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Commentary Article

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Sustainable Extraction Techniques for Bioactive Compounds from Marine Sources

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DESCRIPTION

Sustainable extraction of bioactive compounds from marine sources has garnered increasing attention due to the unique and potent biochemical properties of marine organisms, such as algae, sponges and various microorganisms, which produce compounds with applications in medicine, cosmetics and nutrition. Marine bio resources are abundant in structurally diverse compounds, including polysaccharides alkaloids, peptides and lipids, many of which exhibit therapeutic activities like anticancer, antibacterial, antiviral and antioxidant effects. However, traditional extraction methods, often involving solvents and energy-intensive procedures, are neither eco-friendly nor efficient for sustainable exploitation of these valuable resources. To address these issues, the development of green extraction techniques has emerged, aiming to reduce environmental impact, minimize waste and optimize resource efficiency. Supercritical fluid extraction, ultrasound-assisted extraction and enzyme-assisted extraction are some of the most potential sustainable techniques; they all have unique benefits in terms of yield, selectivity and a decreased need on hazardous chemicals. These approaches are transforming the field of marine bio prospecting by enabling efficient recovery of bioactive compounds with minimal ecological footprint. Supercritical Fluid Extraction (SFE) has proven to be particularly effective for the sustainable extraction of bioactive compounds from marine organisms. This method uses supercritical CO_2 as a solvent, which has a unique ability to penetrate the cellular matrix and dissolve nonpolar bioactive compounds. SFE is favoured for its environmental compatibility, as it avoids the use of toxic organic solvents and allows easy removal of CO_2 by simple depressurization, leaving behind pure extracts.

Another possible sustainable method is Ultrasound-Assisted Extraction (UAE), which uses sound waves to produce cavitation bubbles that break down cell walls and enhance mass transfer, hastening the release of bioactive substances. The integrity of heat-sensitive chemicals is preserved by this method's great energy efficiency, minimal solvent requirements and low operating temperature. The UAE has demonstrated great potential in the extraction of proteins and polysaccharides from marine algae and microalgae, which are becoming more and more known for their immunomodulatory and antioxidant qualities. By enhancing cell permeability, UAE not only increases yield but also shortens extraction times, making it ideal for processing marine resources that are sensitive to prolonged exposure to solvents or heat. Additionally, UAE can be combined with other green techniques, such as SFE, to further improve extraction efficiency and broaden the range of extractable compounds. For example, ultrasound can be applied before SFE to break down cellular structures, facilitating the penetration of supercritical CO_2 into the matrix and allowing for more effective extraction of both lipophilic and hydrophilic bioactives. This combined approach is particularly advantageous for commercial-scale extractions, where maximizing output and sustainability are essential.

Enzyme-Assisted Extraction (EAE) is a biologically-based approach that utilizes specific enzymes to degrade cellular structures, enabling the release of bioactive compounds from marine organisms. EAE has gained traction as a green alternative to conventional extraction, particularly for extracting complex molecules such as proteins, peptides and polysaccharides from marine sources. Enzymes such as celluloses, proteases and alginases are used to selectively break down the cell walls of marine organisms, which often contain rigid structures that conventional methods struggle to penetrate. This process not only improves extraction efficiency but also preserves the bioactivity of compounds, as it can be carried out under mild conditions without harsh chemicals. EAE is highly effective for obtaining bioactive peptides from marine proteins, such as those in fish and crustaceans, which exhibit antihypertensive, antioxidative and anti-inflammatory activities. As enzymes can be selected and tailored for specific substrates, EAE allows for targeted extraction of compounds, enhancing the selectivity and purity of the end products. Furthermore, EAE can reduce the environmental impact of marine extractions by minimizing the need for organic solvents and reducing waste, aligning well with the principles of green chemistry.

Overall, the shift towards sustainable extraction techniques for bioactive compounds from marine sources marks a significant step in the responsible utilization of ocean resources. The development of green extraction methods, such as supercritical fluid extraction, ultrasound-assisted extraction, enzyme-assisted extraction and microwave-assisted extraction, provides efficient alternatives to traditional solvent-based approaches. Each technique offers unique benefits, from preserving bioactivity to enabling targeted extraction, while minimizing environmental harm. The combination of these methods can maximize yield and purity of bioactive compounds, catering to diverse applications in pharmaceuticals, nutraceutical and cosmetics. Moreover, adopting sustainable extraction practices aligns with global efforts to protect marine ecosystems, ensuring that the extraction of valuable compounds does not come at the expense of environmental health.