


Chapter 18

Sustainable Extraction of Bioactive Compounds From Plant Materials: Advances in Green Technologies and Solvent Systems

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ABSTRACT

Plant-derived bioactive compounds, such as polyphenols, flavonoids, alkaloids, and terpenes, exhibit diverse biological properties, making them valuable for food, nutraceutical, pharmaceutical, and cosmetic applications. The extraction process significantly impacts the yield, quality, and environmental footprint of these compounds. While traditional methods have several limitations, emerging green technologies offer efficient, sustainable alternatives. Techniques such as supercritical fluid extraction, microwave-assisted extraction, ultrasound-assisted extraction, enzyme-assisted extraction, and pressurized liquid extraction, maximize bioactive compound recovery while minimizing solvent usage, energy consumption, and thermal degradation. Advances in green solvents, including ionic liquids and deep eutectic solvents, further enhance extraction efficiency and environmental compatibility. Despite challenges like high equipment costs and process optimization, green extraction methods hold immense promise for sustainable bioactive compound extraction.

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1. INTRODUCTION

Plant-derived bioactive compounds have a wide range of applications in various sectors, including food, nutraceutical, pharmaceutical, and cosmetic industries. These compounds, namely polyphenols, flavonoids, alkaloids, and terpenes, are recognized for their beneficial biological properties, such as antioxidant, anti-inflammatory, antimicrobial, and anticancer activities. Moreover, their natural origin, coupled with a growing demand for safer and more sustainable products, is fueling the interest in their extraction and use in health and wellness products (Azwanida, 2015).

The choice of the extraction method is of great importance because it influences directly the quality and yield of bioactive compounds, and has a significant environmental and economic impact. Traditional methods of extraction, like maceration and Soxhlet extraction, often rely on organic solvents, high energy consumption, and long extraction times. Such factors may pose environmental concerns and can lead to poor yield and destruction of sensitive compounds (Wang & Weller, 2006). Advances in green extraction technologies offer efficient and sustainable solutions to maximize the value of bioactive compounds while meeting ecological requirements (Ayyildiz et al., 2024, Dahmoune et al., 2015, Jacotet-Navarro et al., 2015, Çam et al., 2019). This chapter focuses on the emerging green technologies, such as supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), enzyme-assisted extraction (EAE), pressurized liquid extraction (PLE), and other innovative approaches, emphasizing their principles, advantages, applications, and challenges.

Apart from these various individual technologies, this chapter also describes how green extraction methods can be combined together in pursuit of better efficiency and yield of bioactive compound extraction. For instance, combinations involving MAE or UAE with SFE or EAE improve the efficiency in extraction with no environmental damage. In addition, the flexibility of some techniques like MAE and UAE in using safer solvents like water or ethanol further enhances their environmental credentials. Recently, increasing interest is observed in the development of innovative green solvents, such as ionic liquids and deep eutectic solvents associated with green technologies, aiming to reduce the environmental impact during the extraction of the bioactive compounds, and in the same time to enhance the yields obtained. These new solvents present exceptional properties, among which are tunable polarity and low toxicity, which can be further valorized for improving the selectivity and efficiency of the extraction of bioactive compounds (Ventura et al., 2017, Zhou et al., 2018).

In this chapter, each extraction method will be presented, with a focus on aromatic herbs and medicinal plants, such as rosemary (*Rosmarinus officinalis*), cannabis (*Cannabis sativa* L.), green tea (*Camellia sinensis*), and oregano (*Origanum vulgare* L.), well known for their richness in bioactive compounds with important biological activities.

SUPERCritical FLUID EXTRACTION (SFE)

Extraction Mechanism and Influencing Parameters

SFE is a green technology for extracting bioactive compounds from plants, offering an eco-friendly alternative to conventional methods like solvent extraction. It uses supercritical fluids, which possess properties of both gases and liquids, under controlled temperature and pressure to dissolve and extract targeted compounds. The supercritical fluid penetrates plant tissues, dissolves compounds, and carries

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