fermentation

MDPI

Editorial

Marine-Based Biorefinery: A Path Forward to a Sustainable Future

Abdelrahman Zaky [1,*] and Abdelfatah Abomohra [2]

1 School of Biological Sciences, University of Edinburgh, King's Buildings, Edinburgh EH9 3FF, UK
2 Aquatic Ecophysiology and Phycology, Institute of Plant Science and Microbiology, University of Hamburg, 22609 Hamburg, Germany; abdelfatah.abomohra@uni-hamburg.de
* Correspondence: a.s.zaky@live.com

check for updates

Citation: Zaky, A.; Abomohra, A. Marine-Based Biorefinery: A Path Forward to a Sustainable Future. *Fermentation* **2023**, *9*, 554. https://doi.org/10.3390/fermentation9060554

Received: 29 May 2023
Accepted: 5 June 2023
Published: 10 June 2023

Biofuels and bio-based products are among the best alternatives to fossil-based fuels and chemicals due to their capacity for net-negative carbon emissions, which is a vital contribution to the global ambition of a net-zero economy [1–3]. Biorefinery could enhance the overall energy output and the economic feasibility of biomass conversion [4]. However, current biorefinery technologies mainly rely on edible crops and freshwater as the main inputs in the process. With an ever-growing population and demand for biofuels and other bio-based products, there are concerns over the use of the world's limited freshwater and food crop resources for non-nutritional activities. Mainly, there is apprehension regarding the availability of adequate arable land and freshwater to meet the required biomass production for satisfying the projected biofuel demand and effectively capturing the excessive CO_2 emissions that have been released into the atmosphere. It is in this context that marine-based biorefinery represents a new approach, where seawater, marine biomass (seaweed), and marine microorganisms (yeast, bacteria, and/or microalgae) are used in fermentation processes for the production of biofuels and bio-based compounds [5].

Seas and oceans cover more than 70% of the Earth's surface and contain more than 97% of the Earth's water, as well as the minerals needed for seaweed growth and their subsequent conversion to bioenergy. Compared to terrestrial biomass, seaweed grows much faster, is up to 50 times more efficient in CO_2 fixation, and is hugely abundant worldwide. Moreover, seaweed can be cultivated in the sea, forming sea forests with the potential to provide great advantages to the marine environment. Marine yeasts are more tolerant to inhibitors and can carry out fermentation using seawater-based media. Marine microalgae can grow efficiently on seawater and utilize CO_2 from the atmosphere or from fermentation and anaerobic digestion (AD) processes as a carbon source for growth. Combining all of these (seawater, seaweed, marine microalgae and yeast, fermentation, and AD) into an integrated marine biorefinery system could represent a promising approach to supporting the global effort regarding mitigating climate change, as well as addressing the world's water, food, and energy shortages [2,6]. Therefore, this Special Issue aims to feature novel research and review articles as well as short communications on one or more of the marine resources (seawater, seaweed, microalgae, yeast, bacteria) that can potentially be utilised in bioconversion/fermentation processes for the production of food, feed, biofuels, and high-value chemicals.

This Special Issue (SI) showcases research contributions from 40 scientists representing six European countries (UK, Portugal, Germany, Spain, Czech Republic, and Italy), two North African countries (Egypt, and Tunisia), and three Asian countries (Qatar, China, and Indonesia). We extend our gratitude to all the participating researchers and professors for their invaluable contributions to the success of this Special Issue. The articles published in this SI cover various aspects of marine biorefinery. One article focused on marine yeast, three articles focused on marine macroalgae (specifically, that is, on seaweed), and four articles focused on marine microalgae. Among these articles, four investigated biofuel production through marine biorefinery. In addition, one article discussed marine biorefinery for food and feed production, another article focused on the application of marine biorefinery in the production of biofertilizers, while another discussed the potential of marine biorefinery to produce human health products. Furthermore, one article investigated the isolation and molecular identification of one of the marine microorganisms.

An integrative review by Mahata et al. [7] explores the potential of marine microalgae as a renewable and alternative feedstock for various products. The authors emphasize the advantages of marine microalgae over freshwater strains, considering their lower water footprint and competitive edge. Their review highlights the ongoing efforts to develop technologies for utilizing marine microalgae in the production of food, feed, and biofuels. However, the authors also acknowledge the challenges associated with cultivation and downstream processing, stressing the need for further advancements in these areas in order to unlock the full potential of marine microalgae.

Another timely review by Ashour and Omran [8] explores, in light of the COVID-19 pandemic, the role of marine microalgae in producing human health products. The review emphasizes the importance of blue biotechnology and the rich biodiversity of microalgae in addressing social problems. It discusses the advanced technologies employed in the cultivation, harvesting, drying, and extraction processes of microalgae to produce bioactive compounds with potential applications in pharmaceuticals and functional foods. The article also highlights the potential of microalgae, particularly extracts of *Arthrospira platensis*, in combating viral activities, including COVID-19, thereby underscoring their significance in the current global health crisis.

Faisal et al.'s [9] review delves into the potential of anaerobic digestion as a technology to convert organic compounds from marine ecosystems, particularly seaweed, into biogas. The article highlights the importance of integrated approaches, such as the pretreatment, co-digestion, and sequential extraction of seaweed biomass, to enhance biogas production and overcome technical challenges. It also discusses the integration of marine microalgae cultivation with anaerobic digestion, presenting a pathway towards a zero-waste marine-based system.

Bessadok et al. [10], in their article, investigate the molecular identification and biochemical characterization of five novel marine yeast strains. The authors successfully isolated and identified these strains, which exhibited promising properties for industrial biotechnology applications. These yeast strains were found to be rich in protein, essential amino acids, and lipids, making them valuable sources of alternative ingredients for various sectors, including food, feed, and nutraceuticals. Furthermore, the cytotoxicity tests revealed their safety, further highlighting their potential for industrial use.

Prasedya et al.'s [11] article investigates the implementation of seaweed-based fertilizers (SF) in agricultural systems. Their study evaluates the amino acid content of rice and the rhizosphere bacterial community under SF implementation. The results highlight the potential of SF in improving crop growth, increasing grain yield, and reducing dependence on chemical fertilizers. Their study emphasizes the optimal combination of SF and chemical fertilizers for sustainable production and the positive impact of SF on the rhizosphere microbiome.

Llano et al., [12] in their article, focus on macroalgae biorefineries, specifically *Ulva rigida*. Their study presents a technoeconomic analysis of bioethanol and biobutanol production facilities from the seaweed biomass. The findings indicate that both bioethanol and biobutanol plants are economically feasible, with favorable economic parameters such as net present value (NPV) and internal rate of return (IRR). The research highlights the potential of macroalgae biorefineries in providing sustainable alternatives to fossil fuels while valorizing the byproducts of the extraction process.

Moniz et al. [13] explore a novel process for the production of lipids from *Crypthecodinium cohnii*, a microalga rich in valuable fatty acids. Their study demonstrates the utilization of low-cost industrial byproducts to produce *C. cohnii* biomass, followed by the fractionation of the microalgal lipid fraction into polyunsaturated fatty acid ethyl ester and saturated fatty acid ethyl ester fractions. This innovative approach not only valorizes all microalgal lipid fractions, but also contributes to the principles of the circular bioeconomy, reducing the overall costs and increasing the potential revenue.

Collectively, these articles provide valuable insights into the potential of marine-based biorefinery as a pathway to a sustainable future. They demonstrate the promising aspects of utilizing marine resources for energy production, value-added products, and sustainable agriculture. The findings underscore the importance of integrated approaches, technological advancements, and optimization strategies in enhancing process efficiency, overcoming challenges, and maximizing the potential of marine-based biorefinery. We anticipate that this SI will serve as a platform to disseminate knowledge, foster collaboration, and encourage further research in this rapidly evolving field. The contributions of these articles contribute to our understanding of marine-based biorefinery and its role in achieving a more sustainable and environmentally conscious future. By harnessing the vast potential of marine resources and adopting innovative technologies, we can pave the way for a greener, more resilient, and sustainable world.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Abomohra, A.E.-F.; Almutairi, A.W. A Close-Loop Integrated Approach for Microalgae Cultivation and Efficient Utilization of Agar-Free Seaweed Residues for Enhanced Biofuel Recovery. *Bioresour. Technol.* **2020**, *317*, 124027. [CrossRef] [PubMed]
2. Zaky, A.S. Introducing a Marine Biorefinery System for the Integrated Production of Biofuels, High-Value-Chemicals and Co-Products: A Path Forward to a Sustainable Future. *Processes* **2021**, *9*, 1841. [CrossRef]
3. Zaky, A.S.; Moirangthem, K.; Wahid, R. Biofuels: An Overview. In *Waste-to-Energy*; Springer International Publishing: Berlin/Heidelberg, Germany, 2022; pp. 85–144.
4. Wang, S.; Mukhambet, Y.; Esakkimuthu, S.; Abomohra, A.E.-F. Integrated Microalgal Biorefinery—Routes, Energy, Economic and Environmental Perspectives. *J. Clean. Prod.* **2022**, *348*, 131245. [CrossRef]
5. Zaky, A.S. Marine Fermentation, the Sustainable Approach for Bioethanol Production. *EC Microbiol.* **2017**, 25–27.
6. Behera, B.; Unpaprom, Y.; Ramaraj, R.; Maniam, G.P.; Govindan, N.; Paramasivan, B. Integrated Biomolecular and Bioprocess Engineering Strategies for Enhancing the Lipid Yield from Microalgae. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111270. [CrossRef]
7. Mahata, C.; Das, P.; Khan, S.; Thaher, M.I.A.; Quadir, M.A.; Annamalai, S.N.; Jabri, H. Al The Potential of Marine Microalgae for the Production of Food, Feed, and Fuel (3F). *Fermentation* **2022**, *8*, 316. [CrossRef]
8. Ashour, M.; Omran, A.M.M. Recent Advances in Marine Microalgae Production: Highlighting Human Health Products from Microalgae in View of the Coronavirus Pandemic (COVID-19). *Fermentation* **2022**, *8*, 466. [CrossRef]
9. Faisal, S.; Zaky, A.; Wang, Q.; Huang, J.; Abomohra, A. Integrated Marine Biogas: A Promising Approach towards Sustainability. *Fermentation* **2022**, *8*, 520. [CrossRef]
10. Bessadok, B.; Jaouadi, B.; Brück, T.; Santulli, A.; Messina, C.M.; Sadok, S. Molecular Identification and Biochemical Characterization of Novel Marine Yeast Strains with Potential Application in Industrial Biotechnology. *Fermentation* **2022**, *8*, 538. [CrossRef]
11. Prasedya, E.S.; Kurniawan, N.S.H.; Ardiana, N.; Ilhami, B.T.K.; Mulyaningsih, T.; Astuti, S.P.; Jupri, A.; Nikmatullah, A.; Jaya, I.K.D.; Widyastuti, S. Effects of Fermented Seaweed Fertilizer Treatment on Paddy Amino Acid Content and Rhizosphere Microbiome Community. *Fermentation* **2022**, *8*, 420. [CrossRef]
12. Llano, T.; Arce, C.; Gallart, L.E.; Perales, A.; Coz, A. Techno-Economic Analysis of Macroalgae Biorefineries: A Comparison between Ethanol and Butanol Facilities. *Fermentation* **2023**, *9*, 340. [CrossRef]
13. Moniz, P.; Martins, D.; Oliveira, A.C.; Reis, A.; Lopes da Silva, T. The Biorefinery of the Marine Microalga *Crypthecodinium cohnii* as a Strategy to Valorize Microalgal Oil Fractions. *Fermentation* **2022**, *8*, 502. [CrossRef]