Exploring Nature's Pharmacy: Breakthroughs in Herbal Drug Development and Technology

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Abstract

The trend towards alternative treatment includes herbal medications significantly. As more individuals look for natural solutions, herbal therapy is growing in popularity. Since the beginning of civilization, herbal remedies have been used to promote health and treat a variety of illnesses. More medicinally beneficial herbal medicines need to be used and scientifically verified in order to compete with the expanding pharmaceutical industry. This article aims to explain the therapeutic efficacy of various herbal remedies, adverse drug reactions, drug interactions, standardization and stability testing of herbal remedies, pharmacovigilance, and the legal and regulatory status of herbal remedies**.**

Key words: Herbal medicine, standardization, drug technology, applications

1. Introduction

Herbal medicines, often known as plants materials or herbalism, use the whole plant or its parts to cure wounds or illnesses. The use of medicinal herbs as medications is done to cure and prevent illness, as well as to promote health and healing[1] .These are molecules used for any of these uses that are drugs or preparations produced from a plant or plants. The earliest known type of medical care is herbal medicine. There are numerous herbal remedies on the

market that claim to treat the signs and symptoms of a wide range of circumstances, from depression to the common cold and flu. According to the World Health Organization (WHO), unique herbal medications are full-spectrum[2], labelled pharmaceuticals that contain active chemicals, aerial or secretive plant parts, or other plant material.

The examination of the quality, safety, and efficacy of herbal medicines is done in accordance with detailed standards established by the World Health Organisation. According to WHO statistics, 80% of people worldwide currently utilise herbal medicines for their primary healthcare. Exceptionally, herbal medications may also contain by custom natural organic or inorganic active ingredients that are derived from sources other than plants.

Herbal medicine is a key component of conventional medicine and is frequently used in ayurveda, homoeopathic, naturopathic, and other medical systems[3]. Herbs are typically seen as being secure because they come from natural sources. The usage of herbal medications as a result of the toxicity and side effects of allopathic medications has caused a sharp rise in the number of herbal drug makers.[4] Herbal medications have become increasingly popular among those who don't have a prescription during the past few decades.

For thousands of years, herbal medicines have been made from seeds, leaves, stems, bark, roots, flowers, and their extracts. Herbal products have advanced to a point where they are adequate for use as beneficial agents such as antimicrobial, anti-diabetic, anti-fertility, anti-ageing, anti-arthritic, sedative, antidepressant, antianxiety, antispasmodic, analgesic, anti-inflammatory, anti-HIV, vasodilatory, hepatoprotective, for treating cirrhosis, asthma, acne, impotence,etc.

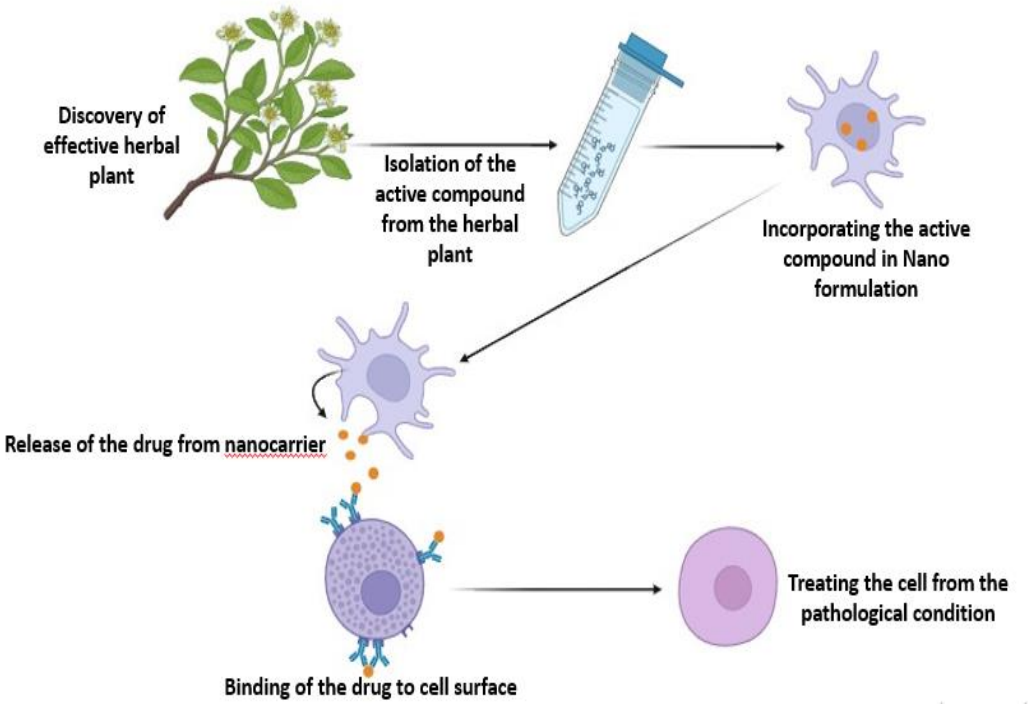

Figure 1. Represents the discovery, isolation, and incorporation of drugs into nanocarrier.

About 4,000 years ago, the use of herbal medicines was acknowledged. These medications have withstood extensive human testing over many centuries and in the real world[5]. Due to their toxicity, several medications have been ceased from use, while others have been altered or combined with Raw materials for herbal medications may come from well tended plants or be gathered from the wild. Herbal medicines can be found in many different forms and frequently need to be prepared before use[6]. Typically, you may buy them in bulk as dried plants, plant parts, or loosely packaged for herbal drinks and concoctions. Herbs are boiled in water to make decoctions, which are then strained to remove the plant matter. Hydro alcoholic tinctures and fluid extracts are accessible as more potent herbal medicine formulations[7,8]. Due to the nature of the active chemical components in plants, preparation techniques may vary.

2. Pharmaceutical Preparation

This comprises the creation of numerous drug delivery systems, including tablets, capsules, injections, creams, and more.Lindberg et al., in 2023proposed that pharmaceutical preparation includes selecting the proper excipients (inactive components), figuring out the proper dosage, and guaranteeing the product's stability and quality[1].

3. Drug Delivery Systems

Drug delivery is the science of getting a pharmaceutical compound into the body to achieve a therapeutic effect. Some key areas in drug delivery include:

3.1. Oral Drug Delivery

This is the most common route for drug administration. It entails creating formulations that can resist the demanding circumstances of the digestive system and release the medication at the proper rate and place[2,3].

3.2. Parenteral Drug Delivery

This involves intravenous, intramuscular, and subcutaneous injections as well as implanted drug delivery methods.

3.3. Transdermal Drug Delivery

Delivering drugs through the skin using patches or creams.By applying herbal medications directly to the skin, transdermal herbal drug administration enables the delayed and regulated release of active ingredients. Monton et al., in 2022 discovered thatbypassing the digestive tract, this method increases bioavailability while minimizing systemic negative effects. Securing skin penetration, formulation stability, and safety are difficulties. The effectiveness and practicality of administering herbal medicines may be improved with further research and innovation in this area.

3.4. Nanotechnology in Drug Delivery

Enhancing drug delivery, increasing bioavailability, and targeting certain cells or tissues using nanoscale nanoparticles[4–6]. Habeeb et al., in 2022 found that nanotechnology expands the potential uses of herbal medicines by protecting sensitive chemicals, enabling combination therapy, and improving penetration across biological barriers.

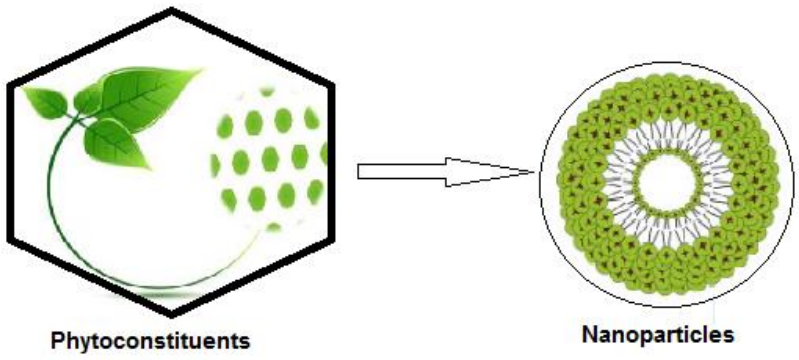

Figure 2. Nanotechnology in herbal drug

3.4.1. Need for new "nano carriers" for delivery of drugs for "herbal remedies

Many of the herbal medications' contents will be destroyed in the stomach's highly acidic pH before reaching the blood, and other constituents may be metabolised by the liver. As a result, the herbal medicines may not enter the blood in the proper amount [14]. There will be no way to demonstrate the therapeutic impact of the treatment if it is not delivered in the ideal quantity to the affected area at "minimum effective level." Bypassing obstacles like the stomach's acidic pH and liver metabolism, nanocarriers applied to herbal medicines will deliver the maximum amount of the drug to its site of action. They will also prolong the drug's circulation into the body.

Due to the following qualities, herbal medicines were chosen as a viable drug candidate for distribution via a nano delivery system:

There are efficient extracts in acetone, chloroform, petrol, and methanol that may not be appropriate for distribution as such.

- Since these medications are in bulk, a dose reduction is intended.
- Target specificity is lacking in currently marketed formulations for a number of chronic illnesses.
- With the formulations that are currently on the market are some additional adverse effects.
- Large doses and lower effectiveness of the current formulations, which causes patient non-compliance.

4. Controlled Release Systems

These systems are designed to release drugs at a predetermined rate, ensuring sustained therapeutic levels in the body. Both the patient's compliance and adverse effects may be improved[7,8].

5. Herbal Drug Technology and Herbal Drug Development

5.1. Herbal Medicine

Herbal medicine involves the use of plant-based materials (herbs, botanicals) for medicinal purposes. It has had a long tradition and is still prevalent throughout many cultures today[9,10].Jo et al., in the year 2022 said phytotherapy, a synonym for herbal medicine, is a branch of medicine that makes use of plants' therapeutic capabilities to treat and prevent disease. The therapeutic power of numerous plant components, including leaves, roots, and herbs, is harnessed in this age-old practice. Herbal remedies have been used extensively in healthcare throughout time and cultures, providing a wholistic approach to heath. They continue to be researched scientifically today and are commonly used in complementary and alternative medical methods due to their possible therapeutic benefits.

Table 1: Traditional use and scientific use of herbs

Traditional use of herbs	Scientific use
Everybody uses common plants or their parts, frequently for varied purposes, as juices, decoctions, or tablets	Making use of properly prepared extracts and medicines from plants.
Combinations of numerous plants, frequently more than ten at once, are typically used. Products frequently don't mention the chemical components or extraction method.	Typically used as symptomatic, for prevention or treatment, and is purified and standardised in the chemical ingredients that have pharmacological effect.
Generally regarded as risk-free and without any negative effects.	Potential adverse reactions, restrictions, medicine interactions, etc.
A patient's personality and emotions are commonly referenced in the pathogenesis of illnesses and therapy (holism), which are frequently founded on philosophical, theological, and socio-cultural conceptions	Diagnostic and therapeutic methodology abides by accepted medical practises because clinical administration is based solely on pharmacological activity as determined by standard laboratory procedures and clinical trials.

5.2. Herbal Drug Technology

Herbal technology combines the use of conventional herbal medicine with cutting-edge science and technology. It includes cutting-edge extraction, formulation, and quality control techniques to guarantee the efficacy and consistency of herbal products. Rafi et al., in 2023 proposed thatwhile strict regulatory compliance and research fuel innovation in the herbal medicine sector, biotechnology and nanotechnology improve the cultivation and distribution of herbal ingredients. It is encouraged by this multidisciplinary approach to use medicinal

plants in healthcare in a safe and efficient manner.Here, natural medications are developed and produced using contemporary pharmaceutical and biotechnological methods[11,12].It includes:

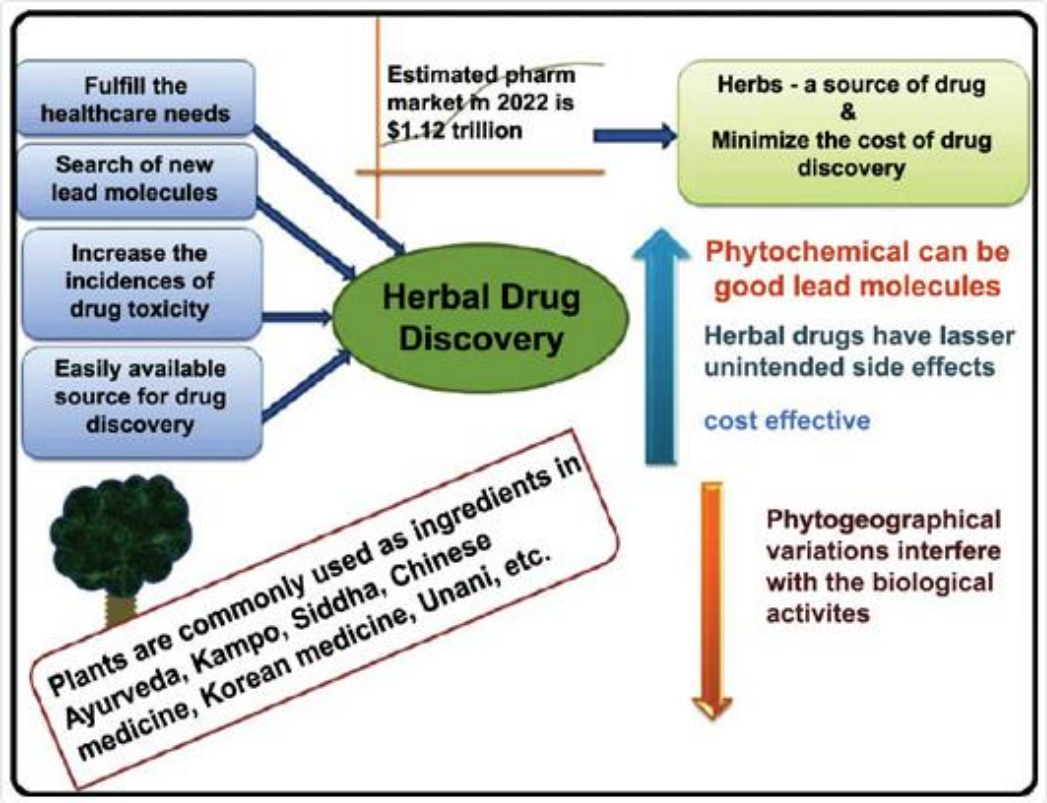

Figure 3. Herbal drug technology

5.2.1. Standardization

Ensuring that herbal products contain consistent levels of active compounds.

Analytical techniques used in herbal drug identification and auantification

1. TLC
2. HPLC
3. HPTLC
4. LCNMR
5. GC-MS

6. DNA FINGERPRINTING
7. GENETIC MARKER
    - RFLP (or Restriction fragment length polymorphism)
    - AFLP (or Amplified fragment length polymorphism)
    - RAPD (or Random amplification of polymorphic DNA)
    - VNTR (or Variable number tandem repeat)
    - Micro satellite polymorphism
    - SNP (or Single nucleotide polymorphism)
    - STR (or Short tandem repeat)
    - SFP (or Single feature polymorphism)

5.2.2. Quality Control

Testing for contaminants, purity, and consistency.

5.2.3. Formulation

Developing herbal products in various forms like capsules, tablets, extracts, or topical creams[13].

5.2.4. Safety Assessment

Evaluating the safety of herbal products through toxicological studies.

6. Herbal Drug Development

This involves the research and development of new herbal medicines or the adaptation of traditional herbal remedies for modern medical use[14,15]. It includes:

6.1. Phytochemical Analysis

Identifying and isolating active compounds in plants[16] .Rai et al.,in 2023 performed scientific examination of the bioactive substances contained in plants is known as phytochemical analysis. It entails locating, separating, and analyzing the numerous chemical elements that are present in plant materials. For this goal, methods like spectroscopy and chromatography are frequently employed. Drug discovery and the creation of herbal remedies are aided by phytochemical analysis, which offers insightful information on the therapeutic and potential health advantages of plants.

6.1.1. COMPUTATION ADVANCEMENT OF NATURAL PHYTOCONSTITUENTS

The 30 % of land on the earth is covered with natural plants, which possess ‘n’ number of medicinally important molecules or leads. The evolving country data disclosed that up to 80 % of the public are hooked on herbal remedies for their prime healthcare, and over 25 % of given medicines are derived from wild plant class molecules [17]. Around 60% FDA FDA-approved drugs are from natural products and their derivatives. The major problem faced in herbal drug discovery is the categorizing, Identification, and separating of phytoconstituents from the herbal plants. As an example, *Tridax procumbens* contains more than 98 phytoconstituents in the leaves itself and similarly many herbal plants possess more than 50 phytoconstituents [18]. The recent advancement in a computational database of the MASS spectrum aids in screening and identifying the existing molecules from herbal medicines (**Figure 4**).

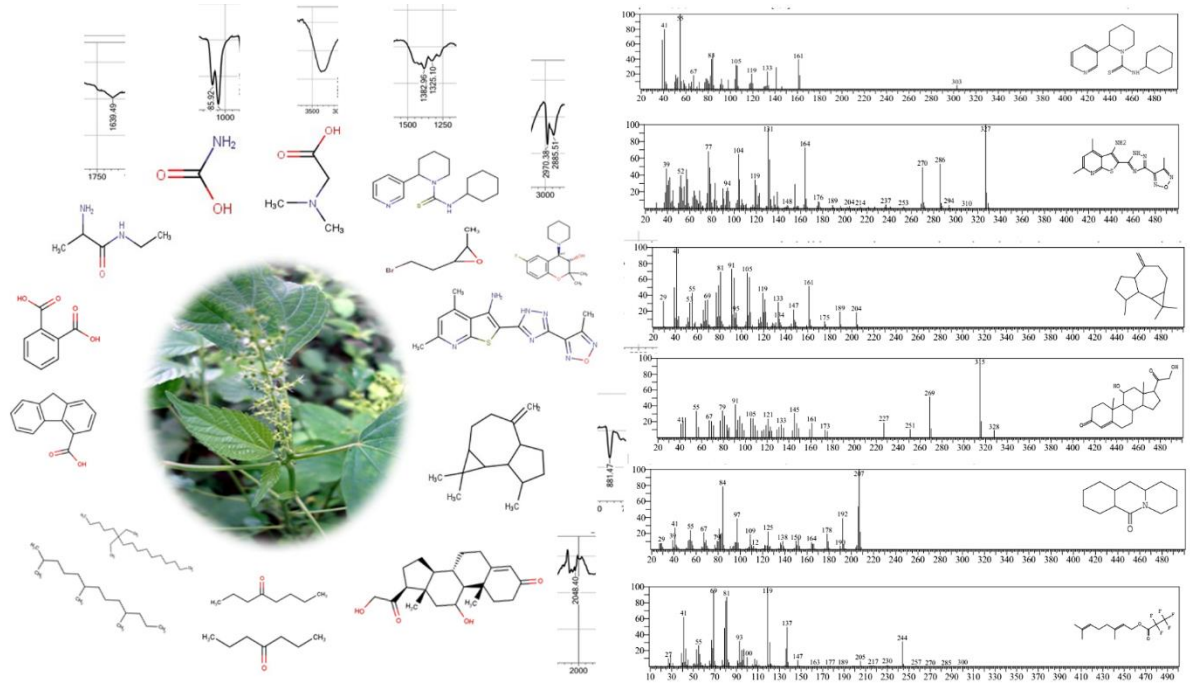

Figure 4. Identification of Phyto constitution from the MS database

The computational drug design (CADD) techniques are taken to the next level to screen and develop the natural product analogs. The docking protocol of CADD illustrates the natural molecule binding inside the binding cavity of the protein and exposes the atomic level insight of interaction between binding side amino acids and natural molecules. For example, Irfan et al., 2023 illustrated the binding of curcumin derivatives in the active site of the PCSK9 protein to treat cholesterol-related diseases [19] (**Figure 2**). Similarly, the same research group collected 98 phytoconstituents from 9 different herbal plants to identify the best lead natural fragment to inhibit the COVID-19 spike protein [18].

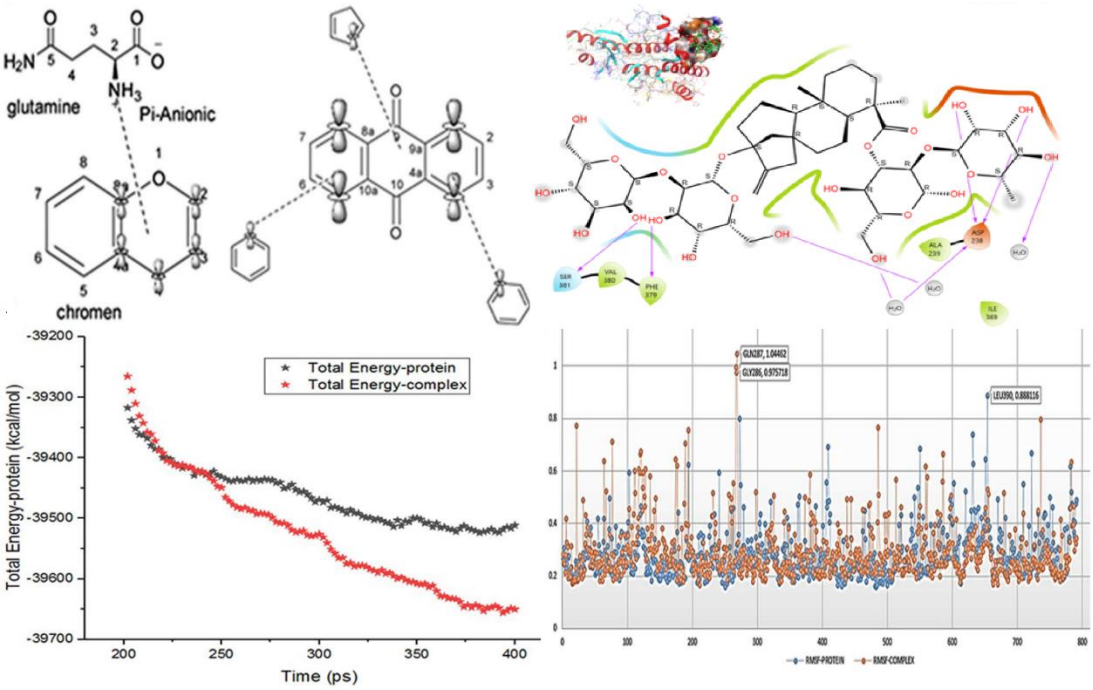

Figure 5. Best binding fragment identification by docking pharmacophore and dynamic simulation analysis.

The Ligand-based drug discovery modules such as pharmacophore and QSAR aid in predicting the fragments or functional groups responsible for the biological activity as well as in predicting the activity without sacrificing animals by the structure of the molecule [18]. Additional quantum mechanics-based molecular dynamic simulation studies mimic the stability of the protein-phytoconstituent complex in body conditions. Which further strengthens and fastens the drug discovery process in small molecule discovery. The study performed by Sakthivel Balasubraminyan et al., (2021) designed and simulated the quinine derivative against the antimicrobial-resistant treatment [20]. These kinds of computational techniques advance and troubleshoot the problem faced in drug discovery and development from natural sources.

6.2. Preclinical and Clinical Trials

Examining the effectiveness and safety of herbal products in both humans and animals.

6.3. Regulatory Approval

Meeting regulatory requirements for herbal medicines in different countries.

The goal of both pharmaceutical and herbal drug development is to offer secure and efficient therapies for a range of medical diseases. While pharmaceuticals typically involve synthetic compounds, herbal drug development relies on natural plant-based ingredients. A greater range of therapeutic alternatives and all-encompassing healthcare solutions may result from integrating the two methodologies[21–23]. It's crucial to remember that, like pharmaceutical treatments, the efficacy and safety of herbal medicines should be thoroughly assessed through scientific research and clinical studies[24,25].

7. Applications of herbal drug technology and development

Employing the medicinal potential of plants and natural substances to create safe and effective medications is the major goal of the pharmaceutical industry's critical sectors of herbal drug technology and herbal drug development[26,27]. Listed below are some important uses and components of the investigation and development of herbal medicines: Medicinal plant identification and screening: To find and screen plants with potential medicinal characteristics, researchers employ a variety of methods, including ethnobotany and phytochemical analyses. Finding the bioactive compounds in these plants is made easier by bioassays and high-throughput screening methods[28,29].

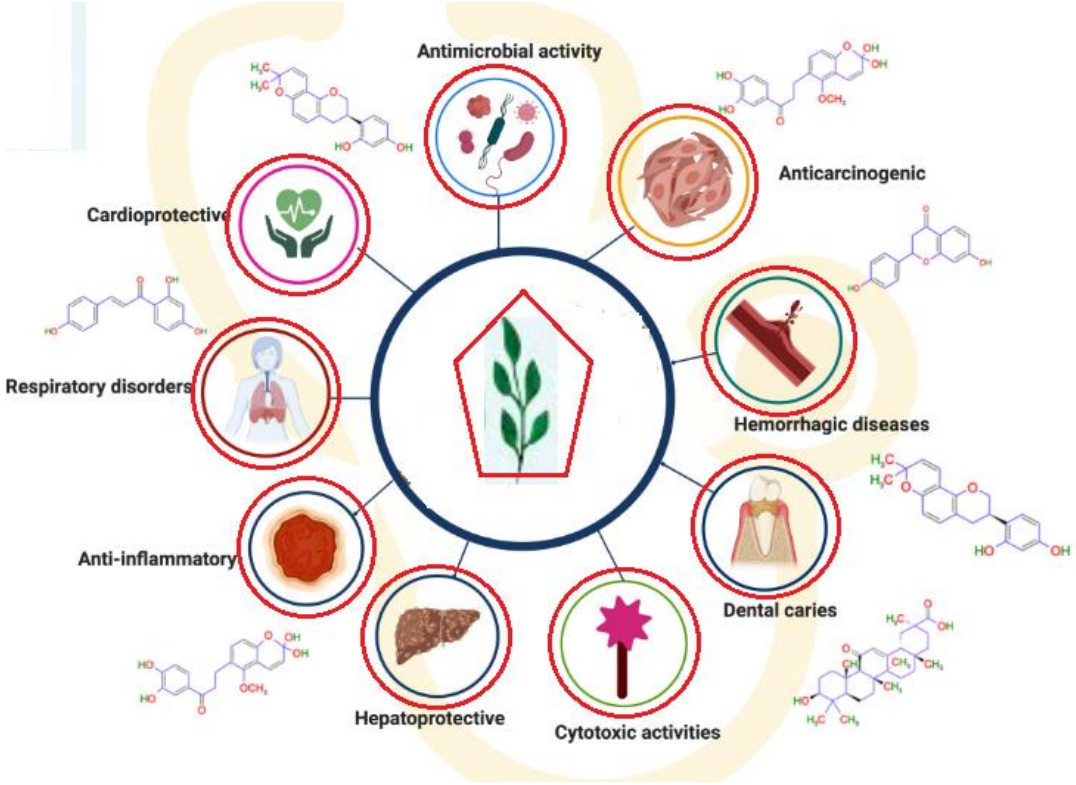

Figure 6. Application of herbal technology

7.1. Extraction and Isolation of Active Compounds

Herbal drug development involves extracting and isolating bioactive compounds from medicinal plants.Techniques like maceration, Soxhlet extraction, and supercritical fluid extraction are commonly used. To assure the safety and effectiveness of these chemicals, purification and characterisation are essential.

7.2. Formulation Development

Herbal medicines often require formulation development to improve stability, bioavailability, and patient compliance. The development of dosage forms such tablets, capsules, creams, and ointments is a research priority.

7.3. Pharmacological and Toxicological Studies

To understand their therapeutic benefits and safety profiles, herbal medications are subjected to extensive pharmacological and toxicological investigations. Efficacy and toxicity are evaluated using animal and cell culture models.

7.4. Clinical Trials

To assess the efficacy and safety of herbal medicines in humans, clinical trials are carried out. These tests are necessary for regulatory approval and adhere to defined norms. Herbal treatments are tested for safety and efficacy in clinical studies related to herbal technology. They employ exacting study methodologies, standardized herbal ingredients, and result metrics. Meta-analyses may provide results and ethical issues are essential. Due to the variances in herbal products, quality control and standardization are necessary.

7.5. Standardization and Quality Control

Developing standardized herbal products is crucial to ensure consistent quality and therapeutic effects. Assessing the presence of active substances, pollutants, and compliance with regulatory criteria are all part of quality control processes[30,31].

8. Genetic markers' function in herbal drug technology

8.1. Gene typing and genetic variation

It is generally known that geographic conditions affect the active components of medicinal plants and, as a result, their activity profiles. Numerous researchers have looked into genetic variations due to geography. Estimates of genetic diversity are useful for developing agricultural improvement projects, managing germplasm, and creating conservation strategies[30]. It has been found that unique neem accessions collected from various geographical sites may be distinguished using RAPD-based molecular markers. To better understand genetic diversity, a lot of work has been done in the critical field of germplasm

analysis. Numerous crops are being fingerprinted, including rice, wheat, chickpeas, pigeon peas, pearl millet, etc.

8.2. Validation of medicinal plant species

DNA-based techniques have been used frequently to confirm the authenticity of plant species with medicinal benefit. This is especially useful for individuals who frequently have other genera or varieties that are identical in terms of morphology and/or phytochemistry replaced or adulterated with them. The dried fruit samples of Lycium barbarum were distinguished from those of related species using RAPD markers.

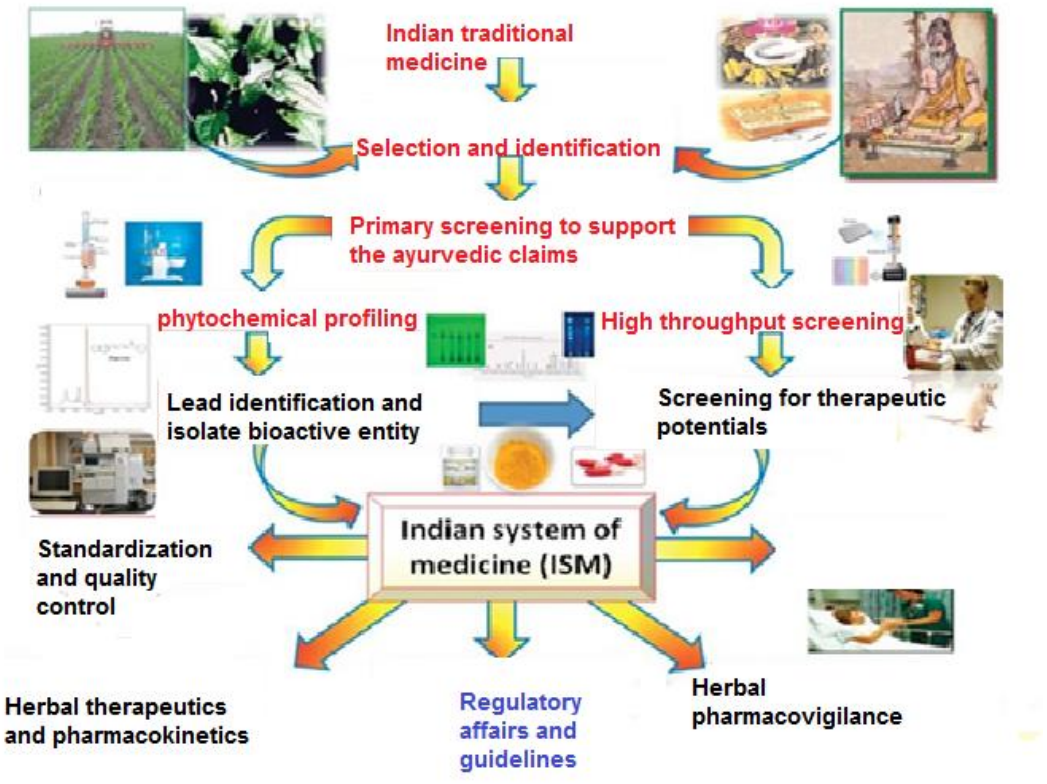

Figure 7. Validation of herbal medicine

8.3. Regulatory Compliance

The development of herbal drugs must follow regionally unique regulatory criteria and recommendations for herbal medications. This comprises supporting materials, safety evaluations, and evidence of effectiveness.

8.4. Pharmacovigilance of Herbal Drugs

Pharmacovigilance's goal is to identify, evaluate, and comprehend any potential negative effects or other drug-related issues associated to herbal, conventional, and complementary medicines. Both industrialised and developing nations employ a variety of herbal medications[31], but recent years have seen a rise in some high-profile herbal safety issues that have an effect on the general public's health. Although historically thought of as being safe, medicinal herbs need to be observed while being used in order to discover any potential hazards. Published evidence demonstrates that the danger is caused by either a contaminant or a medicine that was added[32].

8.5. Stability testing of Herbal Drugs

The goal of a stability test is to establish recommended storage conditions and a shelf-life by demonstrating how the quality of herbal products changes over time under the influence of environmental factors like temperature, light, oxygen, moisture, other ingredients or excipients in the dosage form, drug particle size, microbial contamination, and trace metal contamination[32]. To make sure the product is of sufficient quality for the duration of its storage period, stability testing is required.

8.6. Herbal Supplements and Nutraceuticals

Apart from traditional herbal medicines, herbal drug technology is also applied to develop herbal supplements and nutraceuticals for health promotion and disease prevention[33,34].

9. Future of herbal medicine

Policy-makers, healthcare professionals, and the general public are increasingly expressing concerns about the safety, efficacy, quality, availability, preservation, and further development issues of these herbal products in light of the rapidly expanding market for herbal medicines and other healthcare products in both developed and developing countries of the world[35]. Evidence on the quality, safety, and efficacy of herbal items and TM/CAM practises are also in higher demand among the general public. Extensive research on herbal medicines is required to be done in order to allay these worries and satisfy public desires, not only for their excellent medicinal value but also for the financial benefits.

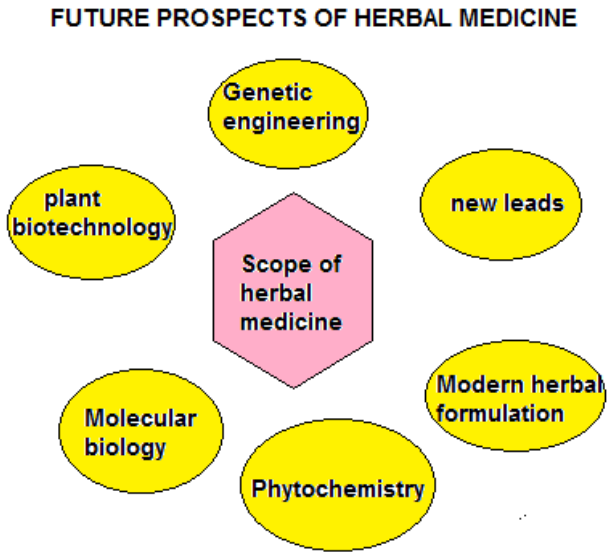

Figure 8. Herbal medicine future prospects

Fortunately, there are already quite extensive phytochemical and pharmacological studies on medicinal plants and herbal remedies in place all over the world. Efforts are being made to isolate and identify these studies' active chemical constituents and to support the efficacy and safety claims made for these treatments. Since most herbal remedies possess the necessary chemical constituents and exhibit the stated effects, it has been demonstrated that they do not entirely lack scientific support. Additionally, the use of many herbal medications is supported by good scientific evidence from randomised clinical trials[36].

10. Conclusion and Future Aspects

In conclusion, the symbiosis of the development of herbal drugs and technology offers hope for safer and more potent treatments. Looking to the future, personalized medicine, AI-driven discoveries, sustainability, combination therapies, regulatory clarity, and raised public awareness are key elements that will shape the evolving field of herbal medicine, enhancing our healthcare options and advancing the fusion of traditional knowledge with contemporary science.

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