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Editorial: Marine microalgae: from biodiversity to biotechnology

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Editorial on the Research Topic
Marine microalgae: from biodiversity to biotechnology

Introduction

The biodiversity of marine microalgae is immense, encompassing various genera and species that exhibit unique biochemical properties, with thousands of species exhibiting a wide range of metabolic capabilities. The monoculture of species isolated from marine environment allows to produce various bioactive compounds, including polysaccharides, lipids, and pigments, which have significant applications in biotechnology. These microorganisms, which include a staggering array of species adapted to an enormous range of environmental conditions, not only sustain marine food webs but also contribute substantially to carbon fixation and oxygen production.

Marine microalgae represent a remarkable intersection of biodiversity and biotechnology, offering numerous opportunities for sustainable development across various sectors, including pharmaceuticals, nutraceuticals, and biofuels. Their unique metabolic pathways and diverse bioactive compounds position them as vital contributors to both ecological balance and human health. These microorganisms, which thrive in diverse marine environments, are crucial for ecological balance and serve as a source of bioactive compounds with applications in various industries, including pharmaceuticals, nutraceuticals, and biofuels (Figure 1). The exploration of marine microalgae for biotechnological applications has gained momentum, driven by their ability to produce a wide range of metabolites that can be useful for human health and environmental sustainability. Today, as we face unprecedented challenges in energy, health, and environmental sustainability, marine microalgae are emerging as key players in a new era of biotechnology.

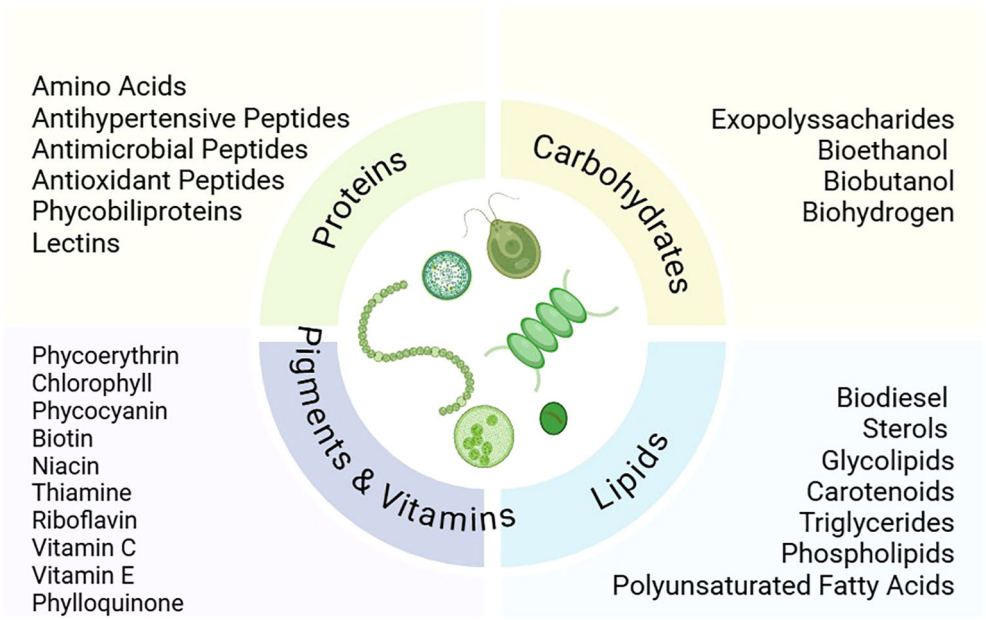

FIGURE 1
The uses and various metabolites produced by microalgae.

Biodiversity and ecological roles

Marine microalgae, including newly characterized species such as *Euchlorocystis marina*, illustrate the extensive physiological adaptations developed to thrive under variable environmental conditions. Studies by Pan et al. have identified this species exhibits a wide range of salinity tolerance that reflects certain physiological and biochemical changes. For instance, research on *E. marina* has demonstrated how salinity affects its growth, photosynthetic pigment composition, and metabolite accumulation, findings that underscore the adaptability and ecological roles of these organisms in stabilizing aquatic ecosystems. Such insights are essential for understanding how environmental stresses shape microalgal communities, with broader implications for monitoring ecosystem health and biogeochemical cycling.

In oligotrophic oceans, nitrogen availability is a critical constraint on primary production. The nitrogen-fixing cyanobacterium *Trichodesmium* spp., for example, supplies a "new" source of nitrogen to surrounding non-diazotrophic phytoplankton. Experimental evidence by Li et al. now confirms that this species releases significant amounts of dissolved organic nitrogen, including urea that stimulate the growth of coexisting phytoplankton species. These findings illuminate a key, cyanobacterium *Trichodesmium* spp. supplies new nitrogen source to marine phytoplankton or microalgae, nutrient transfer mechanism that helps maintain productivity in nitrogen-limited marine environments and paves the way for strategies aimed at enhancing natural nitrogen inputs.

Genomic insights and metabolic engineering

Advances in genomics and transcriptomics have begun to unravel the complex metabolic pathways underlying valuable bioproduct synthesis in microalgae. For instance, high-quality genomic data from *Dunaliella salina* have revealed the intricate regulatory networks controlling β-carotene synthesis, a pigment with high commercial and nutritional value (Chen et al.). Such molecular insights are critical, as they provide the blueprint for metabolic engineering approaches designed to boost carotenoid production. In parallel, molecular cloning and functional studies on enzymes like the plastidial ω3 desaturase from *Emiliania huxleyi* have deepened our understanding of polyunsaturated fatty acid biosynthesis, which is vital for developing sustainable sources of nutritionally important ω3-PUFAs (Sun et al.).

Cultivation strategies and process optimization

To translate biological potential into commercial success, optimizing cultivation techniques remains paramount. Recent studies have explored innovative methods such as chemical induction of polyploidy in *Nannochloropsis oculata* using colchicine to enhance biomass and pigment production. By carefully modulating colchicine concentrations, Rahmawati et al. (2024) achieved significant increases in cell density, chlorophyll,

and carotenoid yields without compromising overall biomass. This approach not only improves product yield but also offers a low-cost strategy for scaling up microalgal production, making industrial applications more economically viable.

Biotechnological applications

The ability of these organisms to thrive in diverse marine environments further enhances their potential as sources of novel compounds for biotechnological applications (Grubišić et al., 2022; Oliveira et al., 2020). In terms of biotechnological applications, marine microalgae have been shown to produce various metabolites with health benefits. Moreover, the exploration of marine microalgae for their bioactive pigments has unveiled compounds with significant antioxidant properties, which could be beneficial in food and pharmaceutical applications. The cultivation of marine microalgae also presents opportunities for sustainable production of high-value compounds.

Future perspectives and conclusion

The collective findings from these diverse studies illustrate that marine microalgae are at the frontier of biotechnology innovation. Their genetic and metabolic diversity offers enormous promise for sustainable production of biofuels, nutraceuticals, and high-value chemicals. Yet, challenges remain. Improved understanding of environmental adaptation, nutrient cycling, and genome stability will be crucial to harnessing these organisms fully. Future research must integrate advanced molecular tools, innovative cultivation techniques, and eco-system-level studies to develop robust, scalable platforms for microalgal bioprocessing. The journey from the biodiversity of marine microalgae to their biotechnological applications is a potency in addressing global challenges. Their unique properties and capabilities not only contribute to ecological sustainability but also hold promise for advancements in health, nutrition, and energy sectors.

In conclusion, from elucidating the effects of salinity on cellular physiology to engineering metabolic pathways for enhanced carotenoid and fatty acid production, current research highlights a dynamic interplay between basic science and applied biotechnology. As our understanding deepens, marine microalgae are poised not only to revolutionize sustainable production systems but also to offer new solutions to global challenges in energy, health, and environmental stewardship. Continued research and development in this field are essential to unlock the full potential of marine microalgae, ensuring their role as a cornerstone of future biotechnological innovations. The future of marine microalgae in biotechnology is bright, promising innovative solutions for health, industry, and environmental sustainability.

Author contributions

YR: Conceptualization, Writing – original draft, Writing – review & editing, Formal analysis, Validation.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. Chat Generative pre trained transformer was used to enhance readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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