MINI-REVIEW article

Extraction of flavonoids from natural sources using modern techniques: A review

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Abstract: Flavonoids, a major class of bioactive polyphenols present in plants, exhibit antioxidant, anti-inflammatory, and antimicrobial properties. Their extraction plays a crucial role in the pharmaceutical, nutraceutical, and food industries. Traditional extraction methods, such as prolonged solvent-based techniques involving elevated temperatures, often suffer from inefficiency and compound degradation. Modern extraction technologies, including microwave-assisted extraction, ultrasound-assisted extraction, pressurized liquid extraction, and supercritical fluid extraction, offer improved efficiency, reduced solvent consumption, and enhanced preservation of bioactive integrity. This review focuses on these advanced methods, highlighting operational parameters, advantages, limitations, and recent improvements, with an emphasize on green and sustainable extraction.

Introduction

Flavonoids, a major class of bioactive polyphenols present in plants, and widely distributed secondary metabolites contributing to plant defense and human health. They exhibit antioxidant, anti-inflammatory, and antimicrobial properties. Flavonoids are structural derivatives that were formed from the phenyl-propanoid pathway, and that exhibit diversity in structure and bioavailability of these compounds [1]. Their extraction plays a crucial role in the pharmaceutical, nutraceutical, and food industries [2, 3]. Efficient extraction techniques are essential to maximize yield, shorten processing time, and minimize environmental impact [4]. such as prolonged solvent-based techniques involving elevated temperatures, often suffer from inefficiency and compound degradation [5]. Conventional extraction processes such as maceration and Soxhlet extraction are simple but solvent-intensive, slow, and prone to degradation of thermolabile compounds [6]. Modern techniques overcome these drawbacks by using physical intensification methods or eco-friendly solvents that enhance extraction kinetics and selectivity [7]. Modern extraction technologies, including microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), pressurized liquid extraction (PLE), and supercritical fluid extraction (SFE), provide improved efficiency [8], reduced solvent consumption, and enhanced preservation of bioactive integrity [9-12]. This review focuses on these advanced methods, highlighting operational parameters, advantages, limitations, and recent improvements emphasizing green and sustainable extraction [13].

Conventional extraction techniques

Maceration and percolation maceration and percolation involve prolonged soaking or solvent flow through plant matrices at ambient temperature using solvents such as water, ethanol, or methanol. These methods are simple and suitable for heat-sensitive compounds but require long processing times, high solvent usage, and risk degradation from extended exposure [14].

Soxhlet extraction Soxhlet extraction uses continuous solvent reflux to ensure efficient extraction, but prolonged heating can degrade thermolabile flavonoids, and the process is solvent- and energy-intensive [2].

Modern extraction techniques

Microwave-assisted extraction (MAE): Microwave energy rapidly heats solvents and plant tissues, enhancing mass transfer through dipole rotation and ionic conduction. This accelerates extraction (minutes instead of hours) while reducing solvent use. Excessive exposure, however, can degrade sensitive compounds, and specialized equipment is required.

Ultrasound-assisted extraction (UAE) Ultrasonication induces cavitation that disrupts cell walls, improving solvent penetration. It is energy-efficient, scalable, and environmentally friendly but demands optimization of frequency and duration to prevent compound degradation.

Pressurized liquid extraction (PLE)/accelerated solvent extraction (ASE): PLE utilizes elevated temperature and pressure to maintain solvents in a liquid state above their boiling point, enhancing solubility and diffusion. This delivers high extraction efficiency and reduced processing time. Careful parameter optimization is needed to avoid thermal decomposition.

Supercritical fluid extraction (SFE): SFE employs supercritical CO_2 as a solvent, combining liquid-like solvating power with gas-like diffusivity. It is highly selective, leaves no solvent residues, and preserves thermolabile compounds. For polar flavonoids, modifiers such as ethanol are often needed [15].

Enzyme-assisted extraction (EAE) Cellulases and pectinases hydrolyze plant cell walls, releasing flavonoids under mild and eco-friendly conditions. This biological approach enhances yield but can be costly and time-intensive.

Electric field-assisted extraction (pulsed electric field, PEF): PEF uses short, high-voltage impulses to permeabilize cell membranes, accelerating mass transfer while retaining compound stability. It is non-thermal and rapid but requires careful equipment calibration for scalability.

Examples of flavonoid extraction from plants: Camellia sinensis (Tea): Extraction with 70.0% ethanol under reflux (90°C, 6.0 hrs.) yields catechins; optimized MAE conditions: 60°C, 70.0% ethanol, 80 min, 1: 20 ratios. Ginkgo biloba: Enzyme pretreatment with cellulase and pectinase prior to ethanol extraction enhances flavonoid yield. Citrus species: Sequential Soxhlet extraction using chloroform, ethyl acetate, and methanol concentrates flavonoids in polar fractions. *Glycyrrhiza glabra* (Licorice): Methanol or ethanol extraction, improved with ultrasonic-cold plasma methods for glycyrrhizic acid. *Scutellaria baicalensis* (Chinese Skullcap): Ultrasonic extraction using 53.0% ethanol yields baicalin-rich extracts with conditions optimized at 62°C for 2.0 hrs. *Sophora japonica*: Water reflux followed by resin purification produces rutin and kaempferol; UAE significantly improves yields. *Vitis vinifera* (Grapes): Extraction with ethanol or water under ambient or ASE conditions recovers flavanols effectively. *Allium cepa* (Onion): MAE with 62.0% methanol at 56°C for two minutes optimizes anthocyanin recovery; UAE isolates quercetin efficiently. *Silybum marianum* (Milk Thistle): Ultrasound extraction in ethanol yields high-purity silymarin. *Trifolium pratense* (Red Clover): Reflux or ultrasound extraction using ethanol-water mixtures effectively isolates isoflavones.

Conclusion: Modern extraction methods significantly improve efficiency, sustainability, and preservation of bioactive compounds compared to conventional processes. Continued research focuses on hybrid extraction systems, response surface methodology for optimization, and the development of natural deep eutectic solvents (NADES) and ionic liquids for green extraction. Industrial-scale adaptation of these greener and more efficient methods will be important for cost-effective and eco-friendly flavonoid production.

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