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Exploring Phytomedicine: Innovations, Efficacy, and Future Directions

Mohd. Wasiullah[1], Piyush Yadav[2], Satish Kumar Yadav[3,*], Rehan Ahmed Khan[4]

Abstract

The use of plant-derived substances for therapeutic purposes has long been a cornerstone of traditional medicine systems worldwide. With increasing interest in natural remedies, the field of phytomedicine is experiencing a revival, marked by innovations in research, formulation, and application. This review article explores recent advancements in phytomedicine, highlighting novel extraction technologies and the efficacy of plant-based treatments in clinical settings. The review also addresses the challenges faced in phytomedicine research, including issues related to standardization, safety, and regulatory hurdles. Furthermore, we provide a comprehensive overview of current trends and future directions, emphasizing the need for interdisciplinary approaches to integrate phytomedicine into modern healthcare practices. By synthesizing recent findings and identifying gaps in knowledge, this article aims to offer valuable insights and guidance for researchers, practitioners, and policymakers working towards the advancement of phytomedicine.

Keywords: Phytomedicine, phytochemicals, herbal medicines, medicinal plant, nutraceuticals

INTRODUCTION

Phytomedicine refers to the use of plant-derived substances for medicinal purposes. It's a field that combines elements of pharmacology, botany, and traditional medicine to develop treatments from plants. Phytomedicine encompasses a range of products including herbal medicines, plant extracts, and essential oils.

The utilization of plant-derived compounds for therapeutic purposes has been integral to human health care for millennia. Rooted in ancient traditions across various cultures, it has historically provided a rich repository of remedies and therapeutic agents. In recent years, there has been a resurgence of interest in phytomedicine, driven by a growing appreciation for natural products and the quest for alternatives to synthetic pharmaceuticals.

***Author for Correspondence**
Satish Kumar Yadav
E-mail: slk.pharma@gmail.com

[1]Principal, Department of Pharmacy, Prasad Institute Technology, Jaunpur, Uttar Pradesh, India
[2]Academic Head, Department of Pharmacy, Prasad Institute of Technology, Jaunpur, Uttar Pradesh, India
[3]Associate Professor, Department of Pharmacy, Prasad Institute of Technology, Jaunpur, Uttar Pradesh, India
[4]Scholar, Department of Pharmacy, Prasad Institute of Technology, Jaunpur, Uttar Pradesh, India

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There are approximately 80,000 species of medicinal plants that have been used throughout the world, and in India, around 20,000 medicinal plant species are recorded for use in different types of diseases [1, 2].

In the present time, about 80% of the world population depends on herbal medicine as a first-line primary health care treatment for human alleviation because there is very less or no chance of side effects.

This review focuses on phytomedicine is not merely a nostalgic return to the past but a reflection of significant advancements in science and technology that are reshaping the field.

Innovations in extraction methodologies, such as supercritical fluid extraction and ultrasonic-assisted extraction, are enhancing the yield and purity of bioactive compounds.

Advances in molecular biology and pharmacology have facilitated a deeper understanding of the mechanisms underlying the therapeutic effects of plant-based substances, revealing novel targets and pathways for treatment.

The efficacy of phytomedicine is being rigorously evaluated through contemporary clinical trials and systematic reviews, which are increasingly validating traditional uses and uncovering new therapeutic applications. These efforts are complemented by innovations in formulation technologies, such as nano-encapsulation and targeted delivery systems, which aim to improve the bioavailability and effectiveness of plant-derived compounds [3].

CURRENT TRENDS IN PHYTOMEDICINE (HERBAL MEDICINE)

As we know, phytomedicine plays a very important role in the development of new drugs by extracting active ingredients from medicinal plants and modifying them to obtain better efficacy and safety.

Herbal medicine remains popular in many developing countries and is rapidly expanding in industrialized nations. Approximately 70% of physicians in France and Germany frequently prescribe herbal treatments, with a growing number of patients seeking these therapies. Globally, around 80% of the population is estimated to use herbal remedies, with rates in some developing nations reaching as high as 95%. In China, traditional herbal medicine accounts for 30%–50% of total drug use, while in Ghana, Mali, Nigeria, and Zambia, it comprises 60% of home-based first-line treatments. In regions, like Europe, North America, and other developed areas, over half the population has reportedly tried herbal remedies at least once. Cities, like San Francisco, London, and South African regions, see 75% of HIV/AIDS patients incorporating herbal formulations into their care. Additionally, between 70%–90% of Canadians and Germans have used herbal treatments at some point in their lives. In the United States, an estimated 158 million adults use herbal medicine, with interest continuing to grow. The global herbal medicine market now exceeds $60 billion annually, with widespread adoption, particularly among adults who often use both conventional and herbal therapies. For those with chronic illnesses, herbal options offer a gentler, long-term alternative with fewer side effects compared to conventional medications, contributing to the rapid global acceptance of herbal medicine [4].

Phytomedicine, the study of medicinal plants and plant-based therapies, is evolving with new approaches focusing on increased efficacy, safety, and target-specificity. Several emerging trends in 2024 emphasize advancements in phytochemical applications, personalized therapies, and innovative delivery systems to improve therapeutic outcomes.

Some Innovations in Phytomedicine

1. *Nanotechnology in Phytomedicine:* Nanoparticles are now widely used to deliver phytochemicals in cancer treatments due to their ability to improve solubility, bioavailability, and targeted delivery. This minimizes side effects and increases effectiveness, as nanocarriers can direct high drug concentrations specifically to tumor cells, enhancing treatment outcomes and reducing drug resistance issues.
2. *Targeted Cancer Treatments:* Specific plant compounds, like cardenolides and certain flavonoids, are gaining attention for their potent anti-tumor properties. Research demonstrates the effectiveness of compounds, like calotropin and polymethoxyflavonoids, in various cancer therapies, particularly through pathways that inhibit tumor growth, trigger apoptosis, and prevent metastasis. Studies indicate that compounds, such as heptamethoxyflavone from citrus plants and Cucurbitacin-B from cucumbers show promising results in combating aggressive cancers, such as nasopharyngeal carcinoma and prostate adenocarcinoma [5].

3. *Phytochemicals in Chronic Disease Management:* Besides cancer, phytomedicine is extending its reach in managing chronic conditions like cardiovascular diseases, neurodegenerative disorders, and diabetes. For instance, phytochemicals with anti-inflammatory and antioxidant properties are being incorporated into therapies to mitigate oxidative stress and inflammation, which are key factors in many chronic illnesses.
4. *Standardization and Quality Control:* As phytomedicine gains popularity, maintaining consistency and safety in herbal preparations is a significant trend. Enhanced methodologies in quality control, including the use of spectroscopy and chromatography for precise compound identification and purification, ensure that plant-based products meet high safety and efficacy standards.
5. *Biotechnological Applications:* Genetic engineering and metabolic engineering emerge as methods to enhance the yield and quality of medicinal plant extracts, such as those used for producing boswellic acids. Biotechnology also aids in sustainable phytomedicine by cultivating rare plant species in controlled environments, addressing the scarcity of certain medicinal plants while protecting biodiversity.
6. *Advanced Quality Control and Standardization:* Improved analytical tools, like chromatography and spectroscopy, are being used to accurately identify and quantify active compounds in plant-based medicines, ensuring consistency and potency. This standardization is essential as phytomedicine becomes more widely adopted in regulated health systems.
7. *Personalized Phytomedicine:* The trend toward precision medicine is extending into phytotherapy, with research focusing on how specific plant compounds interact with genetic markers. This allows for treatments tailored to individual genetic profiles, enhancing the likelihood of positive outcomes while reducing adverse reactions.
8. *Synergistic Combinations with Conventional Medicine:* Researchers are exploring the combination of phytochemicals with conventional treatments, such as chemotherapy and immunotherapy, for enhanced therapeutic effects. For example, combining cocoa extract with doxorubicin, a chemotherapy drug, has been shown to reduce drug toxicity and enhance cancer-fighting potential, indicating a promising trend toward integrative therapies.

Overall, these trends suggest that phytomedicine is becoming increasingly sophisticated, with innovations aimed at maximizing the therapeutic potential of plant-derived compounds while maintaining high safety standards. This growth in targeted delivery systems and enhanced quality controls promises more reliable and effective plant-based treatments across various medical fields [6, 7].

Some Popular Phytomedicines Are Used Today in Various Diseases

Several popular phytomedicines are commonly used today for managing various diseases, and their effectiveness is supported by both traditional knowledge and growing scientific research. There are some widely used phytomedicine and their applications across different health conditions:

Curcumin (from Turmeric)

- *Used for:* Inflammation, arthritis, and cancer.
- *Active Compound:* Curcumin is the primary active ingredient in turmeric with anti-inflammatory and antioxidant properties.
- *Mechanism of Action:* Curcumin inhibits inflammatory mediators, such as cytokines, helping to manage inflammation and pain. Additionally, it has been found to induce apoptosis (cell death) in cancer cells and reduce tumor growth in various cancers.
- *Applications:* Curcumin is used in conditions, like osteoarthritis, rheumatoid arthritis, and even in cancer, adjunct therapies due to its potential to reduce tumor cell proliferation when combined with chemotherapy. The structure of curcumin is depicted in Figure 1.

Ginseng

- *Used for:* Fatigue, immune support, cognitive function, and diabetes.

- *Active Compounds:* Ginsenosides, unique compounds found in Panax ginseng, possess adaptogenic and immunomodulatory effects.
- *Mechanism of Action:* Ginseng boosts immune cell activity and enhances antioxidant defenses. It also has hypoglycemic effects, making it useful in managing blood sugar levels in diabetes.
- *Applications:* It is widely used as an adaptogen to reduce stress, improve mental clarity, and manage blood sugar in diabetes. Studies have shown that it can help improve immune function and energy levels, particularly in people recovering from illness. The chemical structure of ginseng is depicted in Figure 2.

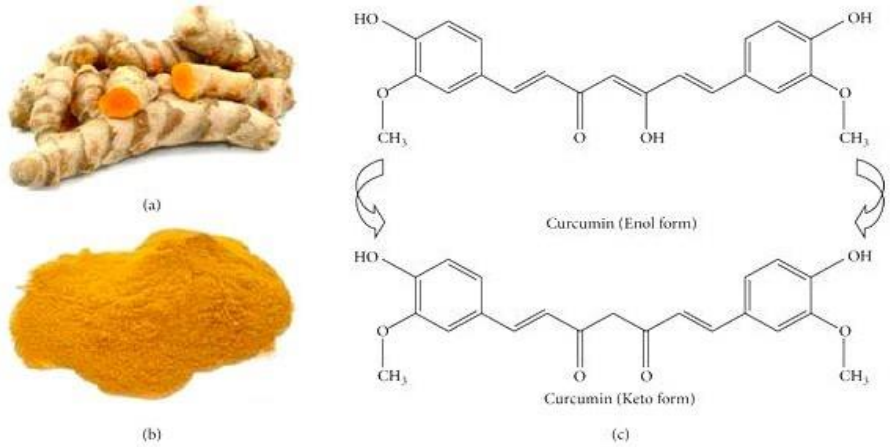


Figure 1. Curcumin chemical structure.

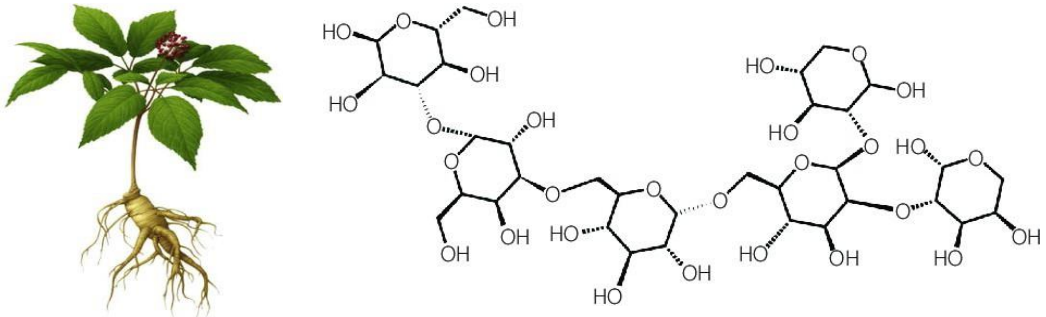


Figure 2. Ginseng.

Milk Thistle (*Silymarin*)

- *Used for:* Liver health, hepatitis, and detoxification.
- *Active Compound:* Silymarin, a flavonoid complex from milk thistle seeds, is known for its liver-protective properties.
- *Mechanism of Action:* Silymarin stabilizes cell membranes in the liver, preventing toxins from entering cells and promoting liver cell regeneration. It also has antioxidant and anti-inflammatory effects that reduce liver damage.
- *Applications:* Silymarin is commonly used to support liver health in conditions like hepatitis, cirrhosis, and fatty liver disease. Studies indicate it can improve liver function tests and reduce liver inflammation in hepatitis patients. The structure of silymarin is depicted in Figure 3.

Echinacea

- *Used for:* Immune support and respiratory infections.
- *Active Compounds:* Phenols, alkylamides, and polysaccharides that stimulate immune responses.
- *Mechanism of Action:* Echinacea is believed to enhance immune function by increasing white blood cell count and inhibiting viruses, which helps prevent and alleviate colds and flu.

- *Applications:* Primarily used as an herbal remedy to prevent and reduce the duration of respiratory infections like the common cold and influenza [8–15]. The structure of Echinacea is depicted in Figure 4.

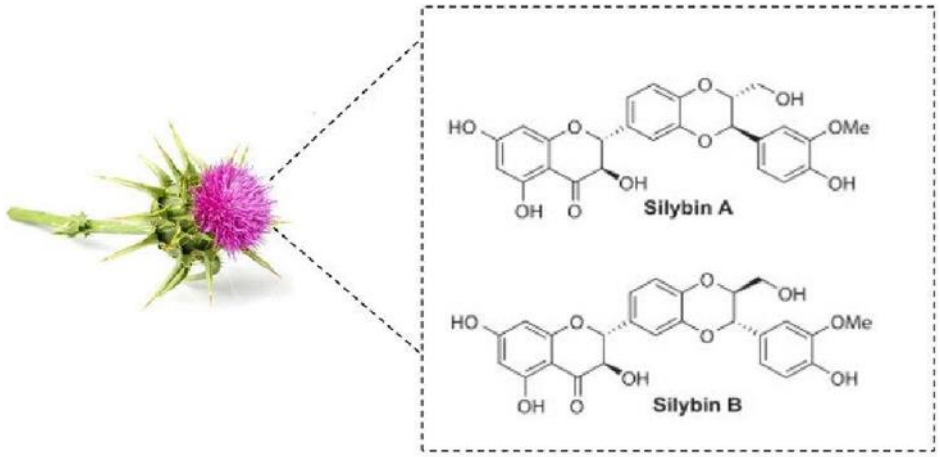


Figure 3. Silymarin.

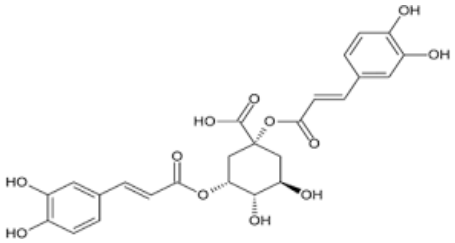


Figure 4. Echinacea.

Ginkgo Biloba

- *Used for:* Cognitive health, dementia, and blood circulation.
- *Active Compounds:* Flavonoids and terpenoids with neuroprotective and vasodilating properties.
- *Mechanism of Action:* Ginkgo biloba increases blood flow to the brain and has antioxidant effects that protect against neuronal damage. It also inhibits platelet aggregation, supporting overall blood circulation.
- *Applications:* Ginkgo is often used in cognitive disorders like Alzheimer's disease and to enhance memory and mental clarity. It is also used in treating peripheral vascular disorders by improving blood flow. The Structure of Ginkgo biloba depicts in Figure 5.

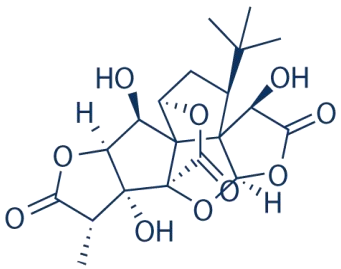


Figure 5. Ginkgo biloba.

Aloe Vera

- *Used for:* Skin conditions, digestive health, and wound healing.

- *Active Compounds:* Mucopolysaccharides, glycoproteins, and anthraquinones.
- *Mechanism of Action:* Aloe Vera exhibits anti-inflammatory, antibacterial, and soothing properties, promoting skin healing and digestive health.
- *Applications:* Commonly used in topical treatments for burns, wounds, and skin irritations. It is also used in oral forms to support digestive health and reduce symptoms in conditions like irritable bowel syndrome (IBS). The structure of *Aloe vera* is depicted in Figure 6.

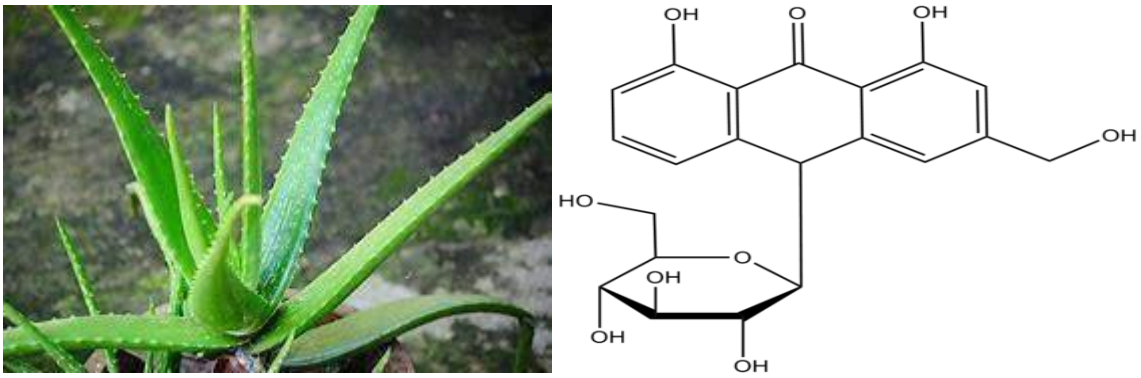


Figure 6. Aloe vera.

Garlic (*Allium sativum*)

- *Used for:* Cardiovascular health, immune support, and infections.
- *Active Compounds:* Allicin, sulfur-containing compounds with antimicrobial and cardiovascular benefits.
- *Mechanism of Action:* Garlic is known to lower blood pressure, reduce cholesterol, and have antibacterial and antiviral effects. It also supports heart health by preventing platelet aggregation and blood clot formation.
- *Applications:* Garlic is commonly used for heart health, reducing blood pressure, and cholesterol levels. It is also used to boost the immune response and fight infections [8–15]. The figure of garlic is depicted in Figure 7.

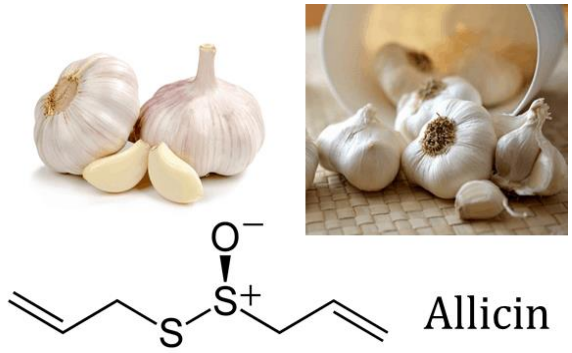


Figure 7. Garlic and allicin structure.

Ashwagandha (*Withania somnifera*)

- *Used for:* Stress reduction, anxiety, and cognitive health.
- *Active Compounds:* Withanolides, compounds with adaptogenic and anti-inflammatory properties.
- *Mechanism of Action:* Ashwagandha reduces cortisol levels and improves resilience to stress. It also has neuroprotective effects, potentially enhancing cognitive functions.
- *Applications:* Widely used to manage stress and anxiety. Studies also suggest its benefits in improving memory, focus, and physical stamina, making it popular for both mental and physical wellness. The Figure of Ashwagandha is depicted in Figure 8.

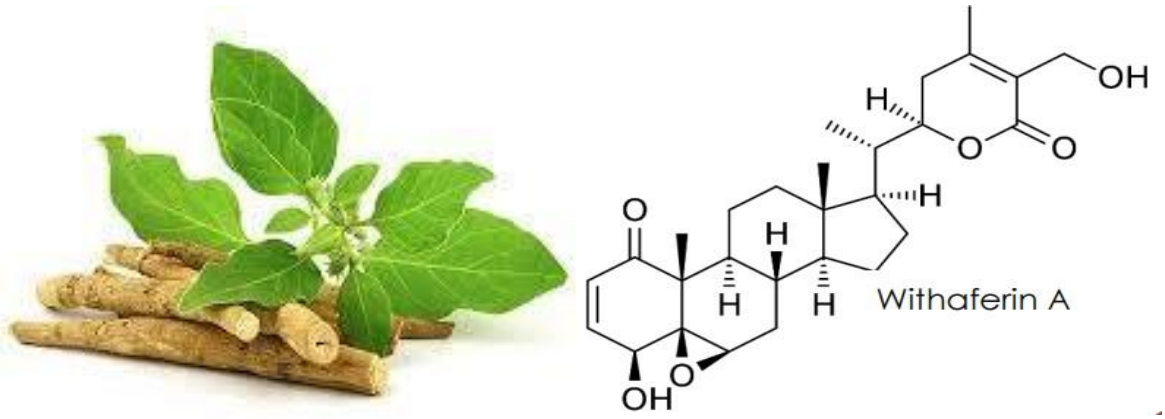


Figure 8. Ashwagandha and withaferin structure.

Peppermint (*Mentha piperita*)

- *Used for:* Digestive health, irritable bowel syndrome (IBS), and headaches.
- *Active Compound:* Menthol, known for its antispasmodic and analgesic effects.
- *Mechanism of Action:* Menthol relaxes the muscles in the gastrointestinal tract, helping to alleviate bloating and discomfort in IBS. When applied topically, it provides a cooling sensation that can reduce headache pain.
- *Applications:* Commonly used as a digestive aid and in managing IBS symptoms. It is also used topically for headache relief. The figure of peppermint is depicted in Figure 9.

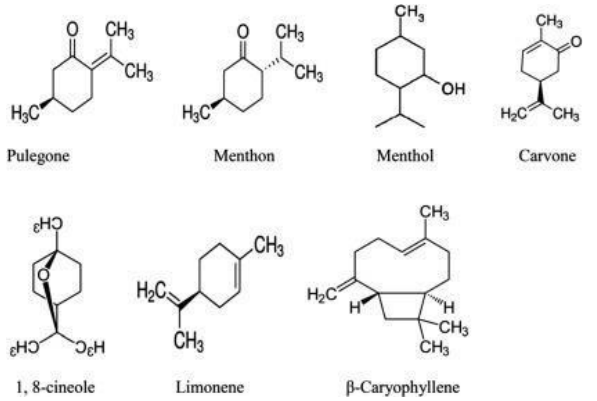


Figure 9. Peppermint.

Green Tea (*Camellia sinesis*)

- *Used for:* Antioxidant support, weight management, and cardiovascular health.
- *Active Compounds:* Catechins, especially epigallocatechin gallate (EGCG).
- *Mechanism of Action:* EGCG has potent antioxidant properties that reduce oxidative stress, boost metabolism, and support cardiovascular health by reducing cholesterol and improving endothelial function.
- *Applications:* Commonly used as a supplement for weight management and heart health and may reduce the risk of certain cancers. The Figure of green tea is depicted in Figure 10.

Ginger (*Zingiber officinale*)

- *Used for:* Digestive health, nausea, and inflammation.
- *Active Compounds:* Gingerols and Gingerin, known for anti-inflammatory and anti-nausea effects.
- *Mechanism of Action:* Ginger's anti-inflammatory effects help with joint pain, while it also acts as a prokinetic in the gut, relieving nausea and digestive discomfort.

- *Applications:* Widely used to manage nausea (especially during pregnancy) and improve digestion. It is also effective in reducing pain and inflammation in arthritis. The Figure of ginger is depicted in Figure 11.

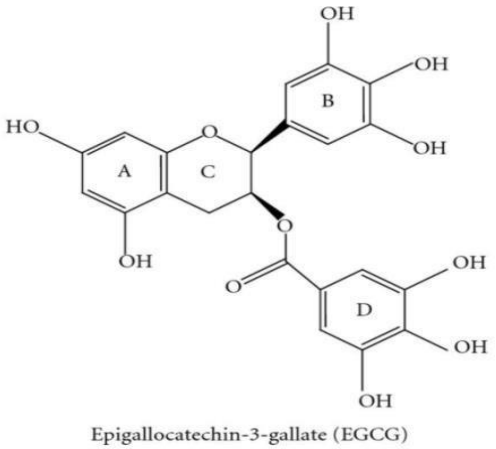


Figure 10. Green tea.

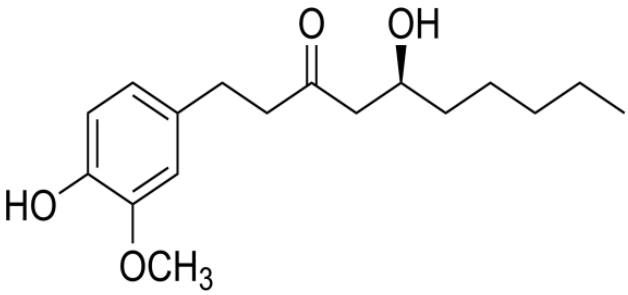


Figure 11. Ginger and gingerol.

Saw Palmetto (*Serenoa repens*)

- *Used for:* Benign prostatic hyperplasia (BPH) and urinary tract health.
- *Active Compounds:* Fatty acids and phytosterols.
- *Mechanism of Action:* Saw palmetto may inhibit 5-alpha reductase, an enzyme involved in prostate enlargement, thus helping relieve BPH symptoms.
- *Applications:* Primarily used for reducing urinary symptoms associated with BPH, like frequent urination and difficulty urination. The figure of saw almetto is depicted in Figure 12.

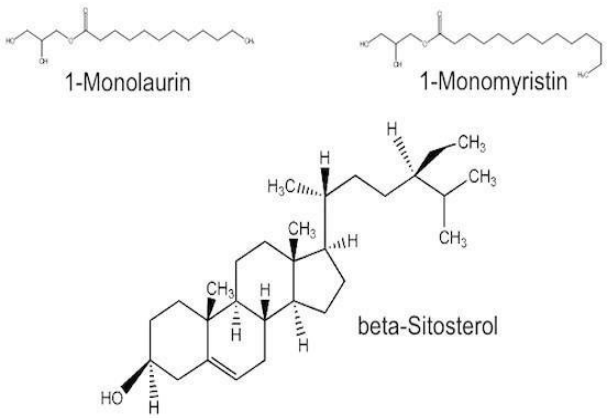


Figure 12. Saw palmetto.

Valerian Root (*Valeriana officinalis*)

- *Used for:* Insomnia, anxiety, and sleep disorders.
- *Active Compounds:* Valerenic acid and valepotriates.
- *Mechanism of Action:* Valerian acts on the gamma-aminobutyric acid (GABA) receptors in the brain, producing a calming effect that aids sleep.
- *Applications:* Commonly used as a natural sleep aid and for reducing anxiety without the addictive effects seen in some prescription sedatives. The figure of valerian is depicted in Figure 13.

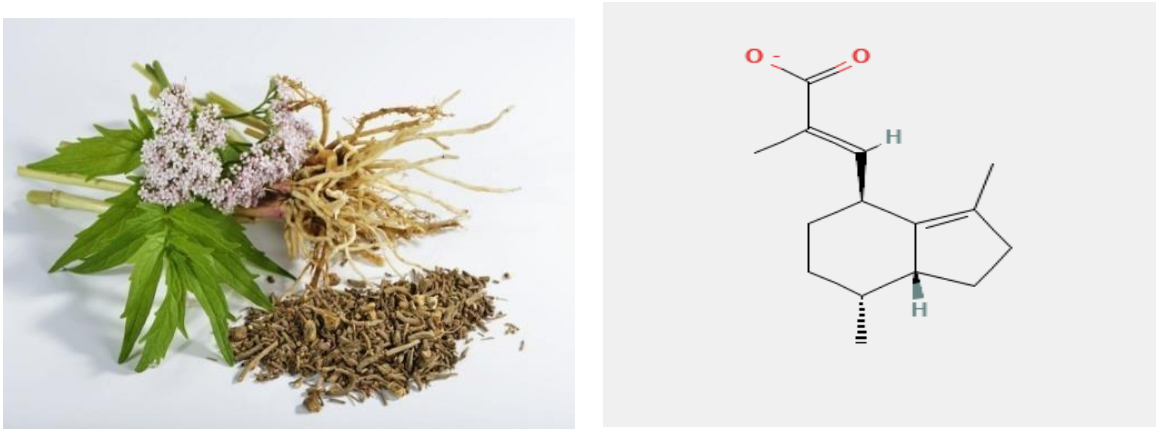


Figure 13. Valerian root and valerenic acid structure.

Cranberry (*Vaccinium macrocarpon*)

- *Used for:* Urinary tract infections (UTIs) and bladder health.
- *Active Compounds:* Proanthocyanidins, which prevent bacterial adhesion.
- *Mechanism of Action:* The proanthocyanidins in cranberries prevent bacteria, particularly E. coli, from adhering to the urinary tract walls, reducing the risk of infection.
- *Applications:* Commonly used in UTI prevention, especially for individuals who suffer from recurrent infections. The figure of cranberry is depicted in Figure 14.

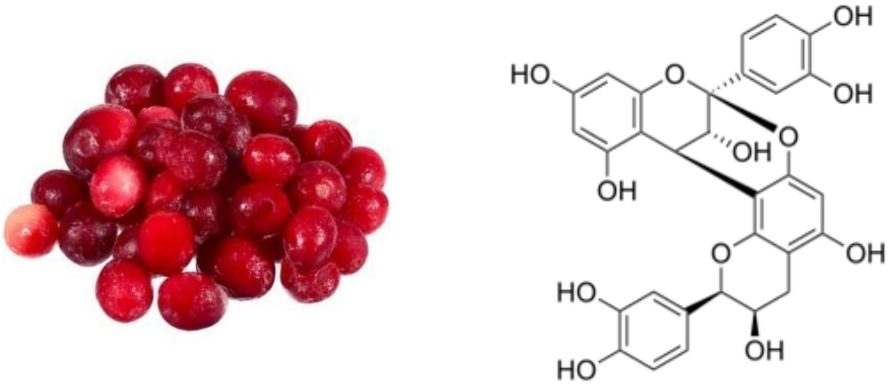
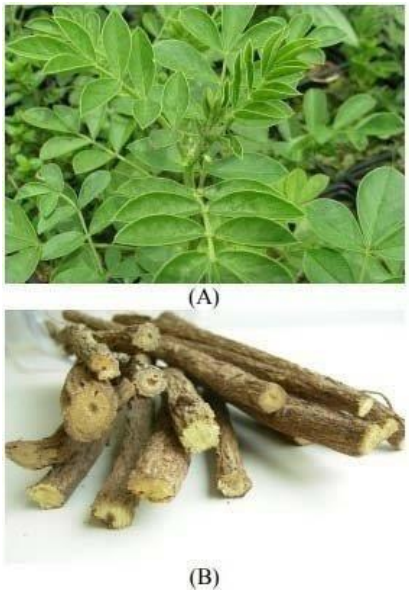


Figure 14. Cranberry.

Licorice Root (*Glycyrrhiza glabra*)

- *Used for:* Respiratory health, digestive issues, and sore throat relief.
- *Active Compounds:* Glycyrrhizin, which has anti-inflammatory and antiviral properties.
- *Mechanism of Action:* Licorice root soothes mucous membranes, reduces inflammation, and has antimicrobial effects, making it beneficial for respiratory and digestive health.
- *Applications:* Used in treating bronchitis, coughs, and digestive ulcers. However, due to potential side effects on blood pressure, it should be used carefully [8–15]. The figure of licorice is depicted in Figure 15.



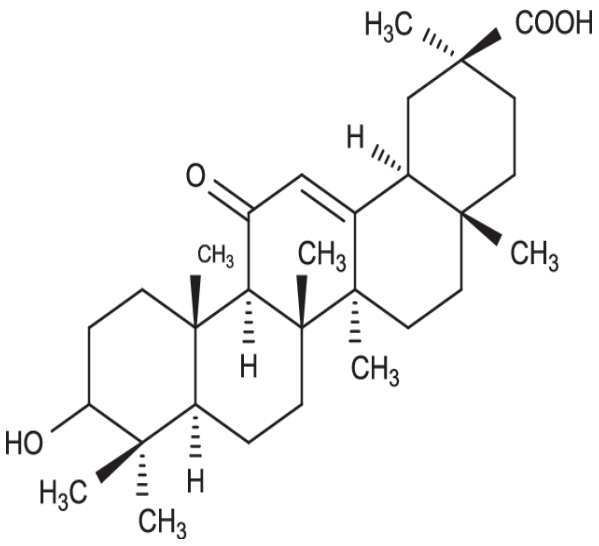


Figure 15. Licorice and glycyrrhizin structure.

CURRENT TECHNIQUES USED FOR THE EXTRACTION OF PHYTOMEDICINE

Plant extracts are usually mixtures of many different types of bioactive compounds or phytochemicals with different polarities and solubilities, making their separation for identification and characterization very challenging. Various separation techniques, such as thin layer chromatography (TLC), gel filtration chromatography, and high-performance liquid chromatography (HPLC) can be used to obtain pure compounds, which can then be used to determine their structures and biological activities.

Chromatographic Techniques

Chromatographic techniques have significantly contributed to discovering pharmaceutically important novel bioactive compounds from plants. Chromatography purifies compounds from a mixture using ion exchange, molecular sieves, or adsorption. High-performance liquid chromatography (HPLC) is a well-analytical technique for separating and determining the components of natural products. Chemical separations using HPLC rely on the different migration rates of specific compounds in a given column and mobile phase. The degree of separation is primarily determined by the choice of the stationary phase and the mobile phase. Bioactive phytochemicals are often present only as minor constituents in crude extracts, making HPLC's high resolving power ideal for processing such multicomponent samples on both analytical and preparative scales (Figure 16) [16, 17].

High-Performance Liquid Chromatography (HPLC)

- *Principle:* Utilizes high-pressure pumps to pass a liquid solvent containing herbal extracts through a column filled with a solid adsorbent material, thereby separating compounds based on their polarity and affinity for the stationary phase.
- *Advantages:* High precision, sensitivity, and versatility for both polar and nonpolar compounds.
- *Applications:* Commonly used for the separation and quantification of flavonoids, alkaloids, and phenolic acids from plants, such as ginseng, turmeric, and chamomile.

Gas Chromatography (GC)

- *Principle:* Involves vaporizing the sample and passing it through a column with a stationary phase, which separates components based on volatility.
- *Advantages:* High sensitivity and resolution, particularly for volatile and semi-volatile compounds.
- *Applications:* Suitable for essential oils and volatile compounds in herbs, such as peppermint, lavender, and eucalyptus (Figure 17) [18].

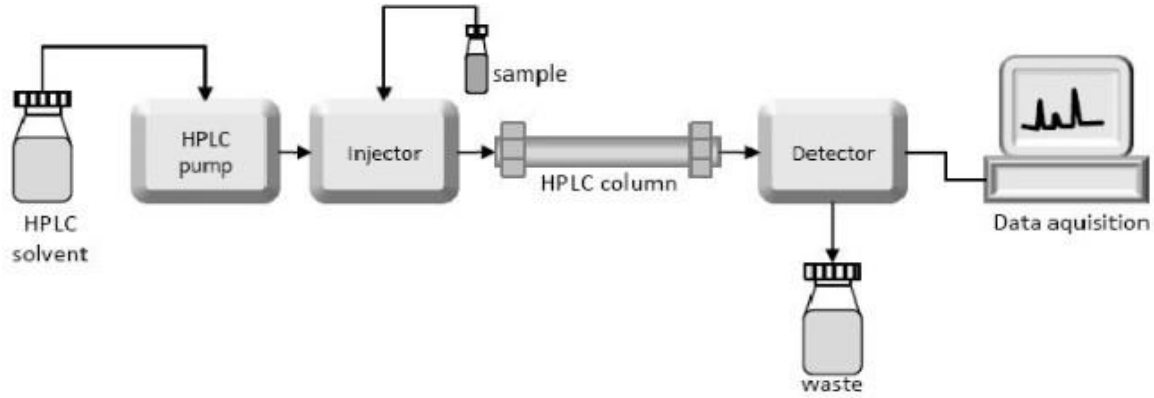


Figure 16. HPLC instrumentation.

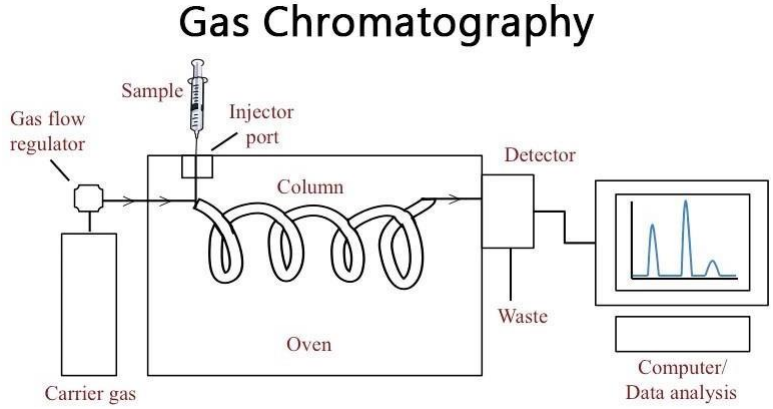


Figure 17. Gas chromatography.

Thin-Layer Chromatography (TLC)

- *Principle:* A straightforward technique in which a thin layer of adsorbent material (e.g., silica) spread on a plate separates compounds based on their affinity for the stationary phase when the sample is applied and developed with a solvent.
- *Advantages:* Cost-effective, simple, and ideal for preliminary screening.
- *Applications:* Frequently used for qualitative analysis and identification of bioactive compounds in extracts from plants like ginkgo, licorice, and ginger (Figure 18) [19].

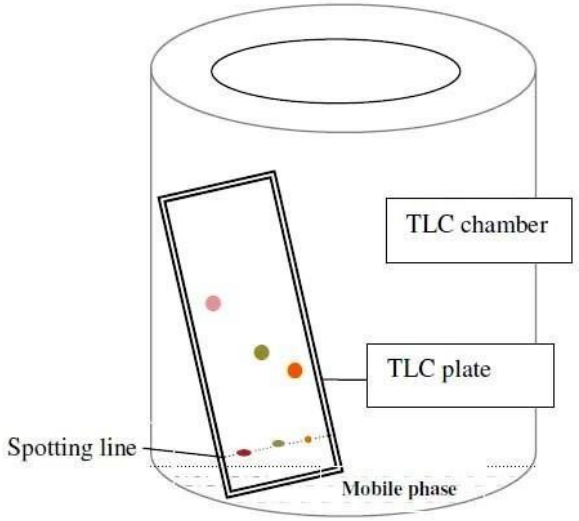


Figure 18. Thin layer chromatography.

Column Chromatography (CC)

- *Principle:* Involves passing a liquid solvent through a column filled with a stationary phase, where compounds separate based on their interactions (affinity) with the adsorbent material.
- *Advantages:* Flexible, scalable, and capable of fractionation and bulk isolation of target compounds.
- *Applications:* Employed to isolate large quantities of alkaloids, saponins, and tannins from herbs, such as Echinacea, Ashwagandha, and milk thistle (Figure 19).

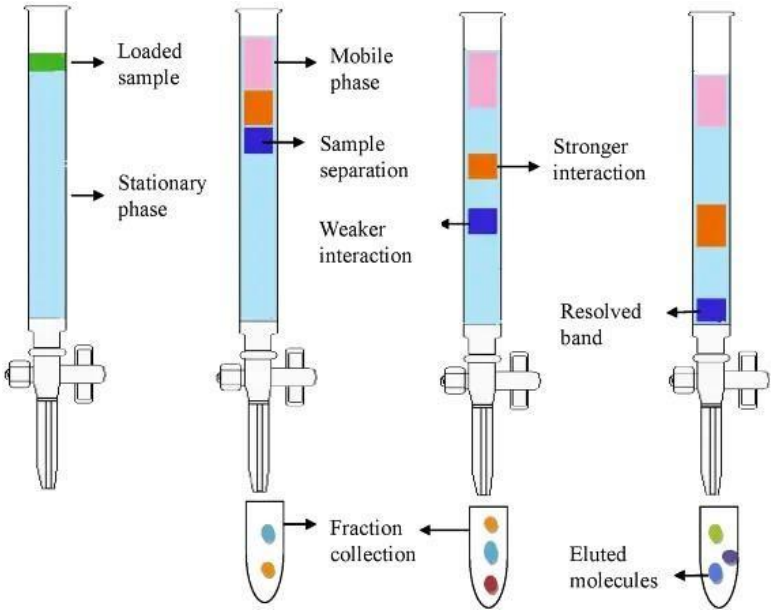


Figure 19. Column chromatography.

Ion Exchange Chromatography (IEC)

- *Principle:* Separates ions and polar molecules based on their charge. Positively or negatively charged compounds are retained on the oppositely charged stationary phase and eluted with buffer.
- *Advantages:* High selectivity for charged compounds, useful for acidic or basic molecules.
- *Applications:* Commonly used for the extraction of amino acids and alkaloids from herbs, such as licorice, nettle, and valerian (Figure 20) [20].

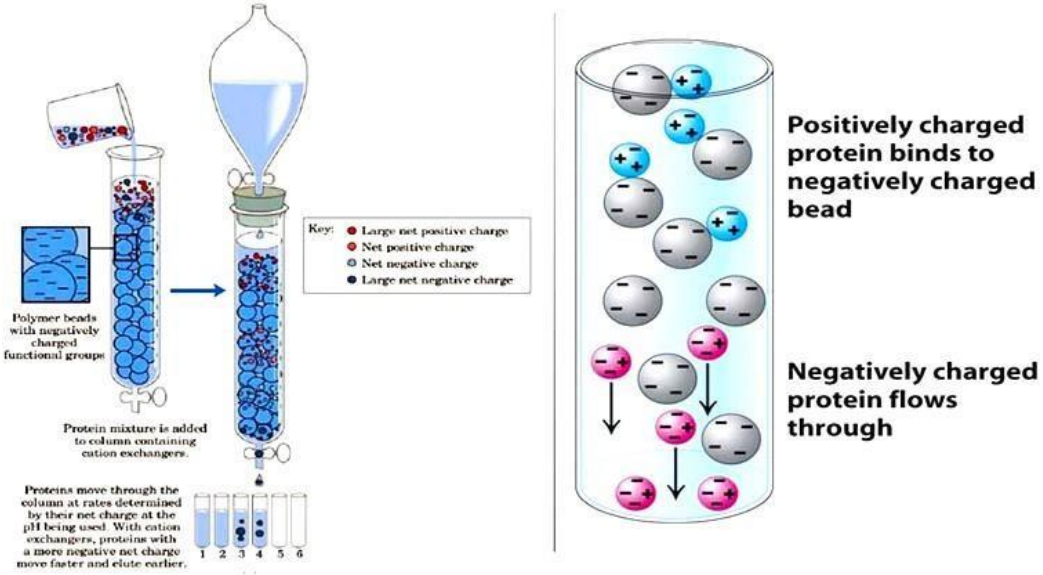


Figure 20. Ion exchange chromatography.

Supercritical Fluid Chromatography (SFC)

- *Principle:* Uses supercritical CO_2 as the mobile phase, allowing separation of non-polar and semi-polar compounds.
- *Advantages:* Fast, low solvent consumption, ideal for non-polar compounds.
- *Applications:* Effective for lipophilic bioactive and phytosterols found in herbs, such as St. John's Wort and Turmeric (Figure 21).

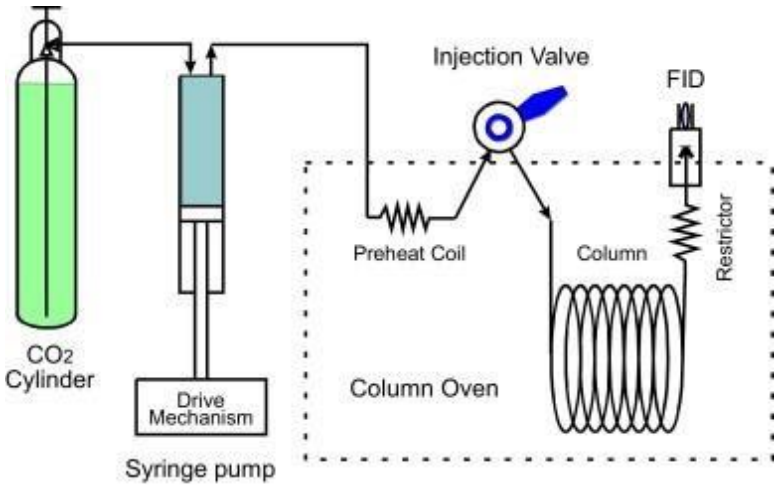


Figure 21. Supercritical fluid extraction.

SOME NOVEL EXTRACTION TECHNIQUES FOR PHYTOMEDICINE

Herbal medicine has seen a significant rise in interest due to its potential therapeutic effects. To maximize efficacy and bioavailability, novel extraction techniques have been developed to isolate and concentrate bioactive compounds with high purity and yield. Here's a review of some recent advanced extraction methods used in herbal medicine:

Ultrasound-Assisted Extraction (UAE)

- *Principle:* Uses ultrasonic waves to disrupt cell walls, improving solvent penetration and accelerating extraction.
- *Advantages:* Fast, cost-effective, and operates at low temperatures, preserving heat-sensitive bioactives.
- *Applications:* Common for extracting essential oils, flavonoids, and phenolic compounds from herbs like ginseng, rosemary, and peppermint (Figure 22) [21].

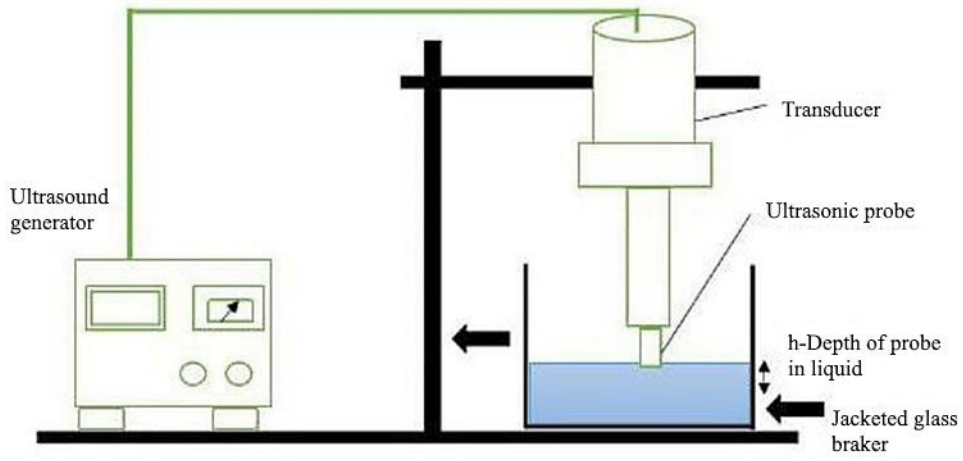


Figure 22. Ultrasound-assisted extraction.

Supercritical Fluid Extraction (SFE)

- *Principle:* Uses supercritical CO_2 as a solvent to penetrate plant materials and extract nonpolar compounds.
- *Advantages:* Eco-friendly, leaves minimal solvent residue, and allows for selective extraction by adjusting pressure and temperature.
- *Applications:* Effective in isolating essential oils and lipophilic compounds in herbs, such as turmeric, ginger, and black pepper (Figure 23).

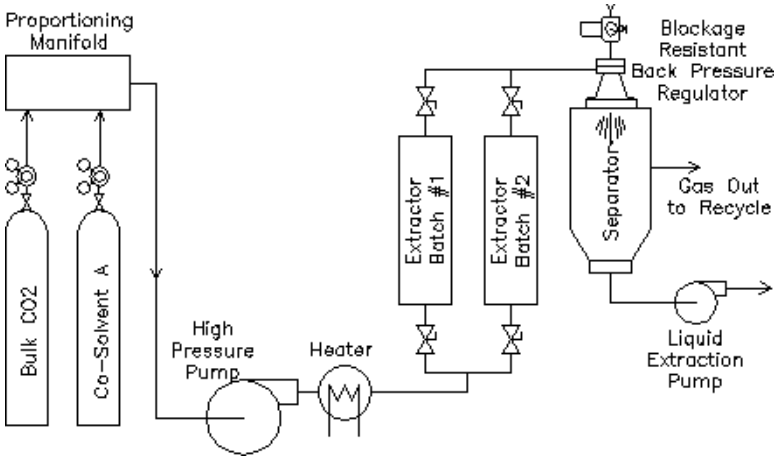


Figure 23. Supercritical fluid extraction.

Microwave-Assisted Extraction (MAE)

- *Principle:* Uses microwave energy to heat polar molecules within plant cells, causing cell rupture and enhancing extraction efficiency.
- *Advantages:* Faster extraction time, high yield, and requires less solvent than conventional methods.
- *Applications:* Frequently used for polyphenols and flavonoids from plants like green tea, sage, and chamomile (Figure 24) [22].

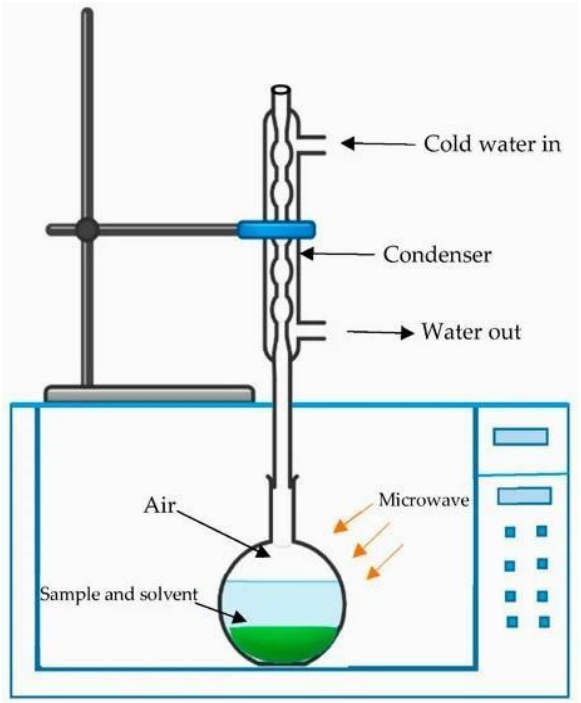


Figure 24. Microwave-assisted chromatography.

Pressurized Liquid Extraction (PLE)/Accelerated Solvent Extraction (ASE)

- *Principle:* Uses high pressure and temperature with organic solvents to enhance solubility and diffusion rates, enabling faster extraction.
- *Advantages:* Efficient for bioactive compounds, minimal solvent usage, and produces high yields.
- *Applications:* Often applied to extract antioxidants and alkaloids from herbal sources like ginkgo biloba and echinacea (Figure 25).

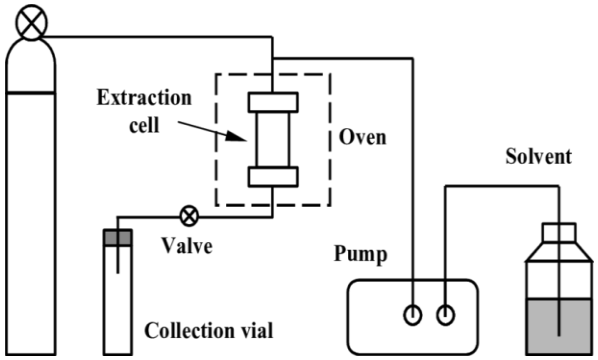


Figure 25. Pressurized liquid extraction.

Enzyme-Assisted Extraction (EAE)

- *Principle:* Uses enzymes like cellulase or pectinase to break down plant cell walls and release bioactive compounds.
- *Advantages:* Eco-friendly, gentle extraction conditions, and can improve the yield and purity of bioactives.
- *Applications:* Effective for polysaccharides and saponins in herbs, such as aloe vera, licorice, and astragalus (Figure 26).

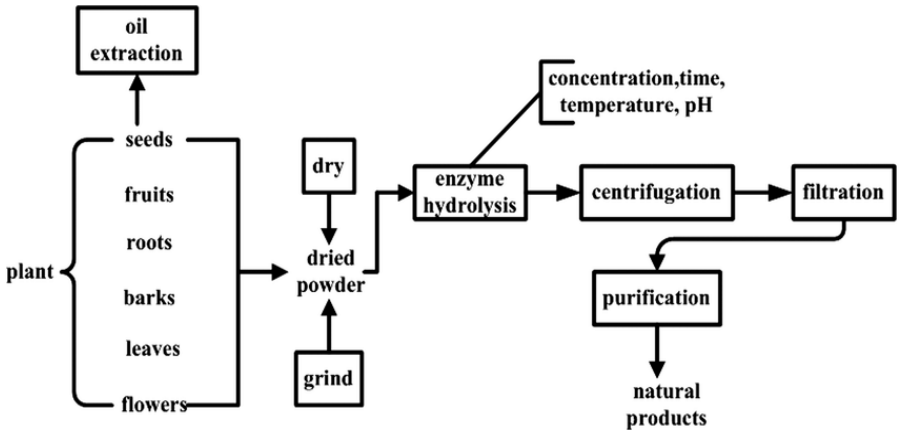


Figure 26. Enzyme-assisted extraction.

Ionic Liquid Extraction (ILE)

- *Principle:* Uses ionic liquids as green solvents to dissolve and extract bioactive compounds without volatile organic solvents.
- *Advantages:* Highly selective, biodegradable, and tunable for various compound types.
- *Applications:* Used for alkaloids and flavonoids extraction from plants like Chinese skullcap and milk thistle (Figure 27) [23, 24].

Pulsed Electric Field (PEF) Extraction

- *Principle:* Applies short, high-voltage pulses to create pores in cell membranes, allowing for easier compound release.

- *Advantages:* Non-thermal method that retains heat-sensitive compounds and uses minimal energy.
- *Applications:* Useful for extracting antioxidants and phenolic compounds from herbs like basil, thyme, and oregano (Figure 28).

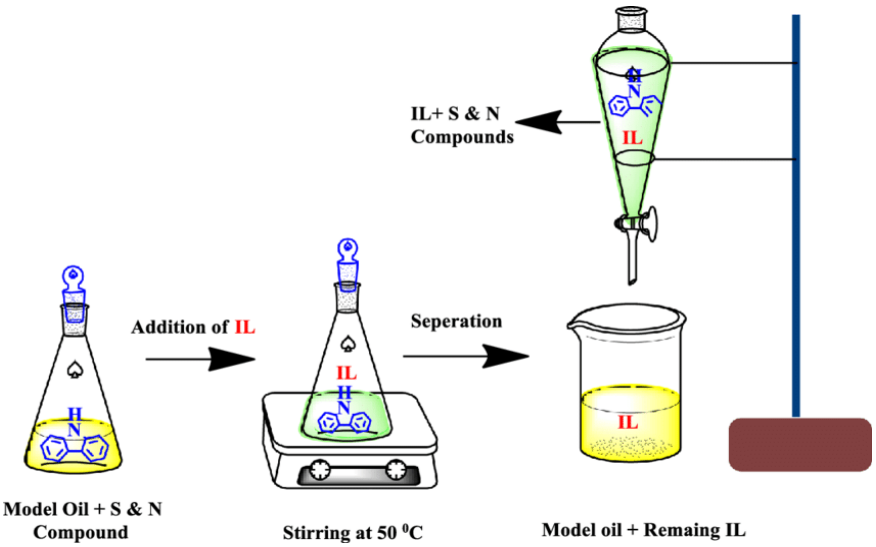


Figure 27. Ionic liquid extraction.

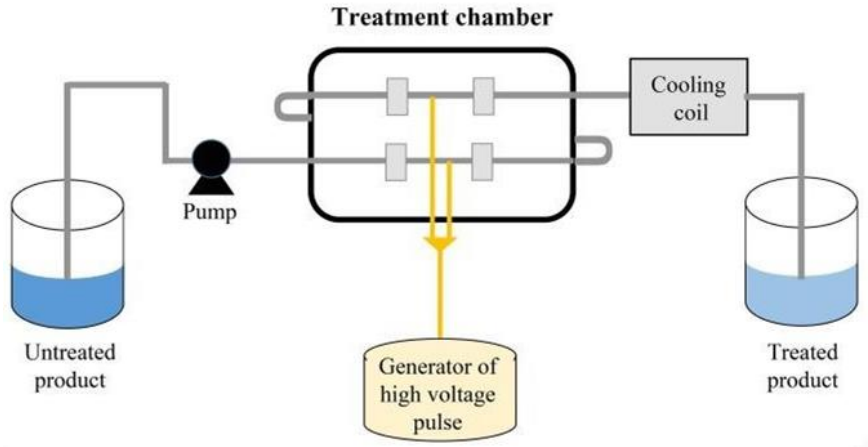


Figure 28. Pulsed electric field extraction.

Efficacy and Safety in Herbal Medicines

The therapeutic utilization of plant-based medicines has been a part of conventional healing frameworks for centuries and proceeds to rise in popularity in cutting-edge health care. These natural cures, derived from roots, stems, blooms, and seeds, offer a wide extend of benefits, from easing persistent conditions to improving gene well-being. Be that as it may, the questions of adequacy and security are central to understanding its part in modern medication [25].

Efficacy

The efficacy of phytomedicine depends on many factors, including the type of plant used, method of extraction, no. of doses, and individual patient-related factors. Scientific studies have supported the efficacy of certain phytomedicines. For instance, *Ginkgo biloba* has been shown to improve cognitive function, *Curcuma longa* (turmeric) is noted for its anti-inflammatory properties, and *Echinacea* is frequently used as an immunity booster. These remedies often have multiple active compounds that act synergistically, making them complex compared to synthetic drugs, which typically target a single molecular pathway.

However, the lack of standardized dosages and active compound concentrations in many phytomedicines can affect the treatment results. In some cases, inconsistent results arise due to variations in plant quality, growing conditions, and preparation methods. This lack of standardization remains a major challenge in confirming the efficacy of phytomedicine through large-scale clinical trials [26].

Security

Despite the widespread belief that natural herbal products are inherently safe, phytomedicine can carry risks, particularly when misused (abused). Risks, like contamination, toxicity from improper dosing, and herb-drug interactions, can cause serious health problems. For instance, St. John's wort, a typical herb which we don't know whose exact mechanism of action and identity of its chemical constituents commonly used for depression, is known to interact with conventional medications, such as antidepressants, anticoagulants, and birth control pills, potentially reducing their potency and effectiveness.

Additionally, the absence of proper regulations in many countries can result in quality control problems. Some herbal products are contaminated with pesticides, heavy metals, or adulterants, which can lead to adverse effects. Therefore, proper identification, standardization, and quality control are essential to ensure both the safety and efficacy of phytomedicine.

HURDLES RELATED TO THE STANDARDIZATION OF PHYTOMEDICINE

Plants contain hundreds of different compounds, some in very low concentrations. Despite advancements in chemical analysis, it is rare for phytochemical studies to fully isolate and characterize all the secondary metabolites within a plant extract. Additionally, the quality control of herbal medicines faces challenges due to the variability in plant constituents, influenced by factors, such as temperature, light, water, nutrients, collection methods, and even the specific part or age of the plant. For instance, some compounds degrade with heat and need low drying temperatures, while others may break down through enzymatic activity that persists after harvest, leading to variability in herbal drug composition [27].

Ensuring quality in herbal medicines requires strict standardization, particularly of raw materials, which play a crucial role in maintaining the stability and efficacy of these preparations. The use of markers is essential for quality testing, especially when active compounds are unidentified, though markers are often untested for their actual therapeutic relevance. Factors, like extraction methods and contamination (e.g., microorganisms, heavy metals, pesticides), also impact the safety and effectiveness of herbal drugs. To reduce these variations, pharmaceutical companies often use cultivated rather than wild-harvested plants, as the consistency of compounds is easier to manage in controlled environments. Cultivation also allows monitoring of secondary metabolite levels, enabling optimal harvest times.

Recent advancements in purification and structural analysis techniques have improved the standardization processes for herbal medicines, helping maintain consistency in plant extracts. Methods, such as thin-layer chromatography, gas chromatography, high-performance liquid chromatography, mass spectrometry, and UV/visible spectrometry, either independently or in combination, are widely used to ensure the quality of both raw materials and finished herbal products [28].

SCOPE AND FUTURE DIRECTIONS

Plants are a valuable source of therapeutic agents and serve as raw materials for producing semi-synthetic compounds used in industries like cosmetics, perfumes, and food. The rising popularity of plant-based health products has also increased their acceptance in the cosmetic as well as pharmaceutical industries. As both health resources and commercial products, medicinal plants play a key role in economic development. Demand for these products is expected to grow in the coming years, with a booming market for herbal supplements and remedies.

The effectiveness of certain herbal products is well-established; recent examples include *Artemisia annua* (artemisinin, a derivative of wormwood with anticancer and anti-malarial properties), *Taxus brevifolia* (taxols from the Pacific yew, known for anticancer effects), and *Silybum marianum* (silymarin from milk thistle seeds, effective in treating liver disorders). With advanced technologies, like High-Performance Liquid Chromatography (HPLC), Gas Chromatography (GC), and GC-Mass Spectrometry (MS), it's now possible to precisely identify and quantify active compounds in these plants. Many medicinal herbs have a promising future, as numerous plants worldwide are not explored in medical research. Ongoing and future studies on their medicinal properties could lead to new and effective disease treatments.

This trend points to increased interest from researchers, doctors, and pharmaceutical companies, particularly in countries, such as China, India, and other developing nations that hold the richest variety of medicinal plant species and lead in exporting herbal materials. As safe and affordable alternatives to conventional treatments, the use of plants, either in whole form or as derived medications, is likely to expand in the future [29, 30].

CONCLUSIONS

For the centuries, nearly every human civilization has relied on herbal medicines for preventing and treating a variety of health conditions, including eczema, wounds, skin infections, swelling, aging, mental illness, cancer, asthma, diabetes, jaundice, scabies, snakebites, gastric ulcers, and more. This widespread use stems from the general belief that herbal remedies are free from side effects, affordable, and locally accessible. With rising demand, however, there is growing concern among policymakers, healthcare professionals, and the public about the safety, standardization, effectiveness, quality, availability, and commercialization of herbal products. Unlike conventional drugs, herbal medicines are often less regulated in many countries, including the United States. Globalization has also increased the worldwide accessibility of herbal medicines, making them available to consumers everywhere. Consequently, there is a pressing need for coordinated efforts to carry out clinical trials to verify the efficacy and safety of these remedies. Many researchers are investigating the therapeutic applications of herbal medicines as documented in traditional texts from systems like Ayurveda, Unani, and Traditional Chinese Medicine (TCM). The recent adoption of advanced analytical techniques and research methods has enabled the evaluation and validation of herbal treatments by modern standards. With improved quality control and regulatory frameworks, herbal medicine is expected to be more closely integrated with conventional healthcare systems, marking the onset of an "herbal age."

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