**REVIEW ON :** **EFFECTS OF OPTIMIZATION OF LIGHT INTENSITY IN BATCH PHOTOBIOREACTOR FOR THE PRODUCTION OF MICROALGAE**

**Abstract:**

The following review paper explores the impact of optimizing light intensity in batch photobioreactors for microalgae biomass production. It investigates the potential of microalgae in environmental sustainability and industrial applications, emphasizing their importance in CO2 sequestration, bioresource production, and wastewater remediation. Additionally, the paper highlights the significance of microalgae biomass in medicine and industry, emphasizing its rich content of essential metabolites and bioactive compounds. The study concludes by emphasizing the importance of optimizing microalgae biomass production to advance the field of algae biotechnology and improve the feasibility of various applications and technologies.

**Introduction**

Microalgae, also known as autotrophic organisms, are highly efficient at extracting CO2 from the atmosphere through photosynthesis. This makes them incredibly valuable for various industrial applications, including cosmetics, health supplements, fertilizers, biofuels, animal feeds, and food products. Alongside their industrial uses, microalgae also play a crucial role in environmental management, particularly in wastewater treatment. They have the ability to remove contaminants and purify water, contributing to ecological balance and environmental sustainability. Recent studies have reviewed the potential of modeling and optimizing microalgae resources as a sustainable biotechnology tool. Specifically, the focus has been on modeling and optimizing microalgae biomass production by regulating light intensity and nutrients in photobioreactors. Microalgae also show promise for phytoremediation of wastewater and reducing high CO2 levels. By modeling and optimizing microalgae biomass production, we can increase the production of microalgae and its byproducts from a small scale to a commercially viable level.

**Microalgae's Potential for Environmental Sustainability and Industrial Uses**

Microalgae are a wide class of microscopic, unicellular organisms that can be either photosynthetic or heterotrophic(AlMallahi, Maryam Nooman, Sara Maen Asaad ., et.al 2022). They play a crucial role in aquatic ecosystems as primary producers, providing energy for a variety of freshwater and marine life.( Siddiki, S. Y. A., Mofijur,2022) . These organisms are highly adaptable and can thrive in various environments, including freshwater, marine, and hypersaline conditions. (Wang, Shi‐Kai, Amanda R 2015)

Autotrophic microalgae are efficient biological factories that help remove CO2 from the environment through photosynthesis.( Lehmuskero, Anni, Matilde Skogen Chauton, 2018).They can also convert CO2, nutrients, and solar energy into valuable bioresources such as proteins, carbohydrates, lipids, and other essential biomolecules.( Romagnoli, F., Weerasuriya-Arachchige, A. R. P. P., Paoli, R., Feofilovs, M., & Ievina, B. 2021).This process not only reduces carbon emissions but also provides important chemicals for various industries, including food, medicine, and biofuel production.(K. Iwamoto, and N. Abdullah 2021)

Heterotrophic microalgae and cyanobacteria fix atmospheric nitrogen and solubilize immobilized phosphorus in the soil to function as biofertilizers. (Bradley, T., Rajaeifar, M. A., Kenny 2023) They are advantageous for sustainable agriculture because they increase soil fertility and lessen the demand for synthetic fertilizers. (Costa, Jorge Alberto Vieira, et al.

Microalgae have a wide range of industrial applications, including production of food, animal feed, cosmetics, aquaculture products, medications, and biofuels.( Yaakob, Maizatul Azrina, et al. 2024) Their biomass, which can contain notable levels of lipids and carbohydrates, is seen as a potential sustainable alternative to conventional, non-renewable resources. (Amaro, H. M., Macedo, Â. C., & Malcata, F. X. 2012) .This makes them an important resource in the efforts to minimize dependency on fossil fuels and support long-term environmental and economic stability.( Brindley, Celeste, et al.2016)

**The Importance of Microalgal Biomass in Medicine and Industry**

The Importance of Microalgal Biomass in Medicine and Industry   
Numerous essential metabolites, including proteins, polysaccharides, fatty acids, minerals, pigments, and vitamins, are plentiful in microalgal biomass.( Khan, Muhammad Imran 2018).These materials are used to make pharmaceuticals and nutritional supplements, and because of their possible applications in medical, they are in great demand.( Russell, Callum, Cristina Rodriguez, 2022) .Microalgae are a great resource for furthering pharmacological research and commercial development due to their vast range of bioactive chemicals.( Meenatchisundaram, Karthikeyan, et al 2024)These metabolites function as vital antioxidants and are utilized to treat a number of illnesses, such as immune system regulation and inflammation.[ Their potential applications in medicine and health promotion stem from the fact that their antioxidant qualities can fortify the body's defenses against oxidative stress.( Ansari, Faiz Ahmad, et al.2022)  
The success of the microalgae-based enterprise depends on the generation of microalgae biomass. Enhancing biomass production is essential since it advances the area of algae biotechnology and raises the viability and effectiveness of many technologies and applications.( Goswami, R. K., Mehariya, S.,2023)

**Advancements in Microalgae Biotechnology: Optimizing Biomass Production and Industrial Applications**

Advancements in algal biotechnology will make it easier to commercialize microalgae applications. (de Jesus Raposo, Maria Filomena 2015 )Optimizing biomass production is crucial for fully utilizing microalgae resources, as it reduces production costs and improves resource utilization efficiency (Chu, 2017).( Gonçalves, J., Freitas, J., Fernandes, I., & Silva, P. 2023) This optimization is essential for ensuring the economic sustainability of microalgae and realizing their potential in various applications. (Chen, Cheng, et al.2022)

Microalgae biomass has numerous industrial uses, including food and animal feed production, fertilizer manufacturing, biofuel, cosmetics, and health product development.( Maltsev, Yevhen, et al. 2021) Its adaptability makes it important across a range of industries, boosting resource efficiency and sustainability.( Sforza, E., Pastore, M., Franke, S. M., & Barbera, E. 2020),( Hossain, S. Z., Sultana, et . , al 2022).

Microalgae biomass is also vital for wastewater treatment due to its effectiveness in cleaning water and removing contaminants. Choi, Hong Il, Young Joon Sung, Choi, Hong Il, Young Joon Sung 2019 )To demonstrate microalgae's potential as a sustainable tool in biotechnology, this research aims to investigate advancements in microalgae resource modeling and optimization.[28] It explores existing modeling techniques and optimization strategies to enhance the performance of microalgae-based systems, ultimately supporting the development of technology and sustainable practices by guiding upcoming R&D projects in this field.(

**Methods of Microalgae Biomass Production: Open vs. Closed Systems and Nutritional Approaches**

The production of microalgae biomass can be carried out using open or closed systems.( Khavari, F., Saidijam, M., Taheri, M., & Nouri, F. 2021). Most research has focused on using open pond-like systems, which are employed in large-scale microalgae growth due to their scalability, low power consumption, simple cleaning procedure, and inexpensive construction cost. Endres, C. H., Roth, A., & Brück, T. B. (2018). However, open systems may be limited by unfavorable climatic conditions and greenhouse gas emissions, which can affect the microalgae's ability to process CO2 and reduce biomass output.[55]

On the other hand, the closed system involves cultivating the algae in a closed photoreactor.(Pradhan, Debabrata, Lala Behari Sukla, 2015) This method reduces both the risk of contamination and the yield of microalgae biomass. It also supports the microalgae's capacity to transform CO2 into biomass.( Xu, Xianzhen, et al.2019) .

The production of microalgae biomass in both closed and open systems (Morales, M., Sánchez, L., & Revah, S. (2018) .depends on the method of nutrition.Autotrophic microalgae have distinct growth requirements compared to heterotrophic microalgae, while mixotrophic microalgae have varying growth conditions.( Kasiri, Sepideh, Ania Ulrich 2019). Nitrate, phosphate, and other necessary components are used in both open and closed systems to promote high biomass production. (Chen, Cheng, et al 2022)

Heterotrophic microalgae produce biomass using organic carbon substrates as a source of energy and carbon, independently of light.( Muylaert, Koenraad, et al.,( Muylaert, Koenraad, et al. 2015) (Pang, Na, et al 2019).They are often grown using glycerol, glucose, and acetate as carbon sources, but research has shown that wastewater can also be used as a source of organic carbon and energy.(Abreu, Ana P., et al 2015) Heterotrophic microalgae biomass production is popular on a commercial scale due to its high lipid buildup, making it suitable for biofuel generation.

In contrast, autotrophic microalgae produce biomass by using CO2 and water in sunlight, while mixotrophic microalgae use both organic and inorganic carbon sources.( Singh, J., & Saxena, R. C. 2015). The mixotrophic process produces microalgae biomass that accumulates more lipids, carbohydrates, proteins, and other biomolecules compared to biomass produced by either the heterotrophic or autotrophic methods.( García-Camacho, F., Sánchez-Mirón, A.,),( del Rio‐Chanona, E. A., Wagner,2019)

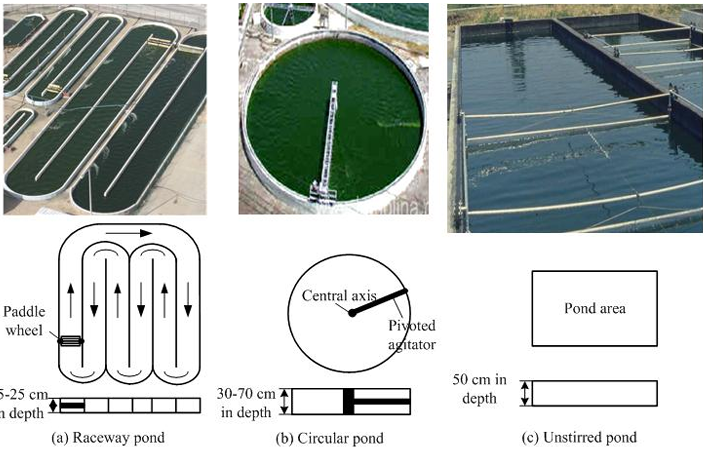
 Fig: different types of open ponds



Fig: a closed photobioreactor

**Mathematical Modeling of Microalgae Growth Kinetics**

Different versions of microalgae models have been developed, incorporating key factors such as light, nutrients, CO2 sequestration, culture system, and microalgae biomass production(Almomani, F. 2020) . Droop introduced the initial model for microalgae growth kinetics in 1983. (Yuan, S., Lei, W., Liu, Q., Liu, R., Liu, J., Fu, J., & Han, Y. (2023) .This model illustrates the relationship between the growth process and the internal substrate of microalgae cells, as described by Equation (1) where μ represents the specific growth rate, μm denotes the theoretical growth rate at infinite quota, Kq is the minimum quota, and Q is the cell quota. After Droop's (1983) work, several studies focused on mathematical modeling and predicting biomass production. (Huesemann, Michael H., et al.2013)monitoring the exterior substrate is easier and more precise than monitoring internal cell quotas, even though most models employ the Monod formulation rather than the Droop model. These models were created using empirical data that showed a connection between microalgae growth and substrate concentration in the culture medium. In order to address the many reasons of differences in microalgae development, dynamic models have been developed.

µ= µ𝑚 S/ks +S(1)

µ= µ𝑚 S/ks +S +S^2/kl(2)

where μ is the specific growth rate, μm is the maximum growth rate , S is the substrate concentration, KS is the half substrate saturation constant,and kI is the inhibition parameter

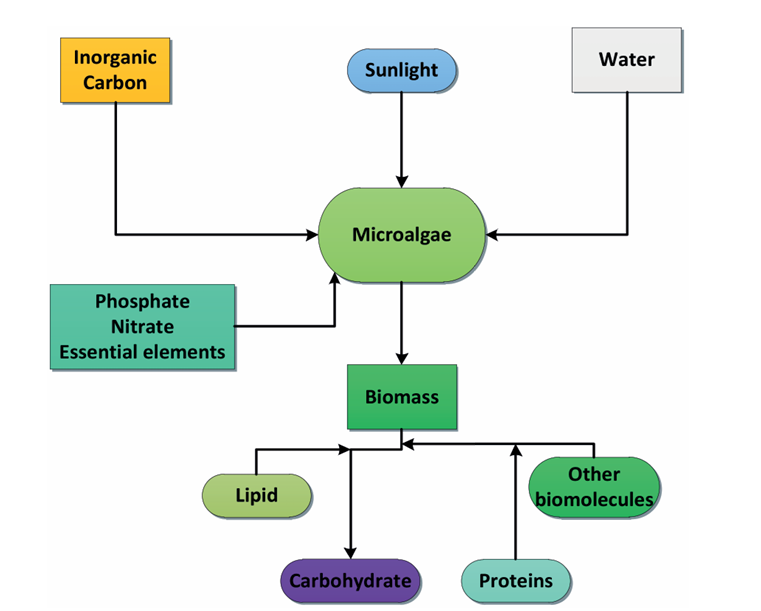


Fig: Mechanism of biomass production by autotrophic microalgae

**Optimizing CO2 Fixation and Biomass Production in Microalgae Systems**

Microalgae play a crucial role in CO2 fixation by using CO2 to produce biomass, particularly lipids, which can be used for biofuel generation.( Barrantes, Maritza Guerrero,2022) To maximize their potential for CO2 fixation and biomass production, it is important to optimize the process under ideal conditions.( Hossain, SM Zakir, Nahid Sultana 2023) .Understanding the behavior of microalgae and identifying the optimal operating parameters can be achieved through modeling microalgae systems. One common application of this research is using microalgae to remove CO2 from power plant exhaust gases. However, it's important to note that flue gas contains other gases such as SO2 and NO2, which can vary based on the source being burned. To develop an accurate model for CO2 fixation during biomass production, it is essential for createing a kinetic model for microalgae's CO2 tolerance in the air, as well as a model for CO2 utilization from the flue gas.( Maltsev, Y., Maltseva,2021) The kinetics of CO2 absorption and its behavior in liquid phase under different pH levels are critical factors to consider for carbon sequestration. Additionally, the pH level significantly affects the rate of CO2 fixation by microalgae, as chemicals like SO2 and NO2 can aid in photosynthesis. Most microalgae species exhibit increased biomass production and CO2 consumption at pH levels between 6 and 11. The models used for forecasting CO2 fixation in microalgae, represented by equations (2) and (3), are the Monod model, which shows monotonic behavior, and the Haldane-like model, which shows non-monotonic behavior characterized by inhibition at high substrate concentrations.

**Understanding the Impact of Light Intensity on Microalgae Biomass Production and Photosynthesis**

AS microalgae can efficiently consume CO2 when exposed to increasing light levels, they can generate biomass even under low light settings.( Braun, J. C., & Colla, L. M. 2023) Light modeling may be used to show how light affects biomass production, as light is essential for microalgae photosynthesis.( Magalhães, Iara Barbosa, et al 2022). In a microalgal cell, the link between light intensity and photosynthesis is represented by the symbol Pl, where l stands for light intensity and P for photosynthesis. The light inhibition regime, the light saturation regime, and the light restriction regime are the three separate regimes that make up Pl.( Saide, Assunta, Kevin A. Martínez 2021) .

Photosynthesis in light-limited regimes often happens at a rate proportionate to the rate of light intensity because the number of protons gathered determines photosynthesis speed.( Huesemann, M., et al 2016) Since the saturation limits for the light intensity necessary for photosynthesis have been achieved, the rate of photosynthesis in microalgae culture is usually at its maximum in light-saturated conditions and is not impacted by light intensity.(2016) Bernard, Olivier, Francis Mairet, Because light intensity over an inhibitory threshold causes key proteins for photosynthesis to become inactive, the rate of photosynthesis in microalgae culture tends to decline as light intensity increases under light inhibition regimes.( Koller, M. 2015).

Although no single model can account for all Pl, research has compiled a variety of interesting models that show how light intensity affects the growth of microalgae biomass.( Weitere, Markus,2018) . Type I, Type II, and Type III models are the three groups into which the created kinetic models may be separated based on theoretical knowledge.( Pang, Na, et al.2019) 73] According to the type I model, every microalgae cell in a well-mixed culture receives the same amount of light intensity and, as a result, has the same average rate of photosynthesis.54] Still, empirical studies have demonstrated that these models' kinetic characteristics depend on operational conditions such system size, incoming light intensity, or cell concentration (Masojídek et al., 2021).( Ramanna, L., Rawat, I., & Bux, F. 2017), 15]

The impact of light gradients on the local rate of photosynthetic activity in microalgae is demonstrated using the type II model.(Dubinsky, Z., & Iluz, D. (2015)) It creates a biological model that describes how local light intensity affects the rate at which photosynthesis occurs locally. (Ezike, Ngozika Chinonyerem Okechukwu, et al.2024) 42]   
Type III models show how the light history of an algal cell influences its rate of photosynthetic activity, accounting for the fact that microalgae experience variations in light intensity as they pass through the system over time.( Sommer, U. (1991) .Usually, to build these models, the light history of the microalgae cells is determined, and a dynamic biological model is used to calculate the rate of photosynthesis of each individual microalgae cell.,( Moreno-Garcia, L., et al. 2019) 75]

**Understanding Nutrient Modeling for Microalgae Growth and Biomass Production**

These nutrients are essential for the formation of biomass by microalgae (Delgadillo-Mirquez et al., 2016). (Echenique-Subiabre, I., Greene, 2023) Microalgae's biomass output is sitively correlated with the concentration of nutrients, particularly phosphorus and nitrogen, which are necessary for microalgae to reach their maximum biomass productivity (Yaakob et al., 2021). (Dalsgaard, T. 2003). Nitrogen and phosphorus concentrations are often the focus of nutrient modeling in microalgae systems (Yaakob et al., 2021). The model used in the modeling and prediction of nitrogen and phosphorus in the system is shown in equations (4–7) below.( Perin, G., Bellan, A.,2019)

Nitrogen models:

μₘcₐ = μₘ (1 − qₙₓᵐⁱⁿ / qₙₓ)

where:

μₘ — max specific growth rate.

qₙₓ — internal nitrogen cell quota.

qₙₓᵐⁱⁿ — min nitrogen cell quota.

μₘcₐ = μₘ Sₙ / (Kₛₙ + Sₙ)

where:

μₘ — max specific growth rate.

Sₙ — nitrogen concentration.

Kₛₙ — half-saturation constant for nitrogen.

Phosphorus model:

μₘcₐ = μₘ Sₚ / (Kₛₚ + Sₚ)

where:

μₘ — max specific growth rate.

Sₚ — phosphorus concentration.

Kₛₚ — half-saturation constant phosphorus.

μₘcₐ = μₘ (1 − qₚₓᵐⁱⁿ / qₚₓ)

where:

μₘ — max specific growth rate.

qₚₓ — internal phosphorus cell quota.

qₚₓᵐⁱⁿ — min phosphorus cell quota.

**Factors to Consider for Modeling Photobioreactors for Microalgae Biomass Production**

It's crucial to predict photobioreactor behavior while doing research on the large-scale generation of microalgae biomass.( Zhao, B., Zhang, Y., Xiong, K., Zhang, Z., Hao, X., & Liu, T. 2011). Time and money will be saved as a result of optimizing the production of microalgae biomass.(Since temperature and light are two factors that directly affect an algae's capacity to create biomass, photobioreactors are essential to the generation of microalgae biomass.( Mimouni,Virginie The latitude and orientation of the photobioreactor, variations in light intensity due to seasonal changes, the influence of nearby objects casting shadows, the reflective qualities of the photobioreactor's surfaces, the absorption of light by microalgae affecting light distribution within the photobioreactor, the specific species of microalgae being used, and the impact of light gradients on microalgae growth and dark respiration.( Shriwastav, Amritanshu, JeenThomas 2017) .should all be taken into account when modeling photobioreactors for sustainable microalgae biomass production.

**Conclusion**

Utilizing microalgae biomass as a resource will help meet current demands without depleting resources needed for future generations.( Shadi W. Hassan, and Fawzi Banat 2022).It is a crucial component in manufacturing pharmaceuticals, biomedical instruments, biofuels, nutritional supplements, and aquaculture feeds.( Kasiri, Sepideh, Ania Ulrich 2016) .Additionally, it is commonly used in phycoremediation of contaminated water.

The long-term sustainability of freshwater and marine habitats is impacted by the disruption of the food chain caused by the production of aquaculture feeds from forage fish. The use of terrestrial plants as aquaculture feed is associated with overuse of freshwater resources and deforestation. As a result, vital food supplies including soybeans, maize, cottonseed, peas, wheat, and barley become scarce. Microalgae are a superior choice for producing feed for aquaculture because they yield higher net biomass than terrestrial plants. (Bose, A., Lin, R., Rajendran 2016) They do not generally require freshwater for growth, and they grow faster in wastewater.

Microalgae biomass is considered an efficient resource for aquaculture feed production due to its metabolic characteristics. Analyzing the effectiveness of microalgae biomass in aquaculture feed production has been published. The use of biofuel is increasing as a potential replacement for fossil fuels due to concerns about high costs and environmental impact. Switching to biofuels is seen as a way to reduce the strain of using over 86 million barrels of crude oil daily and mitigate the financial impact of rising crude oil prices. Fossil fuel usage contributes to over 25% of CO2 emissions, and using biofuels would provide environmental benefits.

The increased use of terrestrial plants for biofuel production has led to rising food crop prices and increased deforestation, raising concerns about the significance of biofuels.( Rehman, M., Kesharvani, S., Dwivedi, G., & Suneja, K. G. 2022) This could also increase greenhouse gas emissions rather than decrease them. The main points of contention in the discussion about the viability of biofuels are fuel vs. food, greenhouse gas emissions, and ecosystem services.( Amaro, Helena M., 2012) The issues related to using food crops for biofuels can be addressed by utilizing microalgae biomass, as they develop more quickly and are more efficient at producing biofuel compared to terrestrial plants. Microalgae can store more lipids in their biomass and sequester inorganic carbon, addressing concerns related to greenhouse gas emissions and ecosystem services.( Huesemann, Michael H., et al 2013

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