems are using mainly for pure culture and most predominant culture system for research or laboratory purposes. Both the systems has gain some advancements to avoid their respective limitations recent years, production costs is still in higher, however. Therefore, to make profitable productions more research needed focusing on lowering production costs.

CONFLICT OF INTEREST

No conflict of interest.

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Author's contributions

All three authors contributed equally.

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