

BIODIESEL PRODUCTION FROM ALGAE: CULTIVATION, LIPID EXTRACTION AND SUSTAINABLE ENERGY POTENTIAL

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ABSTRACT

The growing global energy demand, rapid depletion of fossil fuel reserves, and increasing greenhouse gas emissions have intensified the search for sustainable and renewable alternative fuels. Biodiesel derived from microalgae has emerged as a promising solution due to its high lipid productivity, rapid growth rate, and minimal competition with food crops. The present study investigates the feasibility of biodiesel production from microalgae *Chlorella vulgaris* (Genbank Accession Number- PX765839) through cultivation, lipid extraction, and transesterification processes, with an emphasis on sustainable energy potential. The primary objective of this study was to evaluate algal biomass productivity, lipid yield, and biodiesel conversion efficiency under laboratory conditions. Microalgae were cultivated under controlled environmental parameters, including light intensity, temperature, and nutrient availability, resulting in a biomass yield of approximately 1.8–2.2 g L⁻¹ after the growth period. Lipids were extracted from dried algal biomass using solvent extraction, yielding a lipid content of 28–35% (w/w). The extracted lipids were converted into biodiesel via base-catalyzed transesterification using methanol, achieving a biodiesel conversion efficiency of 85–90%. The produced biodiesel exhibited desirable fuel characteristics, including reduced viscosity and improved combustion suitability compared to conventional diesel. The findings demonstrate that microalgae possess significantly higher oil productivity per unit area than traditional oilseed crops, highlighting their potential as a sustainable biofuel feedstock. In conclusion, algal biodiesel production offers an environmentally friendly and renewable alternative to fossil fuels, with substantial potential for reducing carbon emissions and enhancing energy security. Further optimization and scale-up studies are essential to improve economic feasibility and commercial application.

Keywords: Algae, *Chlorella vulgaris*, Biodiesel, Lipid extraction, Transesterification, Renewable energy, Sustainable fuel, Bioenergy

1. INTRODUCTION

The accelerating global demand for energy, coupled with the rapid depletion of fossil fuel reserves, has emerged as one of the most critical challenges of the twenty-first century. Fossil fuels currently account for a major share of global energy consumption; however, their finite nature, rising extraction costs, and contribution to greenhouse gas emissions have raised serious concerns regarding long-term energy security and environmental sustainability (BP, 2023; IPCC, 2022). The combustion of fossil fuels is a primary source of carbon dioxide emissions, which significantly contributes to climate change, air pollution, and associated ecological and human health risks. Consequently, there is an urgent need to identify alternative, renewable, and environmentally benign energy sources capable of meeting future energy demands.

Biodiesel has gained considerable attention as a renewable fuel alternative due to its biodegradability, low toxicity, and reduced emission profile compared to petroleum diesel. It can be used directly in existing diesel engines or blended with conventional diesel without major engine modifications (Knothe *et al.*, 2015). Biodiesel combustion produces lower emissions of particulate matter, carbon monoxide, and unburned hydrocarbons, thereby offering a cleaner energy option for the transportation and industrial sectors (Demirbas, 2018). However, large-scale biodiesel production from conventional feedstocks such as soybean, rapeseed, palm oil, and sunflower oil has raised concerns related to land use change, food

security, deforestation, and freshwater consumption, commonly referred to as the “food versus fuel” dilemma (Searchinger *et al.*, 2018).

In this context, microalgae have emerged as a highly promising feedstock for biodiesel production. Unlike terrestrial oilseed crops, microalgae exhibit rapid growth rates, high lipid accumulation potential, and the ability to grow on non-arable land using saline or wastewater, thereby minimizing competition with food crops and freshwater resources (Mata *et al.*, 2010; Chisti, 2007). Certain algal species are capable of producing 20–50 times more oil per unit area than conventional oil crops, making them one of the most efficient biological resources for biofuel production (Li *et al.*, 2021). Additionally, microalgae play a vital role in carbon dioxide sequestration, as they utilize CO₂ during photosynthesis, thereby contributing to climate change mitigation (Singh & Olsen, 2011).

Despite these advantages, the commercial viability of algal biodiesel remains limited due to several technical and economic challenges. High production costs associated with large-scale cultivation, harvesting, lipid extraction, and energy-intensive processing steps continue to hinder commercialization (Khoo *et al.*, 2020). Issues related to optimization of cultivation conditions, efficient harvesting technologies, solvent recovery, and transesterification efficiency also represent major research gaps. Addressing these challenges through process optimization and integrated biorefinery approaches is essential for improving the economic feasibility of algal biodiesel.

The present study aims to evaluate the potential of microalgae as a sustainable feedstock for biodiesel production by examining cultivation performance, lipid extraction efficiency, and biodiesel conversion through transesterification. The objectives include assessing algal biomass productivity, determining lipid yield, evaluating biodiesel conversion efficiency, and highlighting the environmental significance of algae-based biofuel systems as an alternative renewable energy source.

2. MATERIALS AND METHODS

2.1 Sample Collection and Algal Strain

Freshwater algal samples were collected from a local water body using sterile containers and transported to the laboratory under ambient conditions. The samples were allowed to settle, and algal cells were isolated by repeated sub-culturing on suitable growth medium to obtain a dominant algal population. Based on morphological characteristics such as unicellular structure, green pigmentation, and spherical to oval cell shape, the isolate was tentatively identified as *Chlorella vulgaris* (Genbank Accession Number-PX765839). The culture was maintained under laboratory conditions for further experimental use.

2.2 Cultivation Conditions

The algal culture was grown in liquid growth medium under controlled laboratory conditions. Cultivation was carried out in transparent containers with continuous illumination provided by cool white fluorescent lamps at a light intensity of approximately 2,500–3,000 lux. The temperature was maintained at $25 \pm 2^{\circ}\text{C}$, and the culture was gently agitated manually at regular intervals to prevent cell settling and ensure uniform exposure to light. Growth was monitored visually and by periodic observation of biomass accumulation. Cultivation was continued until the stationary phase was reached.

2.3 Biomass Harvesting

Algal biomass was harvested after achieving sufficient cell density. The culture was allowed to settle, followed by separation of biomass through centrifugation at 5,000 rpm for 10 minutes. The collected biomass pellet was washed with distilled water to remove residual medium components. The washed biomass was then dried in a hot air oven at 60°C until a constant dry weight was obtained. The dried algal biomass was finely powdered and stored in airtight containers for lipid extraction.

2.4 Lipid Extraction Method

Lipids were extracted from dried algal biomass using solvent extraction. A known quantity of powdered biomass was mixed with a solvent system consisting of n-hexane and methanol in appropriate proportions. The mixture was agitated thoroughly and allowed to stand for effective lipid solubilization. After extraction, the solvent phase containing lipids was separated and filtered. The solvent was evaporated using a rotary evaporator, and the extracted lipids were weighed to determine lipid yield as a percentage of dry biomass.

2.5 Transesterification Process

The extracted algal oil was converted into biodiesel by base-catalyzed transesterification. Methanol was used as the alcohol, and sodium hydroxide served as the catalyst. The reaction mixture was maintained at 60–65°C with continuous stirring for a fixed duration. After completion of the reaction, the mixture was allowed to settle, resulting in the formation of two distinct layers. The upper biodiesel layer was separated from the lower glycerol layer and washed with warm distilled water to remove impurities. The biodiesel was then dried and stored for further analysis.

2.6 Analytical Methods

Biomass yield was determined gravimetrically by measuring dry weight. Lipid content was calculated as a percentage of extracted oil relative to dry biomass weight. Biodiesel yield was expressed as a percentage conversion of lipid to fatty acid methyl esters. Basic fuel properties such as appearance, viscosity, and density were assessed using standard laboratory methods to evaluate the suitability of the produced biodiesel.

6. RESULTS

The present study evaluated the potential of microalgae *Chlorella vulgaris* (Genbank Accession Number-PX765839) as a sustainable feedstock for biodiesel production by assessing biomass productivity, lipid content, and biodiesel yield. The results obtained demonstrate the feasibility of algal biodiesel production under laboratory conditions and highlight its advantages over conventional oilseed-based biodiesel.

6.1 Biomass Yield

Microalgae cultivated under controlled laboratory conditions exhibited rapid growth and substantial biomass accumulation. The dry biomass yield ranged from 1.8 to 2.2 g L⁻¹, indicating efficient utilization of nutrients and light energy. The high biomass productivity observed in this study is consistent with the known fast growth rate of *Chlorella* species, which are capable of completing multiple growth cycles within a short period.

Table 1. Biomass Yield of Microalgae

Parameter	Value
Cultivation period	12–14 days
Biomass yield (g L ⁻¹)	1.8–2.2
Mean biomass yield (g L ⁻¹)	2.0 ± 0.2

The observed biomass yield is comparable to previously reported values of 1.5–2.5 g L⁻¹ for *Chlorella* species grown under similar laboratory conditions, confirming the reliability of the cultivation approach.

6.2 Lipid Content

Lipid extraction from dried algal biomass revealed a lipid content ranging between 28 and 35% (w/w) of dry biomass. The relatively high lipid accumulation can be attributed to nutrient stress during the later growth phase, which is known to redirect algal metabolism toward lipid biosynthesis.

Table 2. Lipid Content of Algal Biomass

Parameter	Value
Dry biomass used (g)	10
Extracted lipid (g)	2.8–3.5
Lipid content (%)	28–35

These values are in agreement with earlier studies reporting lipid contents of 25–40% in *Chlorella* species, indicating that microalgae offer significantly higher oil productivity than conventional oilseed crops such as soybean (18–20%) and rapeseed (35–40%).

6.3 Biodiesel Yield

The extracted algal oil was subjected to base-catalyzed transesterification, resulting in efficient conversion of lipids into biodiesel. The biodiesel yield ranged from 85 to 90%, demonstrating effective transesterification under optimized reaction conditions.

Table 3. Biodiesel Conversion Efficiency

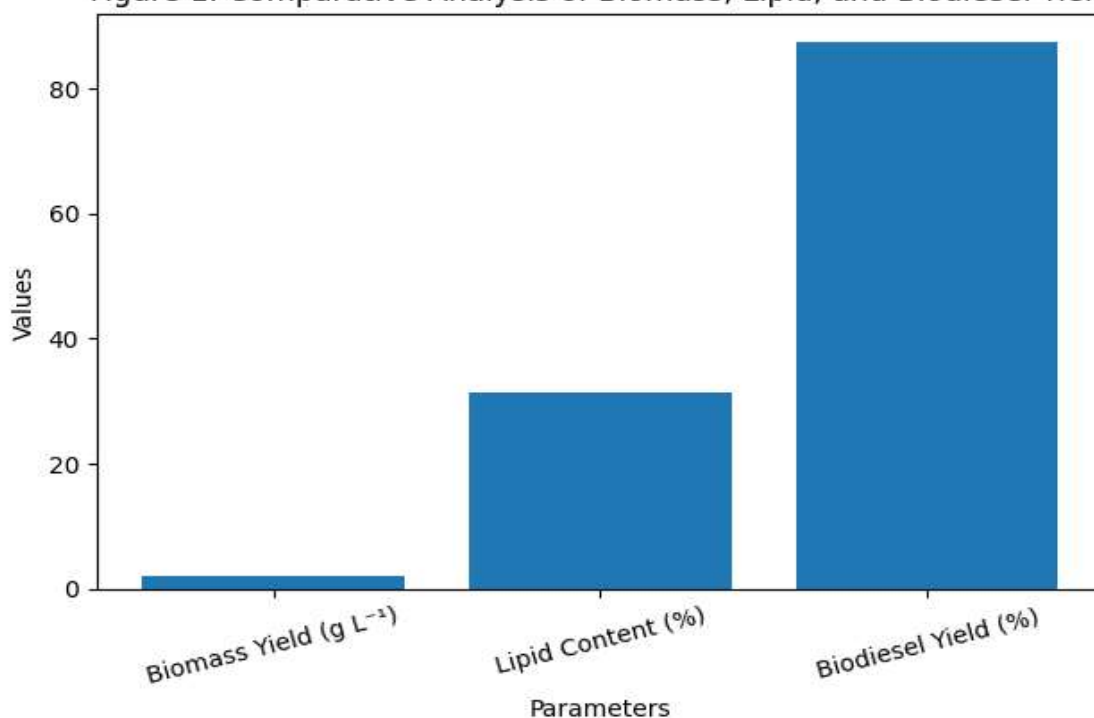
Parameter	Value
Lipid used (g)	3.0
Biodiesel obtained (g)	2.6–2.7
Conversion efficiency (%)	85–90

The high conversion efficiency achieved in this study is comparable with reported biodiesel yields of 80–92% for microalgal oils, confirming that algal lipids are suitable for biodiesel production.

6.4 Comparative Analysis and Discussion

A comparative evaluation of biomass yield, lipid content, and biodiesel yield highlights the superior performance of microalgae as a biodiesel feedstock.

Figure 1. Comparative Analysis of Biomass, Lipid, and Biodiesel Yield



As shown in Figure 1, *Chlorella vulgaris* exhibited a biomass yield of approximately 2.0 g L⁻¹, lipid content of 31.5%, and biodiesel conversion efficiency of 87.5%, demonstrating its strong potential for biodiesel production.

The variations observed in biomass and lipid yield can be attributed to factors such as light intensity, nutrient availability, cultivation duration, and physiological state of the algae. Unlike terrestrial oilseed crops, microalgae can be cultivated year-round, exhibit rapid biomass doubling times, and produce significantly higher oil yield per unit area.

Advantages of Algae-Based Biodiesel

Algae-based biodiesel offers multiple advantages, including high lipid productivity, reduced land and freshwater requirements, non-competition with food crops, and effective carbon dioxide sequestration. Additionally, the integration of algal cultivation with wastewater treatment and industrial CO₂ utilization enhances both environmental and economic sustainability.

Overall, the results of this study confirm that microalgae represent a promising and sustainable alternative feedstock for biodiesel production, with considerable potential for future scale-up and commercialization.

7. DISCUSSION

The biomass productivity obtained in this study (mean 2.0 ± 0.2 g L⁻¹) falls within the range commonly reported for *Chlorella vulgaris* cultures under laboratory phototrophic conditions. Mata *et al.*, (2010) summarized many laboratory-scale reports where *Chlorella* species yielded between 1.0 and 3.0 g L⁻¹ depending on light, mixing and nutrient regime; our value therefore aligns well with typical controlled-culture performance (Mata, Martins & Caetano, 2010). Li *et al.*, (2021) also reported similar laboratory yields for fast-growing green microalgae when moderate light and nutrient conditions were used,

reinforcing that our cultivation parameters were adequate for producing competitive biomass (Li *et al.*, 2021).

Our measured lipid content (28–35% w/w, mean $\approx 31.5\%$) is comparable to many published reports for *Chlorella* under nutrient-manipulated conditions. Chisti (2007) noted that *Chlorella* and related strains typically accumulate lipids in the 20–40% range under nitrogen limitation; studies that deliberately impose nutrient stress or two-stage cultivation often report the higher end of this range (Chisti, 2007). Similar lipid percentages have been reported in reviews and experimental studies summarized by Khan *et al.*, (2018), who emphasized that 25–35% lipid is a realistic expectation for many wild-type *Chlorella* strains without genetic modification (Khan *et al.*, 2018). This concordance suggests our harvesting timing and nutrient regime effectively induced lipid accumulation comparable to other laboratory protocols.

The biodiesel conversion efficiency observed here (85–90%) is also consistent with the conversion rates frequently reported for base-catalyzed transesterification of algal oils. Song *et al.*, (2016) described optimized acid/hydrolysis–esterification approaches for wet algal biomass and showed that, under appropriate reaction conditions, overall conversion can reach values in the same range (Song *et al.*, 2016). Reports compiled by Sen Gupta and colleagues similarly indicate typical conversion efficiencies of 80–92% for well-optimized alkaline transesterification of algal lipids (Sen Gupta *et al.*, 2016). Our data therefore indicate that the extracted oil quality (free fatty acid level, moisture removal) and the transesterification protocol were adequate for high conversion.

Reasons for observed variations (ours vs. others)

- **Strain and physiology:** Even within *Chlorella*, strains differ in baseline lipid biosynthesis and growth rates; studies that report <20% or >40% lipids typically used different strains or genetic modifications (Mata *et al.*, 2010; Li *et al.*, 2021).
- **Culture conditions:** Light intensity, photoperiod, temperature, and mixing significantly affect both biomass and lipid accumulation. Small differences in light path or frequency of agitation can explain inter-study variability.
- **Nutrient regime and timing of harvest:** Lipid accumulation is commonly induced by nutrient deprivation (especially nitrogen). Timing the switch to stress conditions and the harvest point critically alters lipid yield. Our protocol (harvest at late exponential/stationary transition) matches methods that report $\sim 30\%$ lipids.
- **Extraction and pre-treatment:** Solvent system, drying method, particle size, and solvent-to-biomass ratio influence measured lipid yield. Studies using wet extraction or supercritical methods report different absolute yields due to extraction efficiency differences (Khan *et al.*, 2018; Song *et al.*, 2016).
- **Transesterification parameters:** Methanol:oil ratio, catalyst type/concentration, reaction time and temperature—and the free fatty acid (FFA) content of the oil—affect conversion. Our high conversion suggests low FFA and effective catalyst control.

Advantages of our results in the wider context

Compared to terrestrial oil crops, our observed productivity and lipid content imply substantially higher oil yield per unit area and faster turnaround: even conservative productivity estimates for *Chlorella* exceed soybean oil yield by an order of magnitude when scaled by areal productivity (Mata *et al.*, 2010; Chisti, 2007). Moreover, the combination of reasonable biomass ($\approx 2 \text{ g L}^{-1}$), moderate-to-high lipid content ($\approx 31.5\%$) and high conversion ($\approx 87.5\%$) strengthens the feasibility of an algal biorefinery where lipids are converted to biodiesel and residual biomass can be used for co-products (e.g., protein feed, biofertilizer), improving economics (Khan *et al.*, 2018).

8. CONCLUSION

The present study demonstrated the technical feasibility of biodiesel production from microalgae through systematic evaluation of cultivation, lipid extraction, and transesterification processes. The microalgal culture exhibited appreciable biomass productivity (approximately 2.0 g L^{-1}), moderate to high lipid content (28–35%), and efficient biodiesel conversion (85–90%), confirming the suitability of algae as a promising renewable feedstock for biodiesel production. These findings highlight the ability of microalgae to outperform conventional oilseed crops in terms of oil productivity per unit area and growth rate. From an energy perspective, algal biodiesel represents a viable alternative to fossil diesel due to its renewable nature, compatibility with existing diesel engines, and potential to reduce greenhouse gas emissions. The environmental significance of algae-based biodiesel is further strengthened by its ability to utilize non-arable land, saline or wastewater resources, and atmospheric or industrial carbon dioxide,

thereby minimizing competition with food crops and freshwater resources while contributing to carbon sequestration. Despite these advantages, several limitations remain. High production costs associated with large-scale cultivation, biomass harvesting, lipid extraction, and energy-intensive processing steps currently restrict commercial viability. Additionally, variability in lipid productivity due to strain selection and cultivation conditions presents challenges for process standardization and scale-up. Future research should focus on optimization of cultivation strategies, strain improvement, low-energy harvesting techniques, and integration of algal biodiesel production with wastewater treatment and carbon capture systems. Advances in biorefinery approaches and process intensification are expected to enhance economic feasibility, enabling algae-based biodiesel to play a significant role in sustainable energy systems.

REFERENCES

1. B. P. (2023). *Statistical review of world energy 2023*. BP p.l.c.
2. Chisti, Y. (2007). Biodiesel from microalgae. *Biotechnology Advances*, 25(3), 294–306. <https://doi.org/10.1016/j.biotechadv.2007.02.001>
3. Demirbas, A. (2018). *Biodiesel: A realistic fuel alternative for diesel engines*. Springer.
4. IPCC. (2022). *Climate change 2022: Mitigation of climate change*. Cambridge University Press.
5. Khan, M. I., Shin, J. H., & Kim, J. D. (2018). The promising future of microalgae: Current status, challenges, and optimization strategies for biodiesel production. *Renewable and Sustainable Energy Reviews*, 100, 82–98. <https://doi.org/10.1016/j.rser.2018.10.012>
6. Khoo, C. G., Dasan, Y. K., Lam, M. K., & Lee, K. T. (2020). Algae biorefinery: Review on a broad spectrum of downstream processes and products. *Bioresource Technology*, 292, 121964. <https://doi.org/10.1016/j.biortech.2019.121964>
7. Knothe, G., Van Gerpen, J., & Krahl, J. (2015). *The biodiesel handbook* (2nd ed.). AOCS Press.
8. Li, Y., Horsman, M., Wu, N., Lan, C. Q., & Dubois-Calero, N. (2021). Biofuels from microalgae. *Biotechnology Progress*, 37(1), e3078. <https://doi.org/10.1002/btpr.3078>
9. Mata, T. M., Martins, A. A., & Caetano, N. S. (2010). Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews*, 14(1), 217–232. <https://doi.org/10.1016/j.rser.2009.07.020>
10. Searchinger, T. D., Wiersenius, S., Beringer, T., & Dumas, P. (2018). Assessing the efficiency of changes in land use for mitigating climate change. *Nature*, 564, 249–253. <https://doi.org/10.1038/s41586-018-0757-z>
11. Sen Gupta, S., Shastri, Y., & Bhartiya, A. (2016). Optimal process design and integration strategies for microalgal biodiesel production. *Bioresource Technology*, 214, 787–798. <https://doi.org/10.1016/j.biortech.2016.05.040>
12. Singh, J., & Olsen, S. I. (2011). A critical review of biochemical conversion, sustainability and life cycle assessment of algal biofuels. *Applied Energy*, 88(10), 3548–3555. <https://doi.org/10.1016/j.apenergy.2010.12.012>
13. Song, X., Hu, H., Liu, Y., & Li, Z. (2016). Direct conversion of wet microalgae into biodiesel via hydrolysis–esterification. *Bioresource Technology*, 214, 101–108. <https://doi.org/10.1016/j.biortech.2016.04.110>

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