Mini Review

A Mini Review on the Impact of Solvent Polarity and Temperature on Lipid Extraction and Biofuel Production from Algae: Current Progress, Greener Solvents and Promising Technology

Husam Talib Hamzah[1]*, Veluru Sridevi[2] and Fouad Hussein Ali[3]

[1]Department of Fuel and Energy, Al-Ma'moon University, Baghdad, Iraq; [2]Department of Chemical Engineering, Andhra University, Visakhapatnam- 53003. India; [3]Department of Production Engineering and Management, Technical University of Crete, Crete, Greece.

Abstract | Microalgae, due to their high lipid potential, rapid growth rate, and ability to be cultivated without competing with food crops for land, are hailed as among the most promising sources of bioenergy. The production of bioenergy from microalgae is primarily determined by lipid extraction and conversion to fatty acid esters via transesterification. The solvent type and temperature are critical factors that influence extraction efficacy and target selectivity: the physicochemical properties of the solvents dictate which lipids can be targeted, while temperature influences mass transfer rates and the stability of thermally labile compounds. This study discussed the solvent characteristics and temperature conditions affecting algal lipid extraction, emphasizing eco-friendly (green) solvents and modern techniques such as liquefied dimethyl ether, deep eutectic solvents, and supercritical carbon dioxide. It also reviews how approaches such as sonication and microwave irradiation can enhance extraction efficiency, save time, and reduce energy consumption. Moreover, operating parameters such as algal species, moisture content, and pre-treatment that affect the quality of oil obtained from Axenic Chlorella vulgaris and its biofuel conversion efficiency are discussed. The outcome demonstrates that the use of green solvents in combination with novel extraction techniques can significantly accelerate recovery rates, improve process sustainability, and reduce waste disposal costs. However, large-scale industrial methods report challenges in achieving sustainable economic and environmental performance.

Received | March 16, 2026; **Accepted** | March 26, 2026; **Published** | June 15, 2026
***Correspondence** | Husam Talib Hamzah, Department of Fuel and Energy, Al-Ma'moon University, Baghdad, Iraq; **Email:** alwatanaliraqi@gmail.com
Citation | Hamzah, H.T., V. Sridevi and F.H. Ali. 2026. A mini review on the impact of solvent polarity and temperature on lipid extraction and biofuel production from algae: Current progress, greener solvents and promising technology. *Smart Technologies in Science and Engineering,* 1(2): 70-74.
Keywords |Solvent polarity, Lipid content, Biofuel, Green solvents, Lipid extraction, Algae

Introduction

The lipid-rich content, fast growth rate, and high carbon uptake capacities make microalgae a potential sustainable biofuel source, particularly for biodiesel production (Zhang *et al.*, 2022; Sundaram *et al.*, 2023; Yu *et al.*, 2024). Solvent polarity and temperature play a pivotal role in the efficiency of lipid extraction from microalgae: while polarity necessarily defines selectivity (neutral vs. polar lipids), the extraction rate, together with the quality of extracted fatty acids, is governed by temperature (Wang *et al*., 2024; Tzima *et al*., 2023; Siddiqui *et al*., 2023) Therefore, new methods have been researched such as liquefied dimethyl ether (DME), deep eutectic solvents (DES) and supercritical carbon dioxide $ScCO_2$ which are environmentally friendly options that research aims to finetune their properties or operating conditions to tap into optimal yield-biofuel quality performance. Similarly, other parameters, such as algal species, moisture content, and pre-treatment, have significant impacts on production (Wang *et al*., 2024; Tzima *et al*., 2023; Yu *et al*., 2024; Siddiqui *et al*., 2023).

In this work, we examine the role of these factors as cited in recent studies and illustrated in tables. Additionally, it aims to provide a comprehensive scientific evaluation of the effects of solvent polarity, temperature, and other operating factors on lipid extraction efficiency and lipid conversion to biofuel from microalgae. On the other hand, we emphasize the importance of solvent properties for extraction performance and lipid recovery efficiency with green solvents such as DME, $ScCO_2$, and DES. It provides also some more clarity on the effect of thermal conditions and advanced extraction techniques (e.g. ultrasound, microwaves, supercritical-fluid extraction) in terms of improving yield and reducing energy and time costs, as well as discussing how oil properties relate to its subsequent conversion efficiency by transesterification and the key technical and economic challenges towards industrial-scale deployment with future perspectives for efficient sustainable processes."

Polarity and temperature influence on extraction

The polarity and temperature of the solvent are key variables influencing lipid recovery from microalgae and the selectivity of isolated compounds. Neutral lipids, including oils and fats from the complex lipid biosynthesis pathways, are more effective with non-polar solvents because they primarily serve as biodiesel feedstock in their triacylglycerol forms. Examples include liquefied DME and supercritical CO_2, which have demonstrated excellent lipid extraction performance without requiring biomass drying before extraction, thereby reducing energy consumption and enhancing process efficiency (Wang *et al*., 2024; Yu *et al*., 2024). On the other hand, polar solvents or mixed solvent systems such as DES, or the addition of ethanol to $ScCO_2$ systems as a co-solvent, can facilitate the extraction of polar compounds (proteins, carbohydrates, phospholipids), allowing for the separation of a wider range of high-value biocompounds from algal biomass **Table 1**. Provide examples of some selected microalgal species and the optimal extraction conditions. This table summarizes the main extraction methods applied to some algal species to maximize value-added lipid or biopolymer recovery and to demonstrate how operating conditions influence both yield and product quality. The first column, Algal species, lists the organisms studied, including Chlorella vulgaris, Botryococcus braunii, Nannochloropsis sp. and Kappaphycus alvarezii, known for high carbohydrate-based biopolymer (carrageenan) accumulations. The Solvent/technique column describes the use of relatively "green" solvents and processes, including supercritical carbon dioxide with ethanol as co-solvent, liquefied dimethyl ether, various organic/green solvents, and DES based on choline chloride with glycerol or urea. The temperature and other conditions columns indicate that extraction performance is largely parameter-driven. Under these conditions, Chlorella vulgaris has been shown to produce the highest yield of lutein from supercritical CO_2 with ethanol at upper-moderate temperatures (60–80 °C) under high pressure (20–50 MPa). For Botryococcus braunii, liquefied dimethyl ether at near-ambient pressure and high biomass moisture content yields high oil content and high fuel quality without extensive drying. Table 1 illustrates the use of different organic/green solvents for triacylglycerol accumulation in Nannochloropsis sp. The use of DES (ChCl+Gly/Urea) at 85 °C, along with water up to 10%, in Kappaphycus alvarezii yields around 60% carrageenan. Lastly, the Main lipid/yield outcomes column shows that different types of solvents, extraction methods, and temperature/pressure/moisture content push the process from biomass to target products (e.g., carotenoids such as lutein, high-quality oils for biofuel applications, and/or polymers such as carrageenan). Altogether, the table highlights that green-solvent-based extraction technologies represent promising alternatives to traditional organic solvents in algal biorefinery value chains (Tzima *et al*., 2023; Liu *et al*., 2023; Siddiqui *et al*., 2023).

The extraction rate is directly affected by temperature, as it enhances mass transfer and increases the solubility of target compounds; however, this effect is not always linear: high temperatures can degrade

Table 1: *Microalgal species considered and their suitable extraction conditions.*

Algal species	Solvent/technique	Temperature (°C)	Other conditions	Main lipid/yield outcomes	References
Chlorella vulgaris	$ScCO_2$ + ethanol	60–80	Pressure: 20–50 MPa	Highest lutein yield at intermediate T, high P	Yu *et al*. (2024)
Botryococcus braunii	Liquefied DME	Near ambient	High moisture content	High oil yield and high-quality fuel	Wang *et al*. (2024)
Nannochloropsis sp.	Organic/green solvents	Variable	–	High triacylglycerol accumulation	Ye *et al*. (2024)
Kappaphycus alvarezii	DES (ChCl+Gly/Urea)	85	Water addition up to 10%	Carrageenan yields up to 60%	Liu *et al*. (2023)

Table 2: *A claims–evidence statement with key points.*

Claims	Evidence	Supporting studies
Solvent polarity significantly affects the selectivity and efficiency of lipid extraction..	This has been experimentally demonstrated using several modern, green solvents and techniques.	(Wang *et al*., 2024; Tzima *et al*., 2023; Yu *et al*., 2024)
Raising the temperature increases yield up to a certain point, after which it may cause the degradation of sensitive compounds..	This non-linear relationship has been experimentally proven in SFE/UAE/DES.	(Yu *et al*., 2024; Pinto *et al*., 2023)
DME, DES, and $ScCO_2$ technologies are more sustainable and environmentally safer than traditional methods	Multiple reviews and reports confirm reduced toxicity and energy efficiency.	(Wang *et al*., 2024; Tzima *et al*., 2023)
Combining ultrasonic or microwave energy improves yield and reduces time.	This has been practically proven in several studies.	(Pinto *et al*., 2023; Pajot *et al*., 2022)
Some species, such as Botryococcus braunii, produce much higher oil yields..	This has been experimentally proven, but it depends on the growing and processing conditions.	(Wang *et al*., 2024)
High-viscosity DES may hinder large-scale industrial processes..	Practical problems have been observed in some applications.	(Tzima *et al*., 2023)

thermally sensitive compounds, e.g., unsaturated fatty acids or some bioactive proteins. Consequently, the choice of an optimal temperature is crucial for achieving enhanced extraction efficiency while maintaining compound quality (Yu *et al*., 2024; Pinto *et al*., 2023).

Modern extraction and conversion techniques

Due to the need for high-efficiency processes with lower energy and solvent consumption, lipid extraction methods from microalgae have advanced significantly, with modern techniques introduced. Ultrasound-assisted and microwave-assisted extraction are two of the most publicised methods that can disrupt algal cell walls and improve mixing, thereby increasing lipid recovery while simultaneously decreasing processing times (which also protects thermally labile compounds at moderate temperatures) (Pinto *et al*., 2023; Pajot *et al*., 2022). One of the most sophisticated (Yu *et al*., 2024) methods that enables fine control of pressure and temperature with co-solvents to obtain selective extractions of bioactive molecules with high efficiency is supercritical fluid extraction, especially $ScCO_2$. Deep eutectic solvents (DES) have become a new class of tunable green solvents, whose physicochemical properties are shaped to the nature of the target compounds (lipids, carbohydrates, proteins). Their low toxicity and reusability make them appealing candidates for sustainable extraction processes (Tzima *et al*., 2023; Liu *et al*., 2023).

Discussion

Newly published studies have demonstrated that the type of solvent and thermal operating conditions strongly influence the amount and quality of extracted lipids, as well as their suitability for conversion into high-quality biofuel. When comparing the two methods, DME, DES, and $ScCO_2$-based green technologies can be a more environmentally friendly and safer alternative to traditional organic solvents, given their often toxic and energy-intensive properties.

Using intensification methods such as ultrasound or microwaves is indicated to enhance the extraction yield further. It shortens processing time while maintaining end product quality. Nevertheless, issues persist, including the high viscosity of certain green solvents (particularly DES), recycling challenges, and the need for meticulous process control to prevent degradation of thermally sensitive compounds or loss of desired properties. Oil characteristics depend on algal species, cultivation, and pre-treatment conditions. Table 2 provides a claims–evidence summary of key points.

Conclusion

The type of solvent employed and the operational temperature would strongly influence not only microalgal lipid extraction efficiency but also selectivity in biocompound recovery, according to recent investigations. Neutral lipid extraction with non-polar solvents such as DME and $ScCO_2$ is also very efficient, while additional high-value biomolecules can be recovered using polar solvents or mixed solvent systems. Precise temperature control may facilitate mass transfer and allow the extraction of higher amounts without degrading thermally labile compounds. The growing field of emerging techniques such as ultrasound-assisted extraction, microwave-assisted extraction, supercritical-fluid extraction, and DES-based systems offers major opportunities to improve extraction efficiency and mitigate environmental impacts; however, industrial implementation is still limited by operating costs and process design complexity. The development of integrated strategies combining green solvents with extraction-intensification techniques has emerged as a promising pathway to economically viable, sustainable biofuel production from microalgae.

Acknowledgement

The authors would like to express their sincere appreciation to the Department of Fuel and Energy, Al-Ma'moon University, Baghdad, Iraq, for providing academic support and an encouraging research environment for this study.

Novelty Statement

This study provides a comprehensive review of recent advances in microalgal lipid extraction technologies with emphasis on the influence of solvent type and operational temperature on extraction efficiency and selectivity. The review uniquely integrates conventional and emerging extraction approaches, including ultrasound-assisted, microwave-assisted, supercritical-fluid, and deep eutectic solvent (DES)-based systems, while critically evaluating their environmental and industrial implications. Furthermore, the study highlights the potential of combining green solvents with extraction-intensification techniques as an innovative pathway toward sustainable and economically feasible biofuel production from microalgae.

Author's Contribution

Husam Talib Hamzah: contributed to the conceptualization of the study, literature review, data analysis, and manuscript drafting. Veluru Sridevi: participated in the scientific supervision, technical evaluation of extraction technologies, and critical revision of the manuscript. Fouad Hussein Ali: contributed to manuscript editing, validation of scientific content, and final review of the paper. All authors read and approved the final version of the manuscript.

Funding
No funding received.

Generative AI and AI assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

References

Abate, R., Oon, Y., Oon, Y. and Bi, Y., 2024. Microalgae-bacteria nexus for environmental remediation and renewable energy resources: Advances, mechanisms and biotechnological applications. Heliyon, 10. https://doi.org/10.1016/j.heliyon.2024.e31170

De Morais, E., Sampaio, I., Gonzalez-Flo, E., Ferrer, I., Uggetti, E. and García, J., 2023. Microalgae harvesting for wastewater treatment and resources recovery: A review.. New biotechnology. https://doi.org/10.1016/j.nbt.2023.10.002

Del Mar Contreras-Gámez, M., Galán-Martín, Á., Seixas, N., Da Costa Lopes, A., Silvestre, A. and Castro, E. 2022. Deep eutectic solvents for improved biomass pre-treatment: Current status and future prospective towards sustainable processes. Bioresour. Technol., 369: 128396. https://doi.org/10.1016/j.biortech.2022.128396

Igwebuike, C., Awad, S. and Andrès, Y., 2024. Renewable energy potential: Second-generation biomass as feedstock for bioethanol production. Molecules, 29. https://doi.org/10.3390/molecules29071619

Liu, Y., Gao, L., Chen, L., Zhou, W. and Wang, C.L., 2023. Exploring carbohydrate extraction from biomass using deep eutectic solvents: Factors and mechanisms. iScience, 26. https://doi.org/10.1016/j.isci.2023.107671

Lobato-Rodríguez, Á., Gullón, B., Romaní, A., Ferreira-Santos, P., Garrote, G. and Del-Río, P., 2023. Recent advances in biorefineries based on lignin extraction using deep eutectic solvents: A review.. Bioresour. Technol., pp. 129744. https://doi.org/10.1016/j.biortech.2023.129744

Oruganti, R., Katam, K., Show, P., Gadhamshetty, V., Upadhyayula, V. and Bhattacharyya, D., 2022. A comprehensive review on the use of algal-bacterial systems for wastewater treatment with emphasis on nutrient and micropollutant removal. Bioengineered, 13: 10412-10453. https://doi.org/10.1080/21655979.2022.2056823

Pajot, A., Huynh, G., Picot, L., Marchal, L. and Nicolau, E., 2022. Fucoxanthin from Algae to Human, an extraordinary bioresource: Insights and advances in up and downstream processes. Marine Drugs, 20. https://doi.org/10.3390/md20040222

Pendse, D., Deshmukh, M. and Pande, A., 2023. Different pre-treatments and kinetic models for bioethanol production from lignocellulosic biomass: A review. Heliyon, 9. https://doi.org/10.1016/j.heliyon.2023.e16604

Perez-Vazquez, A., Carpena, M., Barciela, P., Cassani, L., Simal-Gándara, J. and Prieto, M., 2023. Pressurized liquid extraction for the recovery of bioactive compounds from seaweeds for food industry application: A review. Antioxidants, 12. https://doi.org/10.3390/antiox12030612

Pinto, J., Colónia, J., Abdolvaseei, A., Vale, C., Henriques, B. and Pereira, E., 2023. Algal sorbents and prospects for their application in the sustainable recovery of rare earth elements from E-waste. Environ. Sci. Pollut. Res. Int., 30: 74521-74543. https://doi.org/10.1007/s11356-023-27767-8

Rahman, M., Hosano, N. and Hosano, H., 2022. Recovering microalgal bioresources: A review of cell disruption methods and extraction technologies. Molecules, 27. https://doi.org/10.3390/molecules27092786

Siddiqui, S., Redha, A., Salauddin, M., Harahap, I. and Rupasinghe, H., 2023. Factors affecting the extraction of (Poly) phenols from natural resources using deep eutectic solvents combined with ultrasound-assisted extraction. Crit. Rev. Anal. Chem., 55: 139 - 160. https://doi.org/10.1080/10408347.2023.2266846

Sundaram, T., Rajendran, S., Gnanasekaran, L., Rachmadona, N., Jiang, J., Khoo, K. and Show, P., 2023. Bioengineering strategies of microalgae biomass for biofuel production: Recent advancement and insight. Bioengineered, 14. https://doi.org/10.1080/21655979.2023.2252228

Tzima, S., Georgiopoulou, I., Louli, V. and Magoulas, K., 2023. Recent advances in supercritical CO_2 extraction of pigments, lipids and bioactive compounds from microalgae. Molecules, 28. https://doi.org/10.3390/molecules28031410

Velásquez-Orta, S., Yáñez-Noguez, I., Ramírez, I. and Ledesma, M., 2024. Pilot-scale microalgae cultivation and wastewater treatment using high-rate ponds: A meta-analysis. Environ. Sci. Pollut. Res. Int., 31: 46994 - 47021. https://doi.org/10.1007/s11356-024-34000-7

Wang, T., Zhu, L., Mei, L. and Kanda, H., 2024. Extraction and separation of natural products from microalgae and other natural sources using liquefied dimethyl ether, a green solvent: A review. Foods, 13. https://doi.org/10.3390/foods13020352

Ye, Y., Liu, M., Yu, L., Sun, H. and Liu, J., 2024. Nannochloropsis as an emerging algal chassis for light-driven synthesis of lipids and high-value products. Mar. Drugs, 22. https://doi.org/10.3390/md22020054

Yu, B., Pyo, S., Lee, J. and Han, K., 2024. Microalgae: A multifaceted catalyst for sustainable solutions in renewable energy, food security, and environmental management. Microb. Cell Factories, 23. https://doi.org/10.1186/s12934-024-02588-7

Zhang, S., Zhang, L., Xu, G., Fei-Fei, L. and Li, X., 2022. A review on biodiesel production from microalgae: Influencing parameters and recent advanced technologies. Front. Microbiol., 13. https://doi.org/10.3389/fmicb.2022.970028