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Editorial: The biorefineries and application of green technologies for recovering bioactive compounds from microalgae

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Editorial on the Research Topic:
The biorefineries and application of green technologies for recovering bioactive compounds from microalgae

Microalgae are attracting growing scientific and industrial interest as a renewable and versatile source of high-value bioactive compounds, including pigments, fatty acids, proteins, and antioxidants. Their rapid growth, ability to adapt to extreme conditions, and rich biochemical composition make them a promising resource for sustainable development across a range of applications. From cosmetics to food supplements, their potential spans multiple industries. Still, the considerable gap between encouraging laboratory research and commercially viable production remains. One of the major challenges lies in developing methods for extracting and preserving these compounds in ways that are both efficient and environmentally responsible.

As awareness of environmental and health-related concerns continues to grow, efforts are shifting toward the development of cleaner and safer extraction techniques. These approaches aim to minimise ecological impact and maintain the structural integrity and biological activity of the compounds, an essential factor for their use in food, pharmaceuticals, and personal care products. Recent studies reflect this shift and offer insight into practical strategies that could move microalgae research closer to broader application.

Xue et al. provided a review of microalgae as a sustainable source of edible oils. They highlighted the high lipid productivity of certain strains and their favourable fatty acid profiles, particularly with respect to omega-3 content such as DHA and EPA. The study explored a range of extraction techniques, including mechanical, enzymatic, solvent-based, and supercritical fluid methods. Some of the challenges were also discussed, such as oxidation, food safety, and economic feasibility. The authors concluded that, with further technical development and integration into biorefinery systems, microalgae could be used as a reliable source of functional oils.

Htoo et al. examined the production of protein hydrolysates from *Spirulina* (*Arthrospira platensis*) and their potential applications in health-related contexts. A

process combining ultrasound and cellulase pre-treatments with enzymatic hydrolysis using Flavourzyme was optimised to yield protein-rich extracts with notable antioxidant activity. These hydrolysates reduced nitric oxide production and stimulated phagocytic activity without inducing cytotoxic effects. The results demonstrated the potential of spirulina-based hydrolysates as functional ingredients in food products aimed at immune support.

Mienis et al. investigated whether freeze-dried microalgae could substitute fresh biomass in lipid extraction experiments. Focusing on *Nannochloropsis*, the study applied ultrasound-assisted extraction and compared lipid yields between fresh and freeze-dried samples. Similar yields were observed when the rehydration step was carefully managed. However, prolonged rehydration led to higher levels of free fatty acids due to lipase activity, which could affect lipid quality. These findings suggested that, with appropriate handling, freeze-dried biomass offered a practical alternative for laboratory-scale extraction.

Sayegh et al. compared two methods for extracting beta-carotene from *Dunaliella salina*: one using the organic solvent tetrahydrofuran, and the other employing bacterial lipase. The microalga was cultivated under varying salinity and nitrogen conditions to enhance beta-carotene accumulation. The solvent-based method achieved the highest yield, 109.00 μg/mL under 2.5 M NaCl and 0.5 g/L KNO_3, while the enzymatic approach reached a lower maximum of 21.4 μg/mL under 3 M NaCl and 1 g/L KNO_3. Despite lower efficiency, the lipase method resulted in cleaner extraction and preserved cell viability, indicating its potential for further development in sustainable microalgae processing.

Taken together, these studies reflect a growing commitment to making microalgae processing cleaner, more efficient, and better suited to real-world applications. From refining extraction methods to exploring alternatives to conventional solvents, the work presented here contributes to a more practical understanding of how valuable compounds can be recovered without compromising quality. As demand for natural and functional ingredients continues to rise, further development of green, low-impact technologies will be essential in addressing the technical and environmental challenges ahead.

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