Review Article

Journal of Microbiology and Related Research
Volume 10 Number 1, January - June 2024
DOI: http://dx.doi.org/10.21088/jmrr.2395.6623.10124.5

Eco-Alchemy - Algae Cultivation and Its Application in Bioplastic Production

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How to cite this article:

Vivek Pandya, Devanshi Trivedi, Kinjal Upadhyay. Eco-Alchemy - Algae Cultivation and Its Application in Bioplastic Production. J Microbiol Relat Res. 2024;10(1):39–45.

Abstract

In this world of rapidly growing techs and steadfast alternatives which rather damage environment than make it flourishing, we need the actual green alternative which will efficiently supersede— the intoxication by petro fuels, waste-treatment machinery, green house effects and many more. This search of alternative has made its way to sleek end through the cultivation of algae and its benefits. As little amounts will do no good to the seeking benefits the major ways found by scientists soaring through early methods like dilution isolation method and use of stencil & gelatine to create patterns to more modern ways of open pond systems to photobioreactors. The review includes various efficient ways of algal cultivation such as use of photobioreactors, open raceways, two-phase hybrid systems and 3D triangular systems by discussing its limitations plus advantages. The photo bioreactors though providing more efficiency than open pond system they still are not much used. The greed for improved systems made discovery of the two-phase hybrid systems which obliterates disadvantage of both systems which are discussed. Though the thirst of improving led to the more different designs in the way of trials like 3D triangular systems which will be honoured in this review. We also go through a brief glimpse of algae's role in replacing synthetic plastics with its bioplastic production as it shows very versatile group of polymers and high degradability.

Keywords: Microalgae; Cultivation-methods; Open system; Closed system; Bioplastic.

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Received on: 21.09.2024 **Accepted on:** 19.10.2024

INTRODUCTION

The world is now going towards green impact as by alternating the use of non-renewable and polluting sources with the more renewable and environmental friendly source. This involves biofuels like bioethanol, biohydrogen, bio-methane using many of the biological species like plants—*i.e.* their seed, leaves, fruits, etc. and microbes like yeast, *Zymomonasmobilis, Bacillus licheniformis and algae.*

Algae are the photosynthetic organisms that are multipurpose for many of the needs for extracting exemplified pigments and vitamins for supplements to treating the waste of industrial lethargy and providing gold standards of eco-fuels in the form of bio-ethanol and biohydrogen, While also using the environmental CO_2 released from petroleum burnt through vehicles in order to make organic carbon for its growth and in turn purifying the environment.

The Algae is divided into groups like green algae, brown algae, red algae, blue green algae, diatoms, golden algae, dinoflagellates, euglenophytes. Out of these mainly blue-green and green algae are used as they are very rich in vitamins and nutrients, also for biofuels too; Others like red and brown algae are majorly used for bioplastic production.

As such of importance are algae that it holds bills of hundreds of millions in dollar for researching it'scultivation, application and products. Almost $200 million were spent in researching and pilot project development by US department of energy (DOE). An investment such high as $600 million is made by an oil company alone in oil production efforts from algae and related advertisements. This led to now blooming many of the experiments revolving around algae cultivation and its fruiting capacity of forming biofuels (Hall and Banemann, 2011)

Salt and wastewater tolerance being a spotlight of algae reduces freshwater use while sometimes wastewater can be considered a hosting nutrient resource in certain circumstances (Schenk *et al.*, 2008). The CO_2 sequestration being cleaning environment property of algae it will not only reduce environmental CO2 but also produce the precious O_2 which accounts 70-80% of the oxygen breath by us (Schenk *et al.*, 2008; Hall, 2011).

There has been report by IMechE, 2009, which told increased CO_2 concentration will increase algae growth rate till other nutrients are in abundance (IMechE, 2009).

The cultivation of algae majorly be done via open system and closed system in which open systems consist of the raceway ponds and other totally open systems and closed systems includes photo-bioreactors.

Cultivation of algae

The algae harvesting is as old as at least 2500 years ago which have been utilized for food and medicine, yet the cultivation began only 300 years ago (Tseng, 1981). As early mentions reverting to 1950's stated their first roles in fuel production (Morton, 1998) and thus began the cultivation from lab to pilot scale.

In algae, they depend on strain specific cultivation criteria so as to increase the yield. Factors include temperature, mixing, hydrodynamics mass transfer, gas transfer, light cycle, water intensity, water quality, pH levels and many others like carbon nutrients availability, cell density/fragility/growth inhabitation. Thus, there has been more special interest lying in its cultivation system designs.

Algae can be grown in various designed systems from low on tech ponds to highly technical and controlled system of bioreactors. The designs firmly differ in terms of its economic requirements to environmental impact to factors in operating systems.

Major there are two systems that cultivation follows: 1) Open systems and 2) Closedsystems

Open systems

The open ponds are basically the natural pits created with specific dimensions. They can either be simple ponds of desired diameter and depths whereas others called raceway ponds have desired diameter and depth plus circulating paddlewheels (Gundula Proksch, 2013).

Basically the depth of 15 to 20cm or 6 to 8inches is ideal whereas diameter can vary (Gundula Proksch, 2013). At lab scale you can also use flasks, beakers and trays to cultivate this green gold so as they can behave as the mimics.

Advantages: (Schenk *et al.*, 2008)

- There is always a low construction cost.
- They idealise low economic margins.

Disadvantages: (Schenk *et al.*, 2008)

- Large land area.
- Low light utilization.
- High contamination.
- Weather changes.

Solutions: (Gundula Proksch, 2013)

These problems can be overcome by using a transparent or translucent barrier which can be covered on the area and thus can be turned into a greenhouse.

Closed system

The algae need around 1000-10,000 lux of light intensity of indirect sunlight to optimize photosynthetic reaction as direct sunlight can cause photo inhibition and photo bleaching (Schenk *et al.,* 2008). This can insist that algae can be grown in 3D space instead of growing just on surface like normal plants (Gundula Proksch, 2013).

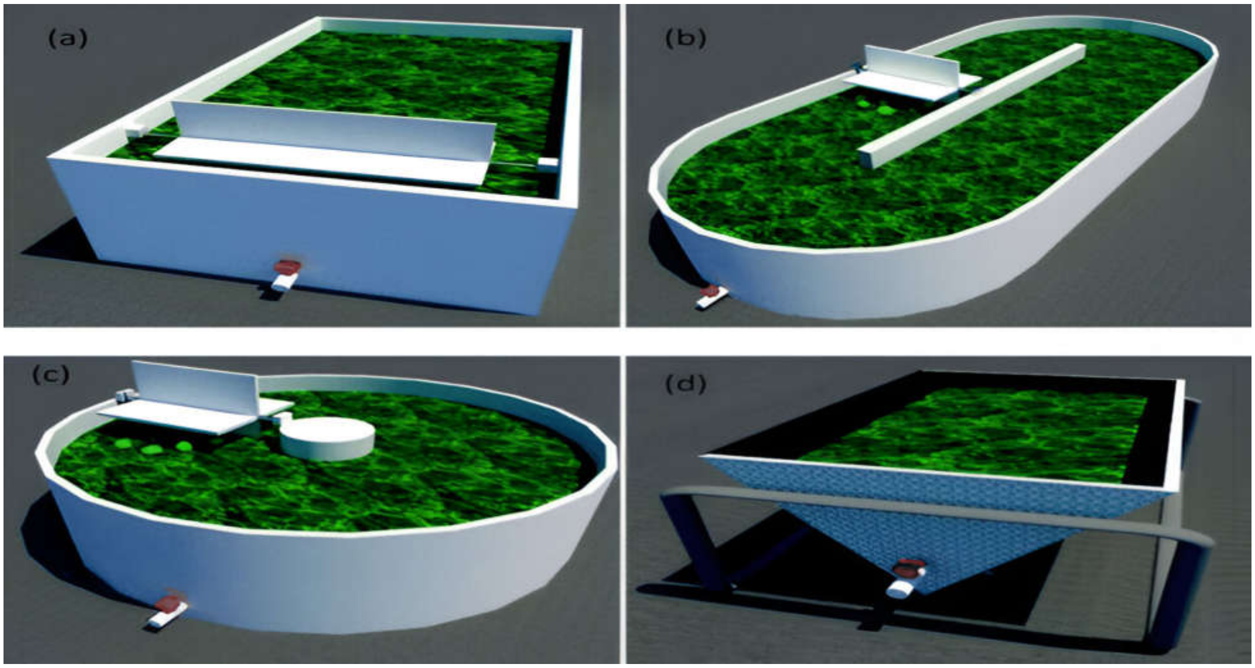

Fig. 1: Open system

Adopted from (Santos *et al.*, 2020)

Vertical closed system increase productivity as the light will diffuse bitterly. They are made of two components: A feeding vessel through which CO_2 and nutrients can be introduced while second is a solar array through which the mixed solution is pumped being exposed to sunlight (Gundula Proksch, 2013). The system increases yield and contamination is eliminated (Gundula Proksch, 2013).

Ther low cost photobioreactor can be made using poly-ethylene bags which can be hanged through rackssuch that all sides of it can be exposed to the sunlight. Algae can be mixed into solution and pumped mechanically using series of bags. Systems like this can sometime require additional

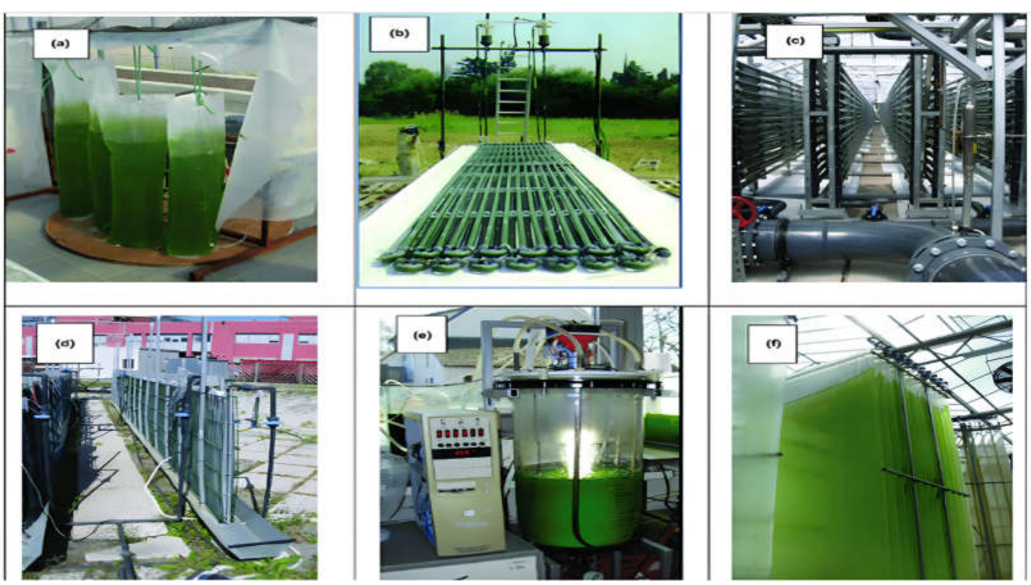

Fig. 2: Closed systems for algal cultivation

adopted from (Masojídek & Torzillo, 2008) construction in order to cut through the weather fluctuations (Kizililsoley and Helvacioglu, 2008).

The 10 times more costly and producing 5 to 10 times higher yields of areal footprint then conventional methods is the closed photobioreactor, Here minimal volume of water is used for maximizing absorption of nutrients and energy under controlled environment. The surface-to-volume ratio provides light saturations and proper mixing ensures even CO_2 distribution and prevents algal cells from settling down. Glass tubes will efficiently be used to grow algae (Schenk *et al.*, 2008). A German company Algomed operates world's largest photo-bioreactor in Klötze and this consists of 500km of glass tubes in about 12,000m^2 green house being able to produce up to 100t algal biomass per year (Gundula Proksch, 2013).

Two-stage Hybrid system

This system is developed as a result of research carried out to reduce disadvantages of both open pond system and photobioreactor and make a setup that falls somewhere in between having advantages of both (Olaizola, 2000; Schenk *et al.*, 2008; Su *et al.*, 2011). This system is made up of open raceways connected to the photobioreactor and the flow happens from photobioreactor to open raceways pond (Narala *et al.*, 2016).

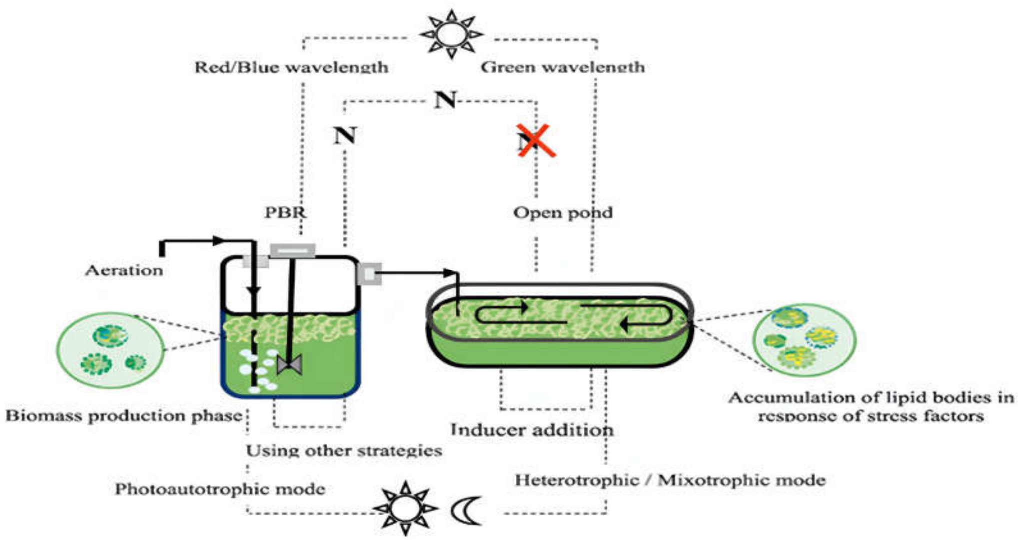

Fig. 3: Two stage hybrid system
Adopted from (Aziz et al., 2020)

Comparison between the different systems

A Tetraselmis sp. M8 is used; The photobioreactor as well as the open raceway pond cultivation results three main growth cycleswhereas the fourth harvest seemed possible at 28th and 29th day. The harvest of only that biomass that is rich in lipids is done. If compared the Two-stage system, the hybrid system produced nearly six cycles and harvests. These results suggested that the average of growth

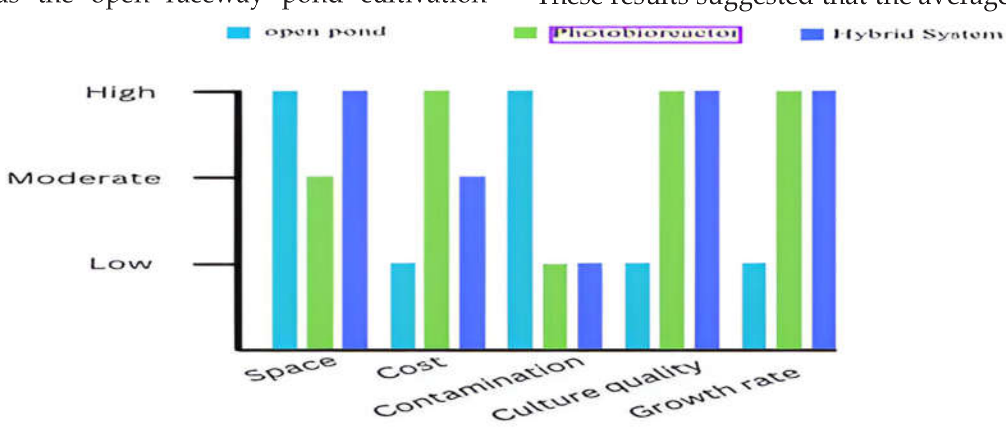

Fig. 4: Comparison between different systems
Data adopted from (Gundula Proksch, 2019)

was higher in the Hybrid system compared to both individual methods (Narala *et al.,* 2016).

This happened because hybrid system has provided biomass growth and lipid inductionan independency as it has two distinct stages. Hybrid system involved higher growth rates and low culture dormancy thanks to the different cultivation system for biomass production and lipid induction.This becomes advantageous as algae can either increase biomass or it can biosynthesize lipid at a single time (Lim *et al.,* 2012; Li *et al.,* 2014; Sharma *et al.,* 2014).

The major disadvantage mostly in open pond system, i.e. contaminating predators or other algae, is overcome by hybrid systems. The issue is solved here as the photobioreactor holds the algae in closed environment for a much of their growth and the open pond systems (prone to contamination) will gain the biomass only few days before harvesting (Moheimani and Borowitzka, 2006; Wang *et al.,* 2013).

Role of algae in bioplastic production

Plastics that are produced from biomass or environment friendly resources like food crops are known as bioplastic and have the same function as petroleum base bioplastic (Mekonnen *et al.,* 2013). Algae makes a preferrable biomass source for the production of bioplastic, which has increased level of lipid content (Khoo *et al.,* 2020; Yew *et al.,* 2020). The biomass of algae consists of protein and carbohydrate-based polymers which can be used as one of the bioplastic constituents. Some of the examples of protein-based polymers are starch, cellulose, PHA (Polyhydroxyalkanoate, PHB (Polyhydroxy butyrate), PLA (Polylactic acid), PE (Polyethylene), PVC (Polyvinyl chloride) from algal biomass which are utilized to develop biodegradable plastics (Karan *et al.,* 2019). Among above mentioned protein-based polymers PHA is a polymer that is most recommended for the production of bioplastic because it can be degraded by enzymatic action (Rasul *et al.,* 2017). Algal biomass can also be blended with other materials in order to prolonged life span, also o provide a better mechanical properties. The materials which can be blended with the algal biomass are petroleum plastics, natural products (cellulose or starch) or polymers, for the production of bioplastic (Rahman & Miller, 2017).

Table 1: Data represents bioplastic products generated by different microalgal species

Algal Species	Product	Bioplastic content (mg ml^{-1})
Microcystis aeruginosa	PHB	0.49±0.5
Haematococcuspluvialis	PHB	0.39±0.42
Botyryococcusbrauni	PHB	247±0.42
Chroocococcusturgidus	PHB	0.1

Data adopted from (Arora *et al.,* 2023)

As shown in Fig 5 the different type of blended materials are used for manufacturing of improved quality of bioplastic. There have been some researchers who manufactured the bioplastics (A. Pownal, 2020).

The few of the bioplastic manufacturing examples by researchers and designers are: Eric Klarenbeek and Maartje Dros, Dutch designers made an algae based bioplastic that can replace the currently used traditional plastics, also establishing lab called Algae Lab for algae cultivation and starch production which can act as raw material for bioplastic production; Austeja Platukyte made biodegradable product mixing agar and algae coated with calcium carbonate having potential to replace petroleum-based plastics; Ari Jonssonmixed water and dried red algae creating plastic bottles that can alternate traditional plastic bottles, these new plastic bottles can retain the form when full and easily biodegrade

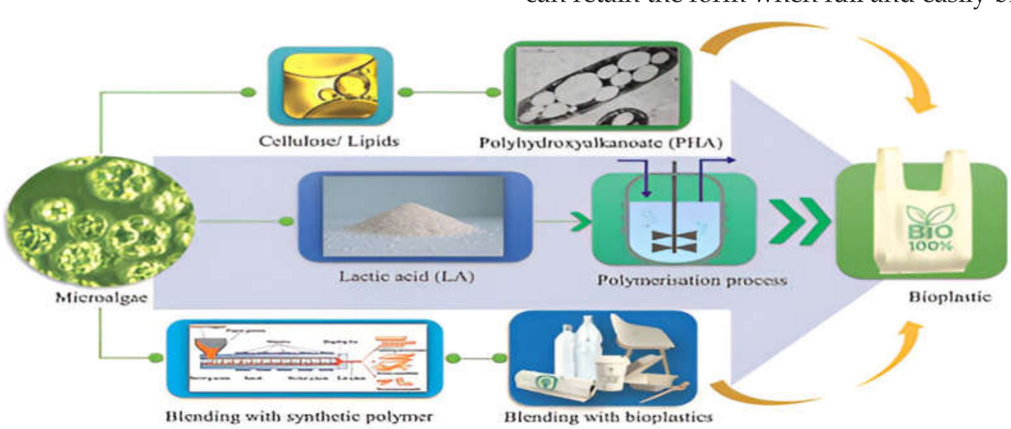

Fig. 5: Bioplastic production
Adopted from (Chong *et al.,* 2022)

when empty;thus, the algae based bioplastic can be promising in replacing the traditional bioplastic very efficiently (Arora *et al*., 2023).

CONCLUSION

Algae being a strong beneficiary can be grown in bulk amounts via the discussed methods out of which bioreactor are more efficient but less used while the hybrid system is very well negating limits of both these systems. Algae being good bioplastic source can also maintain eco-friendly approach.

Conflicts of Interest

There are no conflicts to declare.

Acknowledgements

The authors are thankful to St. Xavier's College (Autonomous), Ahmedabad, India for providing a financial assistance under the scheme of Research Project Seed Grant having award number SXCA/2021-2022/PR-01.

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