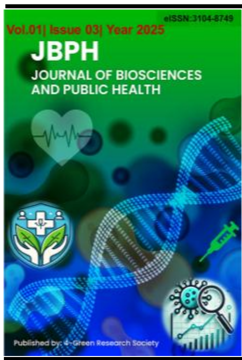

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REVIEW ARTICLE

Advances in Pharmacognosy for Modern Drug Discovery and Development

Geetika Shrivastav[1], Anubhav Dubey[2, *], Mamta Kumari[3], Toyaj Shukla[4]

[1]Department of Pharmacognosy, BSA college of Engineering and Technology, Mathura, Uttar Pradesh, India.

[2]Department of Pharmacology, Maharana Pratap College of Pharmacy, Kothi, Mandhana, Kanpur, Uttar Pradesh – 209217, India.

[3]Department of Pharmaceutical Sciences, Harcourt Butler Technical University, Kanpur, Uttar Pradesh, India.

[4]Govt Rani Durgawati College Wadrafnagar, 497225, India.

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***Corresponding author**
Department of Pharmacology, Maharana Pratap College of Pharmacy, Kothi, Mandhana, Kanpur, Uttar Pradesh - 209217, India.
E-mail:anubhavdwivedi803@gmail.com
ORCID ID: https://orcid.org/0000-0002-9089-4794

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ABSTRACT

Pharmacognosy is the study of natural products with medical, ecological, gustatory, or other functional qualities, especially secondary metabolites. The histories of medicine and pharmacy are intimately related to the history of pharmacognosy. A significant shift in the methodical comprehension and use of medicinal herbs occurred throughout the 19th century, which also saw the start of modern pharmacy. Major discoveries like the discovery of penicillin, the isolation of reserpine, the anticancer properties of Vinca rosea, and the creation of semi-synthetic steroidal hormones propelled the development of modern pharmacology between 1934 and 1960. Recent developments in pharmacognosy and phytochemical research are also highlighted, as is the part phytochemistry plays in drug discovery. Throughout history, minerals, microbes, plants, and animals have been utilized as essential sources of medications for veterinary and human medicine. This review highlights recent trends in phytochemical research, quality control methods, and the role of pharmacognosy in addressing global health challenges, including cancer, Alzheimer's, and infectious diseases. By bridging traditional wisdom with cutting-edge methodologies, pharmacognosy remains a cornerstone of innovative pharmaceutical research and development.

1. INTRODUCTION

Pharmacognosy is the scientific study of the structural, physical, chemical, and sensory characteristics of drugs derived from animal, plant, and mineral sources. Until the early 20th century, pharmacognosy was primarily a descriptive botanical discipline, focusing on the collection, identification, and storage of information about medicinal plants, often used in traditional treatments by local communities [1, 2]. In the early to mid-20th century, pharmaceutical companies and researchers paid attention to the synthetic medicine manufactured from chemicals [3]. This led to the replacement of many plant-based medications with fully or partially synthetic compounds, which were often more tolerable. Consequently, the use of pharmacognosy in professional pharmacy as a natural remedy reduced significantly.

However, in the latter half of the 20th century, interest in phytocosmeceuticals, nutraceuticals, phytopharmaceuticals, and other herbal products rose again, particularly in industrialized nations [4, 5]. This revival was driven by the growing popularity of multi-herb combinations in traditional medicine, prompting a synergistic approach in contemporary phytopharmaceutical research [6]. As a result, pharmacognosy became an interdisciplinary field integrating chemistry, biology, and biotechnology, with a focus on natural product-based drug discovery [7, 8]. Today, pharmacognosy employs advanced technologies such as genomics, metabolomics, and high-throughput screening to explore the vast reservoir of bioactive molecules in natural sources, particularly plants [9, 10]. However, it's noted that 85% of all traditional medicines worldwide are made from plants, and for the preparation of 25% of all modern medications, plant-extracted ingredients are used either directly or indirectly [11]. Both developed and developing nations use traditional treatments and practices. Over 75% of people in the Southeast Asian region receive their medical care from traditional healers and medicines [12]. Recent approvals of plant-derived drugs, such as artemether, galantamine, nitisinone, and tiotropium, underscore the ongoing success of this approach [13]. Moreover, pharmacognosy now plays a pivotal role in phytotherapy and drug discovery, with plant extracts offering a wealth of bioactive compounds targeting diverse pharmacological conditions [14, 15], including cancer [16-18], HIV/AIDS [18, 19], Alzheimer's disease [20, 21], malaria [22, 23], and pain management [24, 25]. To meet the demands of this rapidly evolving field, pharmacognosists require expertise in botany, organic and analytical chemistry, pharmacology, biochemistry, genetics, horticulture, regulatory affairs, and commerce [26].

Despite significant advancements, gaps persist in integrating traditional knowledge with modern technologies, standardizing herbal product quality, and addressing sustainable resource using artificial intelligence, molecular modeling, omics approaches, etc. In addition, from the mixture of natural products, the process of identifying the precise bioactive substances that produce a therapeutic effect is costly and time-consuming. There is a lack of information on long-term effects and dose optimization since clinical research on herbal medicines is not carried out with the same precision as that for prescribed drugs [27, 28].

This review aims to address these gaps by evaluating current trends, emerging technologies, and the expanding scope of pharmacognosy to meet evolving scientific and industrial demands. It emphasizes the critical role of pharmacognosists in adapting to these needs, advancing herbal medicine, and ensuring the field's relevance in modern pharmaceutical research.

2. SOURCES OF NATURAL DRUGS

Pharmacognosy encompasses the study of drugs derived from various natural sources, including plants, animals, and microorganisms, some of which are listed in Table 1.

2.1. Plant-Derived Drugs and Compounds

The most prevalent and broad source of therapeutic chemicals is found in plants. Historically, plant-based remedies have been used in traditional medicine systems, such as Ayurveda, Traditional Chinese Medicine, and African ethnomedicine. Plants generate bioactive compounds such as alkaloids, glycosides, terpenoids, flavonoids, and phenolic chemicals [29]. A variety of medicinal plants are used, such as isolated chemicals, extracts, and crude medications. Typically, crude pharmaceuticals are dried plant pieces that can be utilized straight away or processed further to create extracts [30]. Plant materials are treated with solvents like water, ethanol, or methanol to dissolve and concentrate the active ingredients, resulting in extracts. Conversely, isolated compounds are refined chemicals that are extracted from plant extracts using methods such as chromatography [31].

2. 2. Animals Derived Drugs and Compounds

Animal sources are treated as an important source for rarely synthesized natural drugs. Even though their extraction is very challenging from tissues, secretions, or metabolic byproducts of animals. The medicinal potential of the bioactive compounds produced by marine creatures makes them particularly significant [32]. Evidence for analgesic, anticancer, and antibacterial effects has been found in marine snail, sponge, and coral toxin studies [33]. Animals on land have also contributed medicinally; for example, insulin is made from the pancreas of pigs and cows, and heparin is extracted from pig lungs and intestines. However, there are now more viable alternatives to pharmaceuticals generated from animals, and ethical considerations have led to a decrease in their usage [34].

2. 3. Microorganism-Derived Drugs and Compounds

The microbes, including bacteria, fungi, and actinomycetes, are prolific sources of bioactive compounds, particularly antibiotics and immunosuppressants. Penicillin, first isolated in 1928 by Alexander Fleming from the fungus Penicillium notatum, was a game-changer in the fight against bacterial infections [35]. Streptomycin, tetracycline, and erythromycin are only a few of the numerous antibiotics that have been produced since then from various microbes. Antibiotics aren't the only things that microbes make; they also make vitamins, enzymes, and immunosuppressants [36]. These chemicals can now be mass-produced because of developments in genetic engineering and microbial fermentation [37].

2.4. Other Natural Sources

Pharmacognosy is influenced by a variety of natural sources, including minerals and marine environments, in addition to plants, animals, and microorganisms. While marine species supply new chemicals like trabectedin, an anticancer medication from the sea squirt ecteinascidia turbinata [38], antacids use minerals like calcium carbonate and magnesium hydroxide. Unique species with potential medical uses have been discovered through the investigation of harsh environments, such as deep-sea habitats and geothermal vents.

Table 1. Various sources of natural drugs, bioactive compounds and their uses in treatment.

Source	Types of Compounds	Derived Drugs	Uses	References
Plants	Alkaloids	- Morphine (Papaver somniferum) - Quinine (Cinchona species)	- Analgesic / pain management - Antimalarial	[39], [40]
	Glycosides	Digoxin (Digitalis purpurea)	Treats congestive heart failure	[41]
	Terpenoids and Essential Oils	Artemisinin (Artemisia annua)	First-line treatment for malaria	[42]
	Flavonoids and Polyphenols	Flavonoids from *Ginkgo biloba*	Antioxidant, Anti-inflammatory; cardiovascular and neuroprotection	[43]
Animal	Hormones and Enzymes	Insulin (porcine/bovine pancreas)	Diabetes management	[44]
	Venoms and Toxins	Ziconotide (Conus magus)	Potent analgesic for chronic pain	[45]
	Marine Organisms	Cytarabine (Cryptotethya crypta)	Leukemia treatment	[46]
Microorganisms	Antibiotics	- Penicillin (*Penicillium* spp.) - Streptomycin (*Streptomyces griseus*)	Treatment of bacterial infections	[47], [48]
	Immunosuppressants	Cyclosporine (*Tolypocladium inflatum*)	Prevents organ transplant rejection	[49]
	Anticancer Agents	Doxorubicin (*Streptomyces peucetius*)	Chemotherapy for various cancers	[50]

3. SYSTEMATIC APPROACHES USED IN MODERN PHARMACOGNOSY

Pharmacognosy shows the therapeutic potential of natural products by combining advanced technologies with traditional knowledge. For ensuring the maximum efficiency in treatment, extraction and purification of target bioactive compounds from their sources are very crucial. Therefore, different kinds of systematic approaches are employed to identify, isolate, analyze, and standardize bioactive compounds from plant materials, as illustrated in **Figure 1**. Moreover, all steps have been stated briefly in this section.

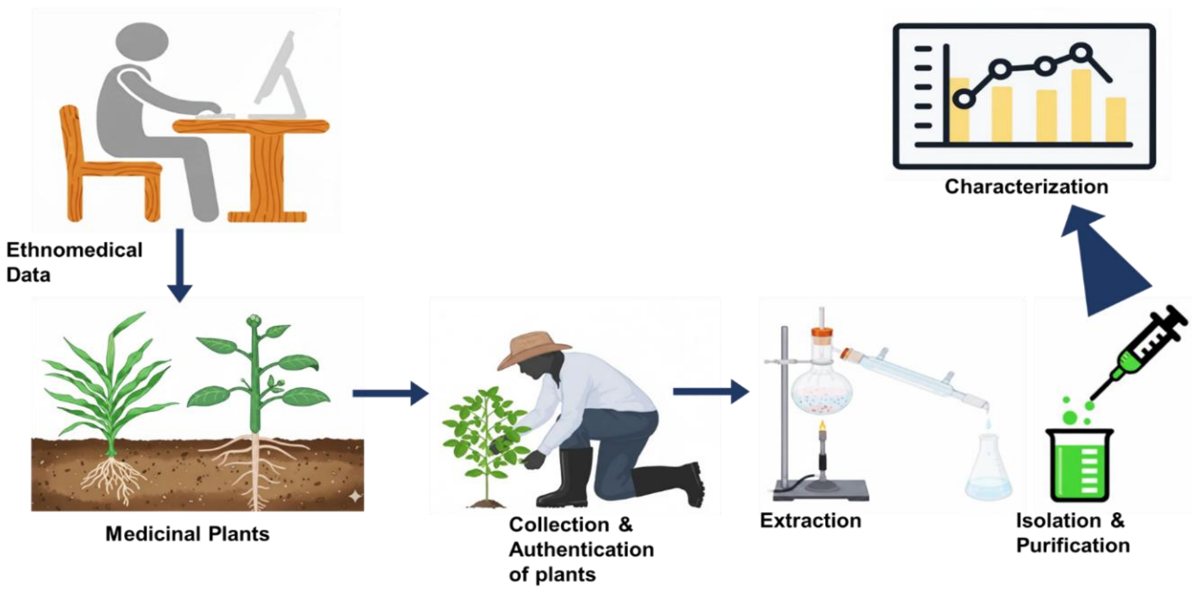

Figure 1. Overview of key steps used in pharmacognosy for drug discovery and development.

3.1. Collection and Identification

In the first stage of pharmacognosy, it is important to ensure the correct species, plant part, and other sources. Ethnobotanical knowledge is commonly used where traditional expertise identifies proper medical plants with therapeutic potential [51]. Then morphological and organoleptic evaluations, like color, texture, and odor, ensure the target sources [52]. In some cases, microscopic examination of leaf vein islet number helps to distinguish species [53]. Modern methods like DNA barcoding, for instance the cytochrome c oxidase I gene, are also applied for precise identification [54].

3.2. Extraction and Isolation

After identification, this stage is used to separate and concentrate active components from plant sources. In classical extraction techniques like maceration by soaking plant material in organic solvents like methanol to extract alkaloids, percolation is applied [55]. For isolating essential oils from spices, Soxhlet extraction using continuous hot solvent cycling is effective, while boiling roots for teas and others targeting water-soluble compounds are commonly used [56].

For example, modern extraction techniques, microwave-assisted extraction (MAE) rapidly isolates polyphenols from green tea, ultrasound-assisted extraction (UAE) uses sonic waves to extract flavonoids from berries, supercritical fluid extraction (SFE) employs CO_2 to isolate caffeine from coffee beans, and pressurized liquid extraction (PLE) extracts antioxidants from algae under high pressure [57]. In addition, bioassay-guided fractionation effectively isolates bioactive compounds, such as anticancer agents from marine sponges [58].

3.3. Characterization by Separation and Chemical Analysis

This stage involves separating, identifying, and elucidating the structure of isolated compounds. Chromatographic techniques such as thin-layer chromatography (TLC) for separating alkaloids on silica plates, high-performance thin-layer chromatography (HPTLC) for high-resolution fingerprinting, high-performance liquid chromatography (HPLC) for quantifying compounds like curcumin in turmeric, and gas chromatography (GC) for analyzing volatile oils in peppermint are mostly used as a traditional technique [59]. Moreover, spectroscopic methods like UV-Vis spectroscopy to detect conjugated systems in flavonoids, infrared (IR) spectroscopy to identify functional groups in terpenoids, mass spectrometry (MS) to determine molecular weights of glycosides, and nuclear magnetic resonance (NMR) to elucidate proton environments in steroids [60, 61]. As modern techniques in pharmacognosy, LC-MS for metabolite profiling, GC-MS for essential oil analysis, and LC-NMR-MS for novel compound structure are used [62]. These techniques ensure accurate characterization of bioactive molecules.

3.4. Quality Control and Standardization

It is crucial to ensure the efficacy, safety, and consistency of natural therapies. In order to identify adulterants in powdered medications, analytical techniques evaluate physicochemical characteristics such as moisture, ash, and extractive values [63]. As demonstrated in medicinal products, chromatographic fingerprinting with HPTLC or HPLC produces distinct profiles for batch consistency [64]. In addition to tests for pesticides, microorganisms, and mycotoxins, safety testing uses methods such as inductively coupled plasma mass spectrometry (ICP-MS) to identify heavy metals, including lead in ayurvedic formulations [65]. By using these techniques, herbal products are ensured to satisfy regulatory requirements for clinical use.

3.5. Advanced and Interdisciplinary Approaches

In modern pharmacognosy, high-throughput and comprehensive approaches are used for ensuring the quality and efficacy of derived drugs. For example, omics methods use genetic engineering to increase the synthesis of alkaloids in transgenic plants. In addition, metabolomics techniques are used for the extraction of secondary metabolites from plants like cannabis using LC-MS [66]. Studies on ginseng demonstrate how systems biology combines omics data to examine gene-metabolite interactions [67]. Recently, computational methods have drawn attention to predicting the bioactivity of natural chemicals, such as high-throughput virtual screening and artificial intelligence for new drug design [68].

Figure 2 presents a comparative overview of conventional and modern approaches, highlighting the advancements in pharmacognosy through the application of advanced technologies for the extraction, purification, and authentication of natural products as potential therapeutics.

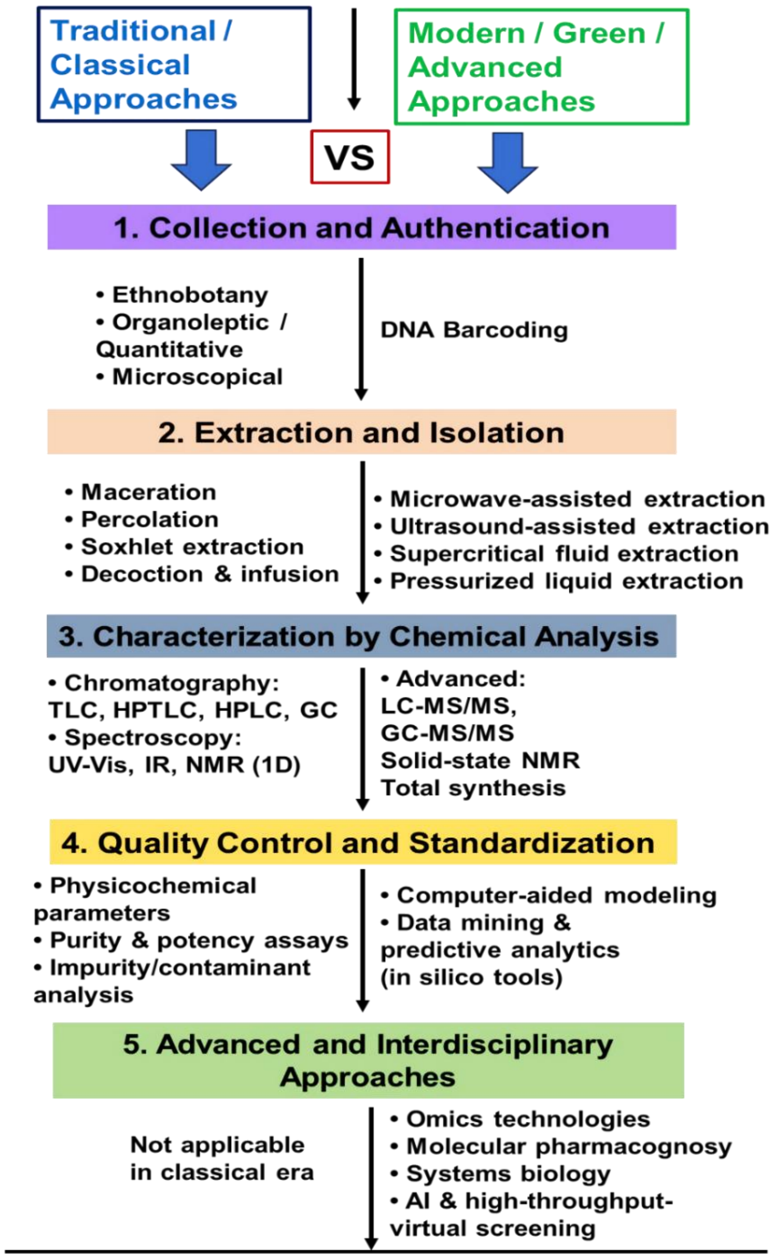

Figure 2. Summary of conventional and advanced techniques employed for the discovery of drugs and others bioactive compounds from natural sources.

4. APPLICATIONS OF MODER PHARMACOGNOSY

4.1. Applications in Drug Development and Treatment

Natural products, particularly medicinal plants, are becoming a vital resource for drug discovery. This rising trend is attributed to the increasing emphasis on molecular modeling, combinatorial chemistry, and other synthetic chemistry techniques by pharmaceutical companies and funding agencies [69]. Many compounds obtained from plants have been used as drugs, either in their original form or as semisynthetic derivatives [70]. Moreover, medicinal plants are key resources for pharmaceutical manufacturing; they play an essential role both in herbal medicine and in the pharmaceutical market. Recently WHO reported that over 50% of modern medicines are derived from natural sources, including antibiotics and painkillers [71].

Table 2. Sources of natural bioactive compounds and their application in treatment as a drug.

Sources	Natural Product	Use in Treatment	References
Willow bark (*Salix* spp.)	Salicin (Aspirin precursor)	Anti-inflammatory, analgesic, antipyretic	[72]
Opium poppy (*Papaver somniferum*)	Morphine, Codeine	Pain management, cough suppressant	[73]
Cinchona tree (*Cinchona* spp.)	Quinine	Antimalarial treatment	[74]
Foxglove (*Digitalis purpurea*)	Digoxin	Treatment of heart failure, arrhythmias	[75]
Pacific yew tree (*Taxus brevifolia*)	Paclitaxel (Taxol)	Chemotherapy for various cancers	[76]
Sweet wormwood (*Artemisia annua*)	Artemisinin	First-line antimalarial therapy	[77]
Rauwolfia (*Rauvolfia serpentina*)	Reserpine	Antihypertensive, antipsychotic (rarely used now)	[78]
Peppermint (*Mentha piperita*)	Menthol	Topical analgesic, digestive aid, cold remedies	[79]
Turmeric (*Curcuma longa*)	Curcumin	Anti-inflammatory, antioxidant; under study for cancer & arthritis	[80]
Cannabis (*Cannabis sativa*)	THC, CBD	Pain relief, epilepsy, multiple sclerosis, anxiety	[81]
St. John's Wort (*Hypericum perforatum*)	Hypericin, Hyperforin	Mild–moderate depression (noted drug interactions)	[82]
Penicillium spp. (fungus)	Penicillin	Antibiotic-bacterial infection treatment	[83]
Camptotheca acuminata (bark)	Camptothecin	Anticancer agent (precursor of topotecan, irinotecan)	[84]
Soybean (*Glycine max*)	Isoflavones (e.g., genistein)	Hormonal therapies, menopausal symptoms, potential anticancer	[85]
Red yeast rice (*Monascus purpureus*)	Monacolin K (Lovastatin)	Natural cholesterol-lowering statin	[86]

As research progresses, the integration of natural products with cutting-edge drug discovery technologies continues to drive innovation in the development of novel therapeutics. Therefore, uses of natural products in modern medical treatment are increasing noticeably, as shown in **Table 2**.

4.2. Pharmacognosy in Education and Research

At present, pharmacognosy is crucial to the drug research and development processes. The increasing use of natural medicines in complementary and alternative therapies reflects a global trend toward natural health solutions. Modern pharmacognosy integrates advanced scientific technologies with traditional knowledge to accelerate natural product-based drug discovery and healthcare innovation. As stated in below, Genomics and metabolomics are examples of new technologies that have improved the precision and efficiency of pharmacognostical research [87].

(i) Molecular Biology Applications

In molecular biology, modern pharmacognosy is helpful to understanding the biosynthesis pathways of naturally occurring chemicals that have pharmacological activity. Enzymes essential to the generation of secondary metabolites can be identified and altered by gene expression profiling, CRISPR-Cas9 genome editing, and heterologous gene expression [88, 89]. At the cellular and subcellular levels, pharmacodynamic interactions are confirmed by receptor-binding tests and molecular docking [90]. Synthetic biology and metabolic engineering reduce dependency on threatened plant varieties by introducing biosynthetic genes into microbial or plant cell culture systems. It supportsincreasing the production of rare phytochemicals [91]. These advancements accelerate new drug development from laboratory to clinical applications.

(ii) Genomics-Driven Discovery and Innovation

Through genome mining and biosynthetic gene cluster (BGC) prediction, genomics changed the process of discovering natural products. Comparative genomics and whole-genome sequencing reveal cryptic or discrete gene clusters that produce new bioactive substances that are not possible using conventional techniques [92]. Rapid dereplication, target-specific molecule identification, and gene discovery from unexplored microbial and plant species are made possible by high-throughput omics platforms combined with bioinformatic algorithms [93, 94]. In addition, molecular authentication and DNA barcoding enhance quality control and stop medicinal plant adulteration [95]. Precision pharmacognosy and specific natural medicine are made possible by integrative genome-metabolome techniques that map genotype-to-chemotype correlations [96].

(iii) Traditional Medicine and Ethnopharmacology

Modern pharmacognosy integrates traditional medicinal knowledge with scientific authentication through ethnopharmacological research. Traditional systems such as Ayurveda, Unani, Traditional Chinese Medicine (TCM), and indigenous tribal healthcare provide leads for bioactive compound discovery [97]. These are validated using metabolomics, high-performance analytical platforms (e.g., LC-MS/MS, GC-MS), and bioassay-guided fractionation to identify clinically relevant phytoconstituents [98]. Ethnopharmacology endorses sustainable and evidence-based therapeutics for clinical and nutraceutical applications.

(iv) Health-Related Databases and Comprehensive Screening

Advanced natural product databases (e.g., NPASS, COCONUT, TCMID) and high-throughput screening platforms are crucial in modern pharmacognosy. For AI-driven drug selection, these archives combine molecular targets, bioactivity profiles, chemical structures, and ethnomedical data [99]. Initial identification for conditions like cancer, diabetes, neurological illnesses, and viral infections is accelerated by virtual screening, molecular docking, machine learning, and inverse pharmacology [100]. Biochemical insights are enhanced by mapping the multi-target interactions of complex herbal remedies using network pharmacology and systems biology [101]. By optimizing drug development procedures, these database-driven methods minimize the time and expense of conventional screening [102].

(v) Sustainable and Ethical Resource Utilization

Sustainability is one of the important concerns in modern pharmacognosy. Many cultivation techniques, such as tissue culture, hairy root systems, aquaponic farming, and microbial fermentation, produce high yields of bioactive compounds without overharvesting wild species [103]. Moreover, it supports minimizing environmental impact by producing rare phytochemicals in engineered microbial systems [104]. Ethical frameworks like the Nagoya Protocol ensure fair benefit-sharing with indigenous communities [105]. Green extraction methods, including supercritical CO_2 and solvent-free microwave extraction, enhance environmental sustainability [106]. These strategies promote biodiversity conservation and scalable, socially responsible natural product research [107].

4.3. Pharmacognosy in Pharmacy Education: Bridging Tradition and Innovation

Pharmacognosy is considered an important study area of pharmaceutical sciences. It has contributed to numerous high-impact and Nobel Prize-winning medicines [108] and continues to advance combined with modern drug development approaches [109]. In many countries, such as the United States, pharmacognosy is treated as a research-based subject for natural drug discovery, phytotherapy, and herbal medicine curricula [110]. According to a report in the UK, inconsistent academic integration is still a problem. Traditional curricula don't emphasize phytotherapy, which may be a reason for a decline in pharmacognosy knowledge in pharmacy schools [111]. The need for better research and training has increased due to the multicultural demand for herbal medications in many countries, like in Chinese and Indian cultures [112]. Therefore, to meet the demand, much research is now being conducted outside of pharmaceutical organizations [113]. In addition, advanced technologies, including chemical libraries, high-resolution spectroscopy, chromatography, virtual screening, and synergy-based natural product evaluation, are being used more and more in the sector to stay competitive [114, 115].

Interestingly, about half of all prescription medications in the world are made from natural components or their derivatives [116]. In order to improve pharmacist knowledge, European reforms now prioritize updating pharmacognosy while maintaining traditional abilities like plant identification, active ingredient analysis, and efficacy assessment [117, 118].

Comprehensive education on biogenic chemicals is promoted by groups such as ESCOP [119]. It is crucial to have a comprehensive, well-defined pharmacognosy curriculum that is separate but integrated with pharmaceutical chemistry and pharmacology. Overprioritizing synthetic medications can limit pharmacists' ability to exploit medicinal plant resources effectively [120]. Pharmacognosy can continue to enhance pharmacy practice, education, and investigations by maintaining its distinct perspectives for green health and environment [121].

5. CHALLENGES AND FUTURE PERSPECTIVES

Pharmacognosy in the 21st century faces multiple challenges, such as the demand for faster drug discovery, sustainable use of natural resources, and the incorporation of modern technologies. Despite its growing relevance, several key challenges still obstruct its full potential in modern healthcare.

5.1. Shortage of Expert Human Resources

Modern pharmacy education still emphasizes synthetic pharmaceuticals, with minimal focus on traditional and natural therapeutics. Most clinical pharmacists are trained predominantly under allopathic systems and lack adequate exposure to phytomedicine and ethnopharmacology [122]. There is an urgent need for skilled professionals with expertise in Ayurveda, Kampo, Traditional Chinese Medicine (TCM), Western herbalism, and other traditional systems to ensure the efficacy, safety, and standardization of natural products.

5.2. Integration of Modern Technologies

The advancement of pharmacognosy strongly depends on the incorporation of cutting-edge technologies such as genomics, metabolomics, bioinformatics, and artificial intelligence (AI). Cross-disciplinary collaboration among experts in molecular biology, biotechnology, agriculture, taxonomy, anthropology, and traditional medicine is essential for accelerating discovery and validation of natural products [123]. AI and machine learning (ML) further enhance big data analysis and aid in predicting the therapeutic potential and drug-likeness of natural compounds [124].

5.3. Sustainable Utilization of Natural Resources

Sustainability is a critical concern, particularly for rare and overexploited medicinal plants. Ethical sourcing, cultivation strategies, and eco-friendly harvesting practices must be implemented to minimize ecological stress [125]. Modern biotechnological tools such as plant tissue culture and genetic engineering offer alternative methods to mass-produce high-value bioactive compounds without depleting natural populations [126].

5.4. Protection from Biopiracy and Indigenous Knowledge

Pharmacognosy has a significant problem with biopiracy, which is the unapproved use of genetic resources and traditional knowledge [127]. The enforcement of international legal frameworks such as the Nagoya Protocol [128] can ensure the protection of indigenous community rights and equitable benefit-sharing from the use of genetic resources.

5.5. Bridging Traditional and Modern Medicine

A holistic and integrative healthcare system can be developed by scientifically validating and incorporating traditional remedies into evidence-based medicine. By collaborating, modern scientists and traditional healers can verify the efficacy of long-standing remedies and speed up the creation of new pharmaceuticals [129]. Research facilities and educational programs can enhance the integration of traditional and contemporary medicine and further encourage the sharing of knowledge [130].

5.6. Exploration of Natural Resources

While land plants have been examined extensively, little is known about natural sources such as microbes and marine creatures [131]. Exploring these sources might lead to the discovery of new bioactive chemicals that have promising medicinal applications. Therefore, it is critical to develop novel methods for growing them and extracting their compounds [132].

5.7. Studies of Chemical Ecology and Biosynthetic Pathway

Understanding the ecological role and biosynthetic pathways of natural compounds offers valuable insight into their therapeutic potential [133]. Chemical ecology and metabolic engineering can be leveraged to design bioinspired compounds or enhance the biosynthesis of clinically relevant molecules [134].

5.8. Development of Novel Drug Delivery Systems

Modern delivery platforms such as liposomes, nanoformulations, and targeted carrier systems can significantly improve the bioavailability, stability, and tissue-specific delivery of natural products [135, 136]. The use of biodegradable and biocompatible delivery vehicles further reduces toxicity and enhances clinical applicability.

6. CONCLUSION

Pharmacognosy is the contemporary science of natural medicines. Pharmacognosy and pharmaceutical sciences may trace their roots back to a number of ancient medical systems, including Ayurveda, Traditional Chinese Medicine, Egyptian medicine, Greek and Roman medicine, and Kampo. The field of pharmacognosy developed out of the Materia Medica and other compilations of traditional medical knowledge made by European scholars over time. Clinical components of pharmacy education rose to prominence throughout the late 19th and early 20th centuries, when modern medicine was at its peak, and pharmacognosy included new scientific discoveries. But in the second part of the twentieth century, Westerners showed renewed interest in herbal remedies. Making sure natural medicines are safe, effective, and of high quality became more important throughout this renaissance. There is an immediate need for bioprospecting and the protection of indigenous healing techniques and knowledge, as, despite advancements, huge areas like tropical biomes, the Amazon, and the Mediterranean have been mostly ignored. Zoopharmacognosy and ethnopharmacology play a crucial role in the search for novel drugs. To further emphasize its interdisciplinary nature, pharmacognosy has effectively combined conventional botanic chemical techniques with cutting-edge innovations. It has become a cutting-edge scientific field that is pivotal to pharmaceutical education and research due to developments in sophisticated analytical and molecular methods. Within this development, subfields such as industrial pharmacognosy, clinical pharmacognosy, and analytical pharmacognosy have arisen. Molecular pharmacognosy, genomic pharmacognosy, and metabolic pharmacognosy are relatively new areas that have emerged to address the expanding needs of biotechnology, bioinformatics, and molecular biology. To ensure its sustained growth as an exciting area in natural medicine research and teaching, pharmacognosy, a multidisciplinary science based on crude drugs, needs robust interdisciplinary and worldwide collaboration in the future.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

This study did not involve any experiments on human participants or animals; therefore, formal written informed consent was not required by the Institutional Review Board. All figures in this study were created; therefore, no permission for reuse is required for any figure presented herein.

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