INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Emerging Technologies in Herbal Drug Development

Shubhum Mhaske, Rushikesh Kale*, Kalyani Kale, Sarika Kadam

Pravara Rural Collage of Pharmacy, Loni, Ahilyanagar, Maharastra 413736

ARTICLE INFO

Published: 04 Aug 2025

Keywords:

Herbal drug development, Advanced Extraction technique, Nanotechnology, Artificial intelligence phytotherapy, Standardization of herbal medicine, Regulatory challenges

DOI:

10.5281/zenodo.16737498

ABSTRACT

The development of herbal medicines has long been grounded in traditional healing systems. However, recent technological innovations are significantly transforming this field by enabling more standardized, efficient, and targeted formulations. Techniques such as high-performance liquid chromatography (HPLC), supercritical fluid extraction (SFE), and eco-friendly methods have enhanced the precision and yield of active plant compounds. Nanotechnology, in particular, is being applied to boost the bioavailability and controlled release of herbal drugs. Emerging disciplines like pharmacogenomics, artificial intelligence (AI), and machine learning are facilitating predictive modeling for therapeutic outcomes and personalized herbal formulations. Biotechnology, including genetic engineering and plant cell culture, also supports sustainable production at scale. Despite these advancements, regulatory and safety challenges remain, underscoring the need for robust evaluation standards. This review highlights the role of advanced technologies in modernizing herbal medicine and explores their potential to integrate traditional remedies with scientific rigor for global health benefits.

INTRODUCTION

Herbal medicine, utilizing plant-derived substances for therapeutic reasons, is one of the oldest healthcare methods, deeply embedded in the traditions of ancient societies like those in

China, India, Egypt, and Greece. These healing practices, such as Ayurveda and Traditional Chinese Medicine, have traditionally employed herbs to tackle numerous health concerns, with wisdom passed down through generations. While its historical significance and widespread use are recognized, a considerable portion of traditional herbal medicine is based on empirical practices that have not been validated by modern scientific criteria. The integration of traditional knowledge and innovative technologies not only enhances the credibility of herbal medicine but also expands its possible role in worldwide healthcare. With the growing demand for natural remedies, this merger

***Corresponding Author:** Rushikesh Kale
Address: *Pravara Rural Collage of Pharmacy, Loni, Ahilyanagar, Maharastra 413736*
Email : nandkumar5001@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

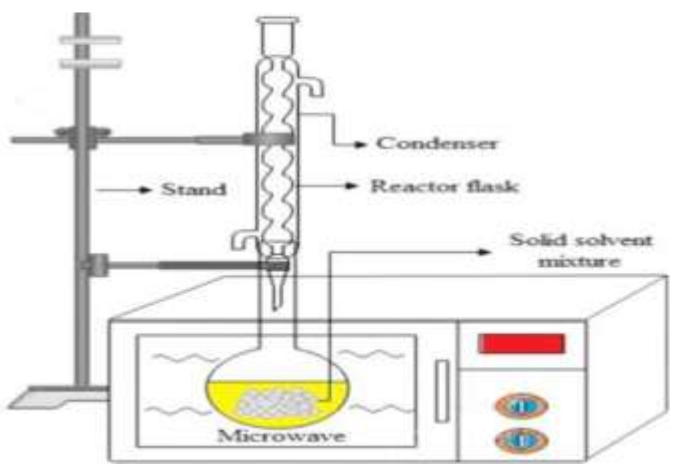
is essential for transforming herbal solutions into scientifically validated, accessible, and effective therapies for modern.

ADVANCED EXTRACTION TECHNIQUES:

Efficient and selective extraction of desired compounds from diverse sources. These techniques offer higher selectivity, improved yields, reduced solvent usage, and faster extraction times, catering to the growing demands of various industries, including pharmaceuticals, food, and environmental analysis.

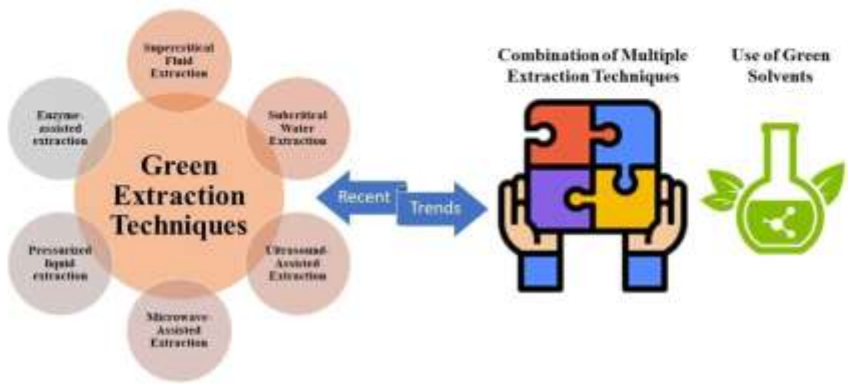
Microwave-Assisted Extraction.

Microwave-assisted extraction (MAE) is a modern extraction technique that extraction (MAE) is a modern extraction technique that utilizes microwave energy to enhance the extraction process. It is widely used in various industries, including pharmaceuticals, food, and natural product extraction.12 In MAE, the sample material is mixed with a suitable solvent in an extraction vessel. Microwave energy is then applied, which rapidly heats the mixture, causing the solvent to boil and creating internal pressure within the sample. This pressure helps to rupture the cell walls and facilitate the extraction of target compounds.12 A detailed and technical illustration of the microwave-assisted extraction (MAE) process is shown in Figure 1.



The extraction vessel is a microwave-safe container that the extraction vessel is a microwave-safe container that holds the sample material and solvent mixture. It is typically made of glass or other suitable materials that can withstand microwave radiation. The sample material is usually finely ground or chopped to increase the surface area available for extraction. It is then mixed with a suitable solvent in the extraction vessel. The solvent choice depends on the nature of the target compounds and their solubility. The extraction vessel is placed under microwave irradiation, which generates and delivers microwave energy to the solution. The applicator ensures uniform and controlled heating of the entire extraction vessel. Microwave power levels can vary depending on the specific application and the characteristics of the sample. When the microwave energy is applied, the solvent absorbs the energy and rapidly heats up. The heat causes the solvent to boil and creates internal pressure within the sample, leading to the rupture of cell walls and the release of target compounds.13 To enhance mass transfer and ensure uniform heating, the sample may be stirred or mixed during the extraction process. This promotes efficient extraction by facilitating the contact between the solvent and the substrate molecules. Parameters such as microwave power, temperature, and extraction time may require optimization based on the sample characteristics and the desired compounds. Safety precautions must be followed when performing microwave assisted extraction, as microwave radiation can be hazardous

Green Extraction Techniques:



PHARMACOGENOMS AND HERBAL MEDICINE-

Role of Pharmacogenoms in herbal

- personalized herbal treatment
- Dose standardization
- predicting Herbal Drug Interaction

Nanotechnology

Figure 2: Schematic representation of applications of nanotechnology formulated herbal drugs and nutraceuticals.

Artificial Intelligence in identifying herbal compound -

- **Bioactive Compound Identification:**
  AI can sift through massive datasets of traditional medicine, plant chemistry, and pharmacological data to pinpoint compounds with therapeutic potential. For example, AI can analyze traditional Chinese medicine practices to identify compounds with potential therapeutic benefits.
- **Synergistic Interaction Prediction:**
  AI can predict how different herbal ingredients interact with each other, helping to develop more effective and synergistic formulations. This is achieved by analyzing the chemical structures of compounds and predicting their interactions.
- **Optimizing Extraction Methods:**
  AI can optimize extraction methods to improve the quality and consistency of herbal products. This can involve analyzing various extraction parameters to maximize the yield of bioactive compounds.
- **Developing New Formulations:**
  AI can aid in the development of new herbal formulations with improved efficacy and safety profiles. This includes optimizing the combination of different herbs and their dosages.
- **Data Mining and Analysis:**
  AI-powered data mining techniques can analyze large datasets of clinical trials, scientific literature, and patents to identify patterns and predict interactions between herbal compounds.

Biotechnology in Herbal Medicine

Biotechnology uses biological processes (like genetic engineering, **fermentation,** tissue culture) to improve, mass-produce, or modify herbal products. Some examples:

- **Plant Tissue Culture**: Growing medicinal plants in labs under sterile **conditions,** especially rare or endangered plants.
- **Genetic Engineering**: Modifying plants to produce more of the active **ingredient** (e.g., boosting alkaloid content in Catharanthus roseus for cancer drugs).
- **Bioreactors**: Growing plant cells or tissues in big tanks to produce herbal compounds at scale (without needing full-grown plants).
- **Metabolic Engineering**: Tweaking metabolic pathways inside plants to **make new** or improved herbal compounds.
- **DNA Barcoding**: Authenticating plant species to avoid adulteration and **ensure** quality control.

General Engineering in Herbal Medicine

- **Extract active compounds**: Designing extraction systems (like supercritical **CO_2** extraction, microwave-assisted extraction) to pull out herbal ingredients efficiently.
- **Formulate herbal products**: Creating capsules, tablets, creams, and **standardized** herbal formulations.
- **Manufacture at scale**: Engineering large-scale manufacturing plants for **herbal** drugs, ensuring purity, stability, and dosage control.
- **Quality control equipment**: Using spectrometers, chromatography **machines** (HPLC, GC-MS) to analyze herbal extracts for active compounds, contaminants, or consistency.
- **Packaging and preservation**: Designing systems for safe, long-lasting **packaging** (anti-oxidation, moisture control).

Regulatory Challenges and Framework

Regulatory Challenges

- **Lack of Harmonized Regulations -** No globally unified standards for herbal drugs incorporating new technologies. Varying classifications across countries (e.g., drug, dietary supplement, traditional medicine).
- **Integration of New Technologies** - Use of AI, machine learning, and big data for compound discovery or toxicity prediction is still under-regulated. Regulatory frameworks have not fully addressed the implications of nanotechnology in herbal formulations (e.g., nanoparticle toxicity, absorption issues).
- **Complexity of Multi-component Systems -** Herbal drugs often contain multiple active ingredients; emerging tech (e.g., metabolomics) helps, but regulators struggle to evaluate efficacy and interactions within complex formulations.
- **Standardization and Quality Control -** Variation in plant sources, harvesting, and processing affects product consistency. Emerging tech improves standardization (e.g., DNA barcoding, NMR profiling), but validation and regulatory acceptance are still in progress.

Regulatory Framework Overview

- **India-** AYUSH Ministry oversees traditional systems; CDSCO governs phytopharmaceuticals.
- **United States -** FDA classifies most herbal products as dietary supplements under DSHEA (1994).
- **European Union -** EMA regulates under Traditional Herbal Medicinal Products Directive (THMPD).
- **China -** Comprehensive regulation of Traditional Chinese Medicine (TCM).

CONCLUSION

The integration of emerging technologies into herbal drug development marks a transformative step toward modernizing traditional medicine. By improving standardization, enhancing safety and efficacy, and enabling scientific validation, technologies like AI, nanotechnology, genomics, and blockchain are bridging the gap between age-old wisdom and contemporary pharmaceutical standards. For herbal medicine to gain global recognition and trust, a balanced approach that combines innovation with respect for traditional knowledge is essential. Moving forward, collaboration between scientists, traditional practitioners, regulators, and technologists will be key to unlocking the full potential of herbal therapies in modern healthcare.

REFERENCES

1. Gangawane RM, Gaikwad S. Advanced herbal technology. Int J Res Publ Rev. 2022;10(1):1-18.
2. Textbook of herbal drug technology of PV publication .
3. Textbook of herbal drug technology of PV publication.
4. Gavali S, Garute S. advance herbal technology. Int J Creative Res Thoughts. 2022;10(1):1-18.
5. Pauzi A, Muhammad N. Current authentication methods of herbs and herbal products: a systematic review. Food Res. 2022;6(4):455-65.
6. Chibuye B, Singh S. A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants.
7. Luque MD, Garcia A. Cordoba, spain; Sapkale GN, Patil SM. supercritical fluid extraction. International journal chemical science. 2010;

8. Kumar K. Shivmurti Srivastava ultrasound assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by products : A review. . Nat Libr Med. 2022;82:105806. doi:10.1016/j.ultsonch.2021.105806.
9. Eskilsson CS. 2000 of Analytical-scale microwave -assisted extraction by PubMed. J Chromatogr A; Basheer C, K H. Puri M. Deepika Sharma Enzyme -assisted extraction of bioactives from plants of trends in biotechnology. Saudi J Biol Sci. 2022;29(3):1565-76.
10. Muhammad MAN, Raanjha R. A Critical Review on Pulsed Electric Field: A Novel Technology for the Extraction of Phytoconstituents. Mol. 2021;26(16):4893.
11. Author biography Teena Satish Dubey, Research Schol
12. Turan, O.; Isci, A.; Y?lmaz, M. S.; Tolun, A.; Sakiyan, O. Microwave-assisted extraction of pectin from orange peel using deep eutectic solvents. Sust. Chem. Pharm. 2024, 37, 101352.
13. Zhang, Y.; Lei, Y.; Qi, S.; Fan, M.; Zheng, S.; Huang, Q.; Lu, X. Ultrasonic-microwave-assisted extraction for enhancing antioxidant activity of Dictyophora indusiata polysaccharides: The difference mechanisms between single and combined assisted extraction. Ultrason. Sonochem. 2023, 95, 106356.
14. Parappa, K.; Krishnapura, P. R.; Iyyaswami, R.; Belur, P. D. Microwave-assisted extraction of chrysin from propolis and its encapsulation feasibility analysis in casein micelles. Mater. Today: Proc. 2023 DOI: 10.1016/j.matpr.2023.08.294.
15. Afoakwah, N. A.; Zhao, Y.; Tchabo, W.; Dong, Y.; Owusu, J.; Mahunu, G. K. Studies on the extraction of Jerusalem artichoke tuber phenolics using microwave-assisted extraction optimized conditions. Food Chem. Adv. 2023, 3, 100507.
16. Azhar, B.; Gunawan, S.; Febriana Setyadi, E. R.; Majidah, L.; Taufany, F.; Atmaja, L.; Aparamarta, H. W. Purification and separation of glucomannan from porang tuber flour (Amorphophallus muelleri) using microwave assisted extraction as an innovative gelatine substituent. Heliyon 2023, 9 (11), No. e21972.
17. Tapia-Quir¢s, P.; Granados, M.; Sentellas, S.; Saurina, J. Microwave-assisted extraction with natural deep eutectic solvents for polyphenol recovery from agrifood waste: Mature for scaling-up? Sci. Total Environ. 2024, 912, 168716.
18. Palaric, C.; Atwi-Ghaddar, S.; Gros, Q.; Hano, C.; Lesellier, E. Sequential selective supercritical fluid extraction (S3FE) of triglycerides and flavonolignans from milk thistle (Silybum marianum L, Gaertn). J. CO2 Util. 2023, 77, 102609.
19. Almeida, C. F.; Manrique, Y. A.; Lopes, J. C. B.; Martins, F. G.; Dias, M. M. Recovery of ergosterol from Agaricus bisporus mushrooms via supercritical fluid extraction: A response surface methodology optimization. Heliyon 2024, 10, No. e21943.
20. Hu, Y.; Yang, L.; Liang, Z.; Chen, J.; Zhao, M.; Tang, Q. Comparative analysis of flavonoids extracted from Dendrobium chrysotoxum flowers by supercritical fluid extraction and ultrasonic cold extraction. Sust. Chem. Pharm. 2023, 36, 101267.
21. Zhou, L.; Luo, S.; Li, J.; Zhou, Y.; Wang, X.; Kong, Q.; Chen, T.; Feng, S.; Yuan, M.; Ding, C. Optimization of the extraction of polysaccharides from the shells of Camellia oleifera and evaluation on the antioxidant potential in vitro and in vivo. J. Funct. Foods 2021, 86, 104678.

22. ACS Omega http://pubs.acs.org/journal/acsodf Review https://doi.org/10.1021/acsomega.4c02718 ACS Omega 2024, 9, 31274?31297

HOW TO CITE: Shubhum Mhaske, Rushikesh Kale, Kalyani Kale, Sarika Kadam, Emerging Technologies in Herbal Drug Development, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 8, 302-308. https://doi.org/10.5281/zenodo.16737498