Bio. Res. Today 2024, 6(1):21-23

Biotica Research Today

e-ISSN: 2582-6654

January, 2024

Article ID: RT1534 **Popular Article**

Biological Carbon Capture through Algae

Sudarshan S.[1], Pritam Sarkar[1], Rathi Bhuvaneswari G.[2] and Satya Prakash Shukla[1*]

[1]Aquatic Environment and Health Management Division, ICAR-Central Institute of Fisheries Education, Mumbai, Maharashtra (400 061), India

[2]Mariculture Division, ICAR-Central Marine Fisheries Research Institute, Vizhinjam Regional Centre, Kerala (695 521), India

Open Access

Corresponding Author

Satya Prakash Shukla

✉: spshukla@cife.edu.in

Conflict of interests: The author has declared that no conflict of interest exists.

How to cite this article?

Sudarshan *et al*., 2024. Biological Carbon Capture through Algae. *Biotica Research Today* 6(1), 21-23.

Copyright: © 2024 Sudarshan *et al.* This is an open access article that permits unrestricted use, distribution and reproduction in any medium after the author(s) and source are credited.

Abstract

Global climate change poses a critical threat, with carbon dioxide (CO_2) emissions from fossil fuels increasing by 2.7% annually in the last decade. To counter this alarming trend, a promising worldwide strategy involves capturing and storing CO_2, notably through carbon capture and storage (CCS) initiatives. Photosynthesis, particularly by microalgae, emerges as a sustainable approach for CO_2 removal due to their exceptional carbon-fixing abilities. Cyanobacteria and algae have developed unique photosynthetic carbon-concentrating mechanisms (CCMs) that optimize the efficiency of ribulose-1,5-bisphosphate carboxylase/ oxygenase (RuBisCO) in capturing carbon dioxide. In this process, carbonic anhydrase (CA), a zinc-containing enzyme, plays a pivotal role within the CCM by facilitating the reversible hydration of CO_2 into bicarbonate and a proton, significantly contributing to CO_2 fixation. The microalgal biomass, post-sequestration, holds potential for producing biofuel, colorants, vitamins, bioactive compounds and livestock fodder.

Keywords: Carbon dioxide, Carbonic Anhydrase (CA), Carbon Capture, Microalgae

Introduction

Global warming is a major concern for governments worldwide. Average surface temperature of earth increased by 0.78 degree Celsius between 1900 and 2005 and the Intergovernmental Panel on Climate Change predicts an additional 2-6 degree Celsius rise by the end of the century. Anthropogenic activities over the past century and a half, have led to an approximately 25% increase in atmospheric CO_2 levels. The combustion of fossil fuels produces flue gas, predominantly composed of carbon dioxide (CO_2), sulfur oxides (SO_x) and nitrogen oxides (NO_x), nitrogen (N_2), oxygen (O_2) and water vapor. Despite this mixture, carbon dioxide remains the dominant gas. This substantial CO_2 output, exceeding 36 billion tons annually, intensifies the greenhouse effect, contributing to catastrophic global warming.

In 2022, the global average atmospheric CO_2 concentration reached 417 ppm, a record high in over 8,00,000 years as reported by NOAA. The oceans have experienced a rise in acidity, with a 0.1-unit decrease in pH, indicating a 30% increase in acidity, attributed to CO_2 absorption. The surge in CO_2 levels is primarily linked to anthropogenic activities like heightened fossil fuel combustion, changes in land use pattern and increased industrial processes. Addressing the climate change crisis effectively requires urgent carbon dioxide capture. Various removal methods, categorized as physicochemical, biological and geological, offer options for extracting carbon dioxide from the industrial flue gas streams or from the atmosphere (Figure 1) (Nanda *et al.*, 2016).

Algae

Algae, whether single-celled or multi-celled organisms, depends on photosynthesis for their growth, contributing to more than half of the global primary production. Similar to plants, algae utilize CO_2 and light to produce oxygen and sugar. Typically found in aquatic environments, they serve as a fundamental food source for organisms in water. Within the two primary categories of algae - microalgae and macroalgae - microalgae particularly excel in carbon sequestration. This diverse assembly of photosynthetic aquatic plants is vital both as primary producers and as a promising resource within the biological community.

Article History

RECEIVED on 29th December 2023 RECEIVED in revised form 19th January 2024 ACCEPTED in final form 20th January 2024

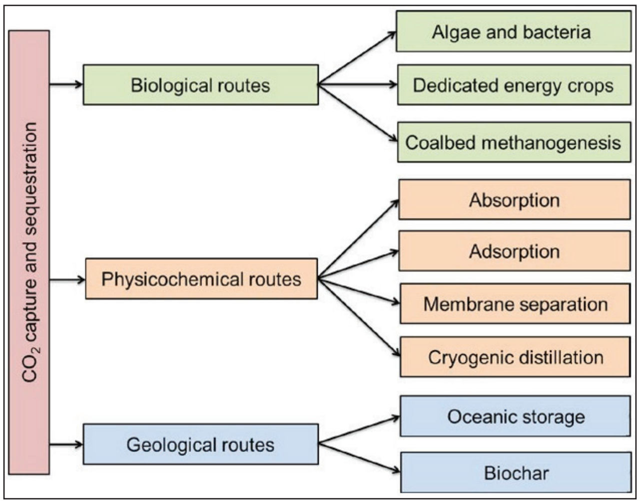

Figure 1: Different methods of carbon capture and sequestration

Microalgal Carbon Capture

Algae are notable for their accelerated growth rate and superior carbon capture capabilities in comparison to other plants. Their enhanced photosynthetic efficiency, attributed to a greater ability to capture and convert light into usable energy, sets them apart from typical terrestrial plants. Despite residing in aquatic environments, microalgae exhibit a photosynthetic process similar to that of higher plants, making the direct passage of CO_2-rich gases through their culture highly effective in capturing CO_2 Algae's rapid growth, coupled with their need for a concentrated CO_2 source for photosynthesis, highlights their remarkable energy conversion efficiency. Additionally, their carbon-concentrating mechanism effectively suppresses photorespiration. Therefore, the adoption of algae for the capture of carbon dioxide is emerging as a feasible choice for converting anthropogenic CO_2.

Algae consist of lipids (7-23%), carbohydrates (5-23%), proteins (6-52%) and a certain amount of fat. While the proportions may vary across individuals, these elements can be transformed for various commercial purposes, such as food, pharmaceuticals, cosmetics and biofuels. Microalgal cells can be viewed as solar-driven factories at the cellular level, proficient in converting captured CO_2 into biofuels, animal feed, valuable bioactive compounds and chemical feedstocks. In the power generation sector, these applications become advantageous following CO_2 capture from coal combustion. Despite the initial expense of algae cultivation, utilizing algae biomass as feedstock can generate revenue by producing a range of products, making this approach feasible (Paul *et al.*, 2021).

In the current era, numerous technologies have emerged to address the growing emphasis on renewable energy sources. Among the proposed carbon capture methods, the direct utilization of CO_2 in autotrophic algal or bacterial cultivation is considered promising. Algae have the ability to assimilate carbon dioxide from various sources. Simultaneously, the resulting biomass can serve as a raw material for biofuel production. The converted chemicals and energy products from CO_2 show great market potential. Additionally, microalgae/ cyanobacteria exhibit CO_2 fixation rates 10 to 50 times higher than terrestrial plants, rendering them highly efficient. The swift evolution of algae strains is achievable through high-throughput technologies, facilitated by the unicellular nature of algae, which duplicate through division. Algal-bacterial consortia, displaying high biofuel productivity, effectively capture and sequester CO_2, transforming algal biomass into biofuel. At a large scale, the cultivation of 1 kg of algal culture involves the absorption of 1.83 kg of CO_2 (Yong *et al.*, 2021).

Recognizing single-celled algal strains that can flourish in heightened CO_2 levels is of considerable significance. The effectiveness of CO_2 biocapture by microalgae is influenced by factors such as algal physiology, pond chemistry and temperature (Onyeaka *et al.*, 2021). Several species have been recognized for their capacity to tolerate high CO_2 levels, including *Cyanidium* sp., *Synechococcus* sp. and *Euglena* sp. with some other species, such as *Scenedesmus* sp., *Chlorococcum* sp, *Chlorella* sp., *Spirulina* sp., *Eudorina* sp., *Nannochloropsis* sp., *Dunaliella* sp. and more. Microalgae demonstrate the capability to assimilate CO_2 across a range of concentrations, from ambient levels (0.04%) to 100% v/v CO_2, depending on the species selected.

Moreover, bacteria play a pivotal role in the global carbon cycle. Acetogenic bacteria, like *Clostridium autoethanogenum*, participate in CO_2 fixation and CO through the Wood-Ljungdahl pathway, a sequential process for CO_2 fixation. In algal-bacterial partnerships, their interactions are mutually beneficial, requiring the exchange of substrates CO_2 and O_2 for both algae growth and CO_2 fixation. The heightened carbon sequestration supports algal photosynthetic activity, leading to increased biogas production. Given recent progress in algal-bacterial collaborations and recognizing their environmental, commercial and economic benefits, this technology is poised to become a pragmatic solution for carbon dioxide removal and global warming mitigation in the foreseeable future. The application of algae and bacteria in CO_2 capture offers significant potential as an alternative to tackle energy and environmental problems.

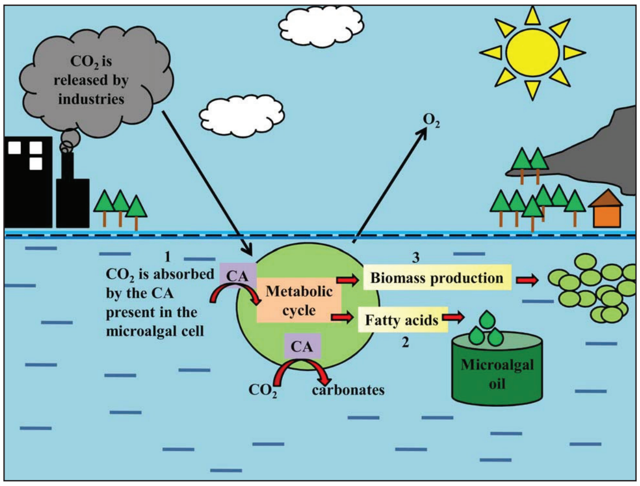

Figure 2: Microalgal carbon capture and storage

The requirement for chlorophyll and CO_2 in algal species is fundamentally dictated by the presence of photosynthesis.

Like terrestrial plants possessing chlorophyll, algal species rely on atmospheric CO_2 as their primary carbon source for photosynthesis, resulting in elevated cell densities and an augmented metabolism rate. This process involves two main stages: the light-dependent stage and a subsequent sequence of light-independent reactions. The carbon dioxide sequestration mechanism observed in algae is a biological natural selection that boosts photosynthetic productivity in microalgae. A crucial contributor to this process is carbonic anhydrase (CA), as depicted in figure 2. CA, an enzyme incorporating zinc, plays a significant role in facilitating CO_2 fixation. Thus, CA's involvement in carbon fixation includes the conversion of bicarbonate to CO_2, acting as material to facilitate a chemical reaction for RuBisCO, the primary CO_2 collection enzyme found in photosynthetic plants (Mondal *et al.***,** 2016).

Microalgal Carbon-dioxide Sequestration in Natural Ecosystems

LOHAFEX

LOHAFEX, an ocean iron fertilization experiment conducted by the AWI in collaboration with the NIO, Goa, aimed to tackle iron deficiency in a specific sea zone. The initiative involved artificially releasing a ferrous sulphate solution to fertilize the iron-deficient region. The iron concentration in the fertilized patch closely resembled the natural iron fertilization processes. Remarkably, the density of the bloom resulting from iron fertilization mirrored that of naturally occurring blooms in the same area.

OMEGA (*Offshore Membrane Enclosure for Growing Algae*)

The OMEGA photobioreactor system comprises large, flexible plastic bags with internal gas-permeable membranes designed for forward osmosis. Utilizing treated wastewater, this setup facilitates the cultivation of freshwater algae. The algae absorb nutrients from the wastewater and CO_2 from the atmosphere, generating biomass and O_2. As the algae grows, the forward osmosis membranes release purified freshwater into the surrounding ocean while retaining nutrients within the bags. OMEGA aids in the remediation of coastal areas by eliminating nutrient sources for toxins. Notably, OMEGA's forward osmosis membrane technology is energy-efficient compared to alternative harvesting methods.

Conclusion

Diverging from conventional carbon capture techniques tailored for power plants, this innovative approach uniquely targets carbon emissions from the transport and industrial sector. It serves a dual purpose by acting as a biofuel source for transportation, fostering net zero emissions. The advanced carbon concentrating mechanisms (CCM), characterized by carbonic anhydrase (CA), play a crucial role in adeptly capturing atmospheric CO_2 and converting it into algal biomass for by-product production. This integrated system not only addresses transportation-related emissions but also contributes to sustainable biofuel production, marking a significant stride towards a more environmentally friendly and carbon-neutral future in the transportation industry.

References

Mondal, M., Khanra, S., Tiwari, O.N., Gayen, K., Halder, G.N., 2016. Role of carbonic anhydrase on the way to biological carbon capture through microalgae - A mini review. *Environmental Progress & Sustainable Energy* 35(6), 1605-1615. DOI: https://doi.org/10.1002/ep.12394.

Nanda, S., Reddy, S.N., Mitra, S.K., Kozinski, J.A., 2016. The progressive routes for carbon capture and sequestration. *Energy Science & Engineering* 4(2), 99-122. DOI: https://doi.org/10.1002/ese3.117.

Onyeaka, H., Miri, T., Obileke, K., Hart, A., Anumudu, C., Al-Sharify, Z.T., 2021. Minimizing carbon footprint via microalgae as a biological capture. *Carbon Capture Science & Technology* 1, 100007. DOI: https://doi.org/10.1016/j.ccst.2021.100007.

Paul, S., Bera, S., Dasgupta, R., Mondal, S., Roy, S., 2021. Review on the recent structural advances in open and closed systems for carbon capture through algae. *Energy Nexus* 4, 100032. DOI: https://doi.org/10.1016/j.nexus.2021.100032.

Yong, J.J.J.Y., Chew, K.W., Khoo, K.S., Show, P.L., Chang, J.S., 2021. Prospects and development of algal-bacterial biotechnology in environmental management and protection. *Biotechnology Advances* 47, 107684. DOI: https://doi.org/10.1016/j.biotechadv.2020.107684.