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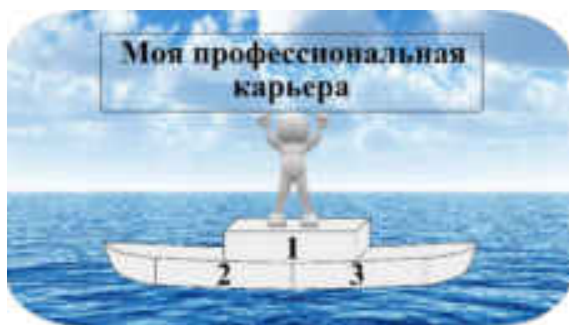


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**Международный научно-образовательный электронный журнал
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Abstract

Capsaicin (8-methyl-N-vanillyl-6-nonenamide) is the principal pungent compound found in *Capsicum* species and has extensive applications in pharmaceuticals, food industries, and biomedical research due to its analgesic, anti-inflammatory, antioxidant, and metabolic regulatory properties. The development of efficient, scalable, and environmentally friendly extraction and purification technologies is critical for both industrial utilization and scientific research. This review comprehensively examines conventional and emerging technologies for capsaicin extraction and purification, their underlying principles, advantages, challenges, and future prospects. Additionally, analytical techniques for capsaicin quantification and quality assessment are reviewed.

1. Introduction

Capsaicin is the major capsaicinoid responsible for the hot sensation in chili peppers (*Capsicum* spp.). Structurally, it is a vanilloid compound with a nonpolar alkyl chain contributing to its hydrophobic nature. Its unique bioactivities—including analgesic and anti-cancer properties—have prompted significant interest in efficient extraction and purification processes. The global demand for high-purity capsaicin in pharmaceuticals and functional foods necessitates optimization of extraction methods that balance yield, purity, cost, and environmental sustainability (Govindarajan & Sathyanarayana, 1991; Collins et al., 1995).

2. Chemical and Physical Properties of Capsaicin

Capsaicin ($C_{18}H_{27}NO_3$) is an oily, hydrophobic compound with limited solubility in water but high solubility in organic solvents such as ethanol, methanol, acetone, and dichloromethane. Its molecular structure consists of a vanillyl group, an amide linkage, and a hydrophobic fatty acid chain, providing both lipophilicity and bioactivity. These properties inform the choice of extraction solvent and purification strategy (Singleton & Rossi, 1965).

3. Conventional Extraction Techniques

3.1 Solvent Extraction

Solvent extraction remains the most widely applied method due to its simplicity and scalability. Typical solvents include ethanol, methanol, acetonitrile, and hexane. Parameters such as solvent polarity, solvent-to-solid ratio, temperature, and extraction time significantly affect capsaicin yield and selectivity. Although effective, conventional solvent extraction is energy-intensive and generates significant solvent waste, a concern for sustainability (Rai et al., 2016).

3.2 Soxhlet Extraction

Soxhlet extraction provides continuous solvent percolation through solid samples, enhancing extraction efficiency. However, prolonged heating can cause thermal degradation of capsaicin, and the method consumes large volumes of solvent and time (Wiktor et al., 2015).

4. Advanced & Green Extraction Technologies

4.1 Ultrasound-Assisted Extraction (UAE)

UAE exploits acoustic cavitation to disrupt plant cell walls and enhance mass transfer of capsaicin into the solvent. Studies report significant reductions in extraction time and solvent usage, with improved yields compared to conventional methods. Optimization of ultrasonic power and duration is crucial to prevent compound degradation (Chemat et al., 2017).

4.2 Microwave-Assisted Extraction (MAE)

Microwave energy rapidly heats the solvent and plant matrix, producing internal pressure that facilitates compound release. MAE achieves enhanced yields and shorter

processing times. However, careful control of microwave power is necessary as capsaicin can thermally degrade under excessive heating (Li et al., 2020).

4.3 Supercritical Fluid Extraction (SFE)

SFE using supercritical CO₂ presents a solvent-free and environmentally friendly alternative, leveraging adjustable temperature and pressure to tune solvating power. Co-solvents (e.g., ethanol) are often added to improve capsaicin solubility. SFE offers high selectivity and minimal solvent residues but requires high investment in equipment (Herrero et al., 2010).

4.4 Pressurized Liquid Extraction (PLE)

Also known as accelerated solvent extraction (ASE), PLE operates at elevated temperature and pressure to enhance solvent penetration and extraction kinetics. PLE efficiently extracts capsaicin with reduced solvent consumption compared to Soxhlet extraction (Mustafa & Turner, 2011).

5. Purification Strategies

5.1 Liquid–Liquid Partitioning

Following extraction, liquid–liquid partitioning with solvents of differing polarity separates capsaicin from co-extractives. For example, hexane–water partitioning can remove nonpolar lipids, while ethyl acetate can further refine capsaicin fractions.

5.2 Column Chromatography

Silica gel column chromatography offers high resolution for capsaicin separation, particularly when combined with gradient elution using mixtures of hexane and ethyl acetate or methanol. While effective, this method is relatively laborious and better suited for smaller scales or analytical purposes (Reverchon & De Marco, 2006).

5.3 Preparative High-Performance Liquid Chromatography (prep-HPLC)

Prep-HPLC remains the gold standard for high-purity capsaicin production. Selection of appropriate stationary phases (e.g., C18 reversed-phase columns) and mobile phase gradients (e.g., water and acetonitrile) enables precise separation. Prep-HPLC achieves >95% purity but has high operational costs and solvent requirements (Lapornik et al., 2005).

6. Analytical Characterization

6.1 High-Performance Liquid Chromatography (HPLC)

Analytical HPLC with UV detection at 280 nm is standard for quantitative capsaicin analysis. Calibration curves using authentic standards allow precise quantification. HPLC provides high sensitivity and repeatability, essential for quality control.

6.2 Mass Spectrometry (MS)

Coupling HPLC with MS (LC-MS) enables structural confirmation and detection of capsaicinoid analogues. MS provides enhanced selectivity and can identify trace impurities.

6.3 Nuclear Magnetic Resonance (NMR)

NMR spectroscopy offers definitive structural elucidation and assessment of compound purity, particularly in research environments.

7. Discussion

Emerging technologies such as SFE and UAE offer promising avenues for sustainable and efficient capsaicin extraction. Challenges remain in achieving industrial scalability while maintaining compound integrity and minimizing environmental impact. Hybrid strategies, combining multiple extraction and purification technologies, may yield optimal results.

8. Conclusion

The technological landscape for capsaicin extraction and purification has evolved considerably, offering techniques that balance efficiency, environmental sustainability, and product purity. The integration of green extraction technologies with advanced analytical and purification strategies stands to enhance industrial exploitation and research applications. Future research should focus on process intensification and life-cycle assessments to further optimize efficiency and sustainability.

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