A REVIEW ON TRADITIONAL KNOWLEDGE AND HERBAL MEDICINE

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ABSTRAST

Ethnopharmacology is an interdisciplinary field that examines the relationship between traditional medicinal knowledge and the therapeutic use of natural resources, including plants, animals, and minerals. It focuses on understanding how different cultures have developed healthcare practices over generations and how these practices contribute modern medicine. Traditional medical systems such as Ayurveda, Siddha, Unani, Traditional Chinese Medicine, and various indigenous healing traditions have played significant role in maintaining health and treating diseases through natural remedies.The study of ethnopharmacology provides valuable insights the identification of bioactive compounds that can developed into safe and effective medicines. Many modern drugs have originated from traditional remedies after scientific investigation of their pharmacological properties.

Ethnopharmacological research involves documenting indigenous knowledge, evaluating the safety and efficacy of traditional treatments, and conserving medicinal plant resources. This approach helps bridge gap between ancient wisdom,contemporaryhealthcare practices.Traditional systems of medicine emphasize a holistic approach to health by considering physical, mental, and environmental factors. These systems use herbal formulations, dietary modifications, and lifestyle interventions promote well-being and prevent disease. Despite advances in modern medicine, traditional healthcare practices continue to serve large portion of the global population, particularly in rural and resource-limited regions.The integration of ethnopharmacological knowledge with modern scientific methods has the potential to support drug discovery, healthcare accessibility, and biodiversity conservation. Preserving traditional medicinal knowledge is essential because it represents valuable cultural heritage and a potential source of future therapeutic agents. Therefore, ethnopharmacology remains an important field for advancing sustainable and culturally informed healthcare worldwide

KEYWORDS:

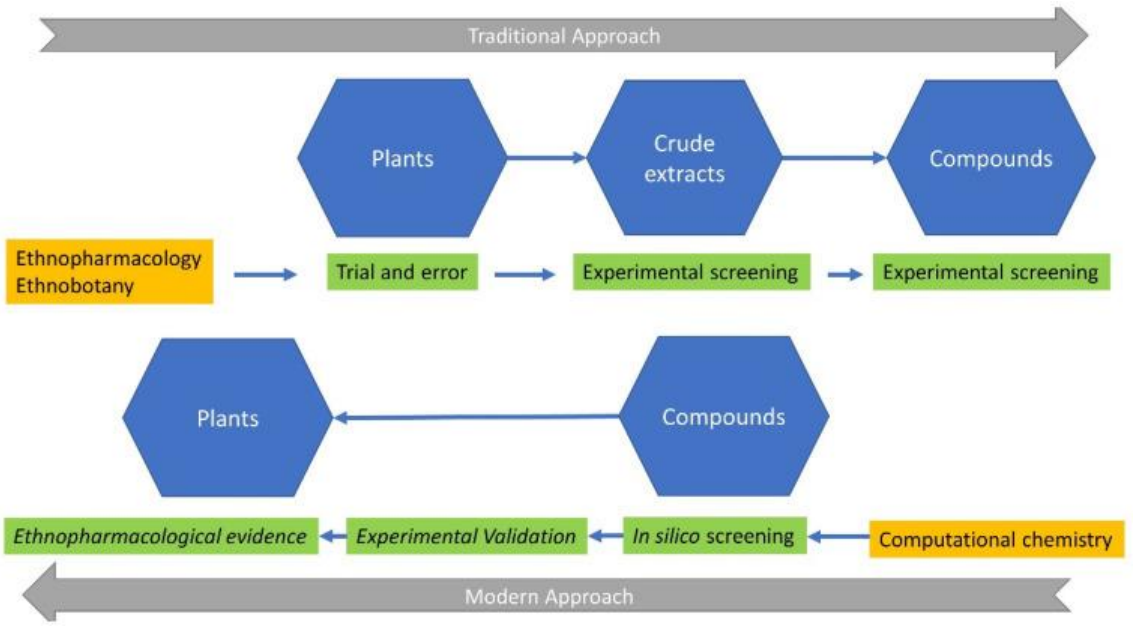
Ethnopharmacology; Traditional Medicine; Medicinal Plants; Indigenous Pharmacological Research; Healthcare Systems.

1.INTRODUCTION

Ethnopharmacology is the scientific study of traditional medicinal knowledge and the use of natural resources for disease prevention and treatment. Since ancient times, human communities have utilized plants, minerals, and other natural substances to manage various health conditions, developing healthcare practices that have been transmitted across generations [1,2]. These traditional systems of medicine represent an important source of cultural heritage and continue to contribute to healthcare in many parts of the world.

In recent decades, increasing attention has been given to the scientific validation of traditional remedies. Although modern medicine has achievedremarkable progress, a largeproportion of the global population still relies on traditional healthcare practices for primary health to the needs [3,4,5] This has encouraged researchers to investigate the safety, efficacy, and pharmacological properties of medicinal plants and natural products. Advances in analytical chemistry, biotechnology, and computational sciences have enabled the identification of numerous bioactive compounds responsible for therapeutic effects[6,7].Ethnopharmacological research has also played a crucial role in drug discovery. Several important medicines used today have originated from natural products that were first recognized through traditional healing practices[8,9]. By combining indigenous knowledge with modern scientific methods, researchers can develop new therapeutic agents while preserving valuable traditional information.

Furthermore, the conservation of medicinal plant resources and documentation of indigenous knowledge are essential for sustainable healthcare development. The integration of traditional medicine with evidence-based scientific research can enhance healthcare accessibility and promote the responsible use of natural resources[10]. Therefore, ethnopharmacology remains a significant field that bridges traditional wisdom and modern medical science.



At the same time, sophisticated analytical techniques including high-performance liquid chromatography (HPLC), liquid chromatography–mass spectrometry (LC–MS), gas chromatography–mass spectrometry (GC–MS), nuclear magnetic resonance (NMR), and crystallographic studies have enabled detailed characterization of plant-derived substances. These advances have strengthened the scientific validation of traditional medicinal knowledge and supported the development of novel therapeutic agents[11].

The diversity of these compounds is influenced by ecological adaptations, environmental conditions, and evolutionary processes. Additionally, different plant parts and extraction procedures may produce extracts with distinct chemical compositions and biological activities [12,13]. As a result, evaluating the medicinal value of traditional remedies requires extensive laboratory, pharmacological, and clinical investigations. Despite significant progress, transforming a natural compound into an approved medicine remains a lengthy and challenging process, with only a small fraction of investigated compounds reaching clinical use[14].

The growth of computational technologies has further accelerated the drug discovery process. The availability of extensive chemical databases and advanced computational tools, including molecular docking, quantitative structure–activity relationship (QSAR) modeling, molecular dynamics simulations, and ADMET prediction, has enabled researchers to identify promising drug candidates more efficiently [15]. These approaches reduce the time and cost associated with early-stage drug development by prioritizing compounds for experimental testing.

Furthermore, network pharmacology has emerged as an important approach for understanding how natural compounds interact with multiple biological targets and signaling pathways simultaneously[16,17]. This holistic perspective aligns well with the multi-component nature of traditional herbal medicines and provides valuable insights into their mechanisms of action. Although computational methods have become indispensable in modern pharmaceutical research, laboratory and clinical validation remain essential to confirm the safety, efficacy, and therapeutic potential of candidate compounds.

Ethnopharmacology is the scientific study of traditional medicines and naturally occurring substances used by different cultures for the prevention and treatment of diseases. It combines knowledge from several disciplines, including pharmacology, botany, chemistry, anthropology, history, and medicine, to investigate the therapeutic value of natural products and traditional healingpractices[18]. By examining indigenous knowledge and medicinal resources, ethnopharmacology contributes to the discovery of new drugs and the understanding of traditional healthcare systems.

The World Health Organization (WHO) defines traditional medicine as the collective body of knowledge, skills, and practices developed by various cultures to maintain health and manage physical or mental illnesses. These practices are based on cultural beliefs, experiences, and observations that have evolved over generations. Traditional medicine includes a broad range of therapies and is often referred to as complementary and alternative medicine (CAM) in many parts of the world .

Traditional medical practices continue to play an important role in global healthcare. Many individuals use herbal medicines and other traditional therapies either as primary treatments or alongside conventional medical care. In countries such as India, traditional systems including Ayurveda, Siddha, Unani, and folk medicine form an integral part of healthcare and cultural heritage[19,20]. The rich diversity of medicinal plants and indigenous knowledge available in these systems provides valuable opportunities for scientific research and pharmaceutical development.

The development of ethnopharmacology began with efforts to document and scientifically evaluate medicinal plants used by indigenous communities. Over time, researchers explored traditional remedies and identified compounds that later became important medicines. These investigations demonstrated the significant contribution of traditional knowledge to modern healthcare [21].Several well-known drugs originated from natural products that were initially used in traditional medicine. Quinine, derived from *Cinchona* species, became one of the earliest effective antimalarial drugs. Digitalis, obtained from foxglove plants, was developed for the treatment of heart diseases. Similarly, aspirin was inspired by the traditional use of willow bark for

relieving pain and fever[22]. More recently, research on *Artemisia annua* led to the discovery of artemisinin, a highly effective antimalarial compound that has saved millions of lives worldwide[23].

Natural products have made a substantial contribution to modern medicine and continue to serve as an important source of therapeutic agents. A large number of approved drugs have been derived from plants, microorganisms, and other natural sources or have been developed based on naturally occurring compounds. These substances have provided valuable treatments for various diseases, particularly cancer and infectious disorders[24].

Many widely used medicines, such as quinine, morphine, digoxin, aspirin, artemisinin, vincristine, vinblastine, and paclitaxel, originated from medicinal plants that were traditionally used for healing purposes[25]. The success of these drugs demonstrates the importance of traditional knowledge in identifying biologically active compounds with clinical value. Even with the advancement of synthetic drug development, natural products remain a rich source of novel chemical structures for pharmaceutical research.

Traditional Indian medicine has also contributed significantly to modern therapeutics. Medicinal plants described in Ayurveda have yielded compounds with antihypertensive, anti-inflammatory, antiviral, hepatoprotective, and immunomodulatory properties. Scientific evaluation of these traditional remedies has enhanced understanding of their pharmacological actions and potential therapeutic applications[26].

At present, numerous plant-derived compounds are being investigated in laboratories and preclinical studies for their possible use in treating a wide range of diseases. To ensure the safety, quality, and effectiveness of herbal medicines, regulatory organizations and healthcare agencies worldwide have developed guidelines and standards for the evaluation and standardization of botanical products[27]

The process of discovering new drugs has become increasingly complex, requiring significant investments of time, resources, and technology. Identifying novel therapeutic molecules remains a major challenge for the pharmaceuticalindustry[28]. As a result, ethnopharmacology has emerged as a valuable strategy for guiding drug discovery efforts.Ethnopharmacology combines centuries of practical experience with modern scientific investigation. Through this integration, it offers opportunities to develop safe, effective, and affordable medicines while preserving valuable cultural and medicinal heritage.

Rather than relying solely on random screening of thousands of compounds, ethnopharmacology focuses on medicinal plants and remedies that have a history of traditional use. This knowledge-based approach increases the likelihood of identifying effective bioactive compounds while reducing the cost and duration of research[29]. Furthermore, the growing problems of antimicrobial resistance, adverse drug reactions, and emerging diseases have increased the demand for new therapeutic options, making traditional medicinal knowledge an important resource for future drug development[30].

Ethnopharmacology combines centuries of practical experience with modern scientific investigation. Through this integration, it offers opportunities to develop safe, effective, and affordable medicines while preserving valuable cultural and medicinal heritage.Ethnopharmacology plays a critical role in connecting traditional healing practices with modern biomedical research. It provides a scientific framework for studying medicinal plants that have been used by indigenous communities for generations. By investigating the pharmacological properties of these natural resources, researchers can identify promising compounds and evaluate their potential for therapeutic use[31].

Many Traditional preparations have been used for years and claimed to be the most potent and effective dosage forms but very few scientific studies are carried out on these products due to lack of communication amongst traditional healers, physicians and scientists. this gap can be filled by translating the old concepts in modern understanding providing possible explanation and hypothesis[32]

Ethnopharmacology has become an important tool in modern drug discovery; however, several challenges must be addressed to ensure the credibility and acceptance of research findings. As pharmaceutical research advances, scientists are required to follow rigorous experimental standards and validation procedures to generate reliable and reproducible results. The use of scientifically sound methodologies is essential for identifying truly effective therapeutic agents and avoiding inaccurate conclusions

One of the major limitations of ethnopharmacological research is the variability in experimental design and evaluation methods. Inadequate testing procedures, inappropriate dosages, and insufficient validation can lead to misleading interpretations of biological activity. Therefore, careful laboratory investigations and well-designed studies are necessary to establish the pharmacological value of traditional medicines[33]

The development of new medicines requires evidence demonstrating quality, safety, and therapeutic effectiveness. While traditional remedies have often been used successfully for generations, many lack comprehensive clinical documentation and standardized preparation

methods. As a result, regulatory authorities require additional scientific evidence before such products can be widely accepted within modern healthcare systems[34].

Standardization of herbal medicines, quality control measures, and clinical evaluation are therefore essential components of modern ethnopharmacological research.

Protection of traditional knowledge has also become an important issue. Indigenous communities have contributed valuable medicinal knowledge over centuries, and appropriate measures should be taken to ensure fair recognition and benefit-sharing. International organizations and regulatory bodies continue to develop frameworks aimed at safeguarding intellectual property rights while promoting ethical utilization of traditional medicinal resources.

In recent years, botanical medicines have gained increasing recognition as complex therapeutic products containing multiple active constituents. Regulatory agencies and international health organizations have established guidelines for the assessment, quality control, and safe use of medicinal plants. These efforts support the development of standardized herbal medicines and facilitate their integration into evidence-based healthcare practices[35,36]According to the World Health Organization (WHO), a large proportion of the global population relies on traditional medicine either as a primary healthcare option or as a complementary approach to conventional medical treatment[37] Practices such as Ayurveda, traditional Chinese medicine, herbal medicine, yoga, acupuncture, and indigenous healing systems continue to be widely utilized across many countries due to their accessibility, affordability, and cultural acceptance[38].

The integration of traditional and modern medicine has gained increasing attention in recent decades. One aspect of this integration involves the formal recognition of traditional healthcare practices within national healthcare systems, allowing them to coexist with conventional medical services. Such recognition helps improve healthcare accessibility and promotes the safe and regulated use of traditional therapies[39]

Another dimension of integration involves combining traditional remedies with modern medical interventions. Researchers and healthcare professionals are increasingly investigating traditional medicines to evaluate their safety, efficacy, and mechanisms of action using contemporary scientific methods[40]. As a result, many patients utilize both conventional and traditional treatments to manage various health conditions[41].

Integration is also evident in education and research, where traditional medicinal knowledge is systematically examined through pharmacological, chemical, and clinical studies. Although traditional an

Table 1: Diverse range of drugs and therapeutic compounds that have been discovered or obtained through ethnopharmacological research.

Sr. No	Name of Herb	Latin Name	Derived /Origin	Treatment
1	Artemisinin	Artemisia annua	Artemisia plant	Malaria
2	Quinine	Cinchona officinalis	Bark of cinchona tree	Malaria and Babesiosis
3	Vinblastine	Vinblastinum	Madagascar periwinkle plant	Cancer including leukemia
4	Morphine	Papaver somniferum	Opium poppy	Pain reliefer
5	Aspirin	Acidum acetylsalicylicum	Bark of willow tree	Pain reliefer
6	Paclitaxel	Taxus brevifolia	Pacific yew tree	Cancer like breast, lungs
7	Quercetin	Quercetinum	Plants likes onions, apples	Cardiovascular and Cancer
8	Curcumin	Curcuma longa	Turmeric plant	Antioxidant
9	Ginsenosides	Panax ginseng	Ginseng roots	Improve cognitive functions
10	Echinacea	Echinacea purpurea	Echinacea plant	Boost immune system

2.EVOLUTIONOF NATURAL PRODUCT.DERIVED DRUG DEVELOPMENT

2.1Traditional Ethnopharmacology and Ethnobotany

Ethnopharmacology and ethnobotany are close neighboring fields. Ethnobotany is the study of complex relationships between cultures and their use of plants, focusing primarily on how plants are managed, used, and perceived across human societies. Ethnopharmacology, on the other hand, is defined as the interdisciplinary scientific exploration of traditionally employed indigenous drugs and biologically active agents[42]. Therefore, ethnopharmacology has a broader focus on exploring biologically active agents from plants, minerals, animals, fungi, and microbes. In both fields, a first step consists in the presentation of the use of extracts in a given disease, without investigating any potential causal relationship with contained ingredients/compounds (for a concrete example, see[43]. Ethnopharmacology has significantly contributed to the field explorations of indigenous and traditional medical knowledge and the biodiversity component to which such knowledge is linked.

In modern societies, this traditional use of plants as alternative pharmacological agents still persists. In China, traditional Chinese medicine is still serving many of the health needs of the population. It is practiced in parallel with modern medical treatment, due to the extensive recording of the plants' medicinal properties. A series of institutions have been established to promote traditional Chinese medicine, such as the Academy of Traditional Chinese Medicine and training institutions. Almost all hospitals have an additional department of traditional medicine. Interestingly, the Chinese government proposes that both traditional Chinese and Western medicine can be combined to treat pneumonia caused by SARS-CoV-2, with promising results [44].

In contrast, western societies have mostly lost their traditional healing practice, although some elements of the plants' medicinal properties have survived. Phytotherapists or naturopaths, operating within alternative and complementary health care systems, promote the ethnopharmacological use of plants. In some countries, they

undergo training that is more or less regulated (in many cases by competent authorities) and have associations that recognize qualified members, making herbal medicine safe, effective, and standardized. In contrast, some other countries simply promote the exploitation of medicinal plants, without incorporating any regulatory policies, leading to the rapid loss of traditional practices. In the latter countries, the practice of ethnopharmacology and ethnobotany consists in the use of entire plant or crude plant extracts. It is worth mentioning, however, that the use of an entire plant, crude extract, or mixture of different plant extracts, with no isolation of components, results, in some cases, in a better therapeutic effect than the administration of individual compounds[45]. This is attributed to a synergy of active compounds included in the preparation (seefor a discussion and references therein). For this reason, teabags with the plant's dried components, and bulk dried plant material both suggested as concoctions in use, are provided in the herbal markets[46]

2.2 Pharmacological Testing

Yeung[47] the ethnopharmacology literature with regard to publication and citation data. They showed that research on recording medicinal plant species used by traditional medicine persists, but the evaluation of specific properties or treatment effects of extracts and compounds has increased enormously. Interestingly, the publications' impact was directly related to the number of indigenous species in the authors' countries. Currently, the trend of research has shifted from identifying and recording the medicinal plant species used in traditional[48]medicine to the evaluation of specific properties or treatment effects of crude plant extracts, or particular naturally derived products, such as flavonoids[49]alkaloids[50], tannins[51], saponins, phenols, and terpenoids[52](an analysis of the provided bibliography together with applied methodology is presented in.

2.3Mass Bioprospecting

Although pharmacological research on medicinal plants has increased significantly over the past few decades, the number of plant-derived products successfully reaching the market remains relatively limited. A major reason for this gap is that many studies focus on preliminary biological activities without progressing to comprehensive preclinical and clinical evaluations. Consequently, numerous promising compounds fail to advance through the drug development pipeline due to insufficient evidence of safety, efficacy, or clinical usefulness[53]

The successful transformation of a traditional remedy into a modern medicine requires a continuous process that links ethnopharmacological knowledge, laboratory testing, clinical research, regulatory approval, and commercial production. Challenges such as limited availability of plant materials, environmental conservation policies, sustainable harvesting practices, and regulatory restrictions can significantly influence the development of new botanical products. Therefore, effective coordination between each stage of research is essential to ensure successful translation from traditional knowledge to therapeutic application[54]

Research on traditional medicinal systems has demonstrated that combinations of medicinal plants are often used to manage common illnesses. In many cultures, herbal mixtures rather than individual plant species are employed because their combined constituents may produce enhanced therapeutic effects through synergistic interactions. Scientific investigations have shown that such formulations may possess antioxidant, anti-inflammatory, antimicrobial, and antiviral activities, supporting some of their traditional uses[55]

2.4Computational Chemistry

Computational drug discovery has over the past few decades become very relevant mainly due to the reduced risks, time, cost-effectiveness, and resources as compared with the traditional experimental approaches[56]. The substantial increase in computational power, the development and implementation

of artificial intelligence methods, and the availability of huge freely available data collections were the main reasons for the development of computational methods with a special impact on novel drug compound identification. The development of novel powerful analytical techniques, as described above, (see[57]for a critical review and presentation of available resources). Computational methods include, among others: (1) the 3D resolution of the conformation of a large number of noncrystallized proteins [58,59], using modern artificial intelligence methods, with AlphaFold and AlphaFold2 being the more successful; (2) molecular docking developments, permitting the fully flexible association of (druggable) compounds to their putative targets (seefor a discussion). This was made possible with the recent increase in computational power. Indeed, older solutions considered the macromolecular target of drugs as a rigid molecule and tried to associate a rigid or flexible micromolecule/drug/natural product at a given binding pocket. However, it is known that the conformation of the macromolecule is equally modified by the binding of the ligand. With the increase in computational power, fully flexible solutions have been developed, in which all atoms of the macromolecule are also modified by the binding, providing a more accurate determination of the binding affinity[60]. These methods have been enhanced by

molecular dynamics simulations, permitting the calculation of the movements of all atoms in the micromolecule for short (fsec) to very long (μsec) periods of time and the resulting conformational poses of the complex macromolecule–ligand, along with enhanced sampling techniques and elaborate methods of analysis, which have allowed unprecedented insight into complex phenomena in biology at extreme efficiency and accuracy. The combination of these methods, especially for the conformational changes of proteins, has permitted the simultaneous detection of movements and conformational states of thousands or millions of atoms and molecules in a given structure ; (3) the development of solutions mimicking the molecular mechanisms triggered by the activation of the (druggable) micromolecule to its (protein) target (seefor a discussion and a concrete example); (4) the development of "network pharmacology" methods , in which the exploitation of experimental and/or bibliographic evidence of signaling pathways and specific effects is explored, with increasingly sophisticated methods (see for example), lead to a prediction of potential effects of a given substance, including natural products (see the thematic issue in ref.[61]) for a recent discussion on the subject); (5) the development of QSAR (quantitative structure–activity relationship) methods, in which, through sophisticated statistical methods, "active" parts of the ligand/drug/natural product, at a given conformation are extracted and predictions about a large number of putative or potential novel ligands can be drawn (seefor a critical analysis, pitfalls, and solutions of this methodology); (6) the development of bioinformatic methods for the prediction of absorption–distribution–metabolism and excretion of druggable molecules (ADMET), integrating artificial intelligence methods (seefor concrete examples and solutions).

With the help of computational chemistry, thousands of molecules have been evaluated for potential efficacy and safety at a small cost in a very short interval of time[62], overcoming the limitations of the experimental approach, helped by progress in artificial intelligence. The lead compounds should have high-affinity prospective binding and specificity for a target associated with a disease and favorable pharmacodynamic and pharmacokinetic properties[63]. Of course, being a cheaper and less time-consuming process, when compared to experimental high-throughput screening, computational chemistry and pharmacology are expected to increase the output of the drug development process. Indeed, the median number of new molecules and biological license application approvals from 2010 to 2019 has increased by 60%, compared to the prior decade. However, the productivity of the pharmaceutical industry may be also linked to regulatory incentives, such as breakthrough therapy, fast-track designation, and Orphan Drug and GAIN acts, through which a large proportion of new drugs have been approved. As a concrete example, increased investments in basic neuroscience research by regulatory research authorities, such as the NIH or the European Union, have recently been linked to an

increase in CNS startup investments[64]

It is estimated that computational chemistry has increased the quality of filtering and selection and improved the filtering efficiency by several orders of magnitude but without increasing the output substantially, mainly due to the bottlenecks of the R&D chain, as the necessity for experimental and clinical trials remains. Indeed, despite the increasing number of successful applications in prospective computational chemistry, the computational methods are still limited to reliably predicting biological activity from chemical structure[65].

The discrepancies between preclinical research, with the use of computational chemical methods and clinical results, need a thorough evaluation, as only a small part of the computationally suggested compounds in the literature are experimentally tested, and negative results are not published. Moreover, many computational screening applications in industrial R&D departments are kept confidential, and compounds of interest are not disclosed, before a successful intellectual property filing. The reverse is also true, as disclosing candidate active compounds for drug development without patent protection discourages possible investments from the pharmaceutical industry (see for a recent overview and discussion). Therefore, integrating computational and preclinical experimental screening (see[66]for a discussion) is necessary for a successful prospective screening, both for the strong patent protection and for further efficacy improvement of clinical trials, influencing the output of the drug production process. However, a number of successes have been acknowledged, with a number of novel drugs already approved by regulatory authorities and being on the market, while an extensive list of other, potential druggable natural product candidates is under investigation [67,68]. The interested reader should consult Issues 7 and 8 of the journal *Drug Discovery Today* (2022) for a series of articles

Effect of a mixture of three aromatic plants ((thyme, Greek sage, and Cretan dittany) in SARS-CoV-2 infection. (**A**). In vitro testing. Left panel: light microscopy photographs of CPE in control (0, DMSO) and SARS-CoV-2–infected Vero cells (strain B.1, 0.1 m.o.i), pretreated or cotreated with different concentrations of CAPeo, in DMSO. Lower panel: Curves representing relative abundance (% of untreated control) of SARS-CoV-2 RNA after pretreatment (left curves) or cotreatment (right curves) with different concentrations of CAPeo, using real-time quantitative RT-PCR, targeting N and E regions of SARS-CoV-2 genome and E-common region shared by SARS-CoV and SARS-CoV-2 viruses. Values are shown as mean ± SD of three separate measurements. No significant differences in pretreated or cotreated cells were found. In both cases, CAPeo was efficient in concentrations almost 100 times lower than those

administered per os and compatible with the estimated circulating concentration of the product. (**B**). Evolution of selected symptoms in our CAPeo-treated group (red curves), in a proof-of-principle trial. $T_{1/2}$ for the resolution of symptoms was calculated with a logistic regression fit. For comparison, the frequency of symptoms in the reference populations is also presented (green curves)The successful development of a medicine from a natural source requires a continuous and coordinated process that connects traditional knowledge, pharmacological testing, clinical evaluation, regulatory approval, and commercialization. The selection of appropriate medicinal plants and bioactive compounds is a critical step in this process because traditional use often provides valuable clues regarding potential therapeutic benefits . In addition, challenges related to sustainable harvesting, conservation of biodiversity, regulatory restrictions, and the availability of plant materials can significantly influence the development of new botanical product.

Studies investigating traditional herbal formulations have shown that combinations of medicinal plants may provide greater therapeutic benefits than individual plant species. Traditional communities frequently use mixtures of aromatic and medicinal plants for the prevention and treatment of common illnesses. Scientific evaluation of such formulations has demonstrated biological activities, including antioxidant, antimicrobial, antiviral, and anti-inflammatory effects, which may contribute to their traditional therapeutic application.

3.DATABASE

The preservation and organization of ethnomedical information have been greatly improved through the development of specialized databases. These digital resources compile data related to traditional medicinal practices, medicinal plants, phytochemical constituents, and pharmacological studies, providing researchers with a reliable source of scientific and ethnobotanical information[69].

Among the available databases, NAPRALERT (Natural Products Alert) is recognized as one of the most extensive repositories of natural product information. It contains records for more than 27,000 plant species and includes details regarding their traditional uses, chemical composition, biological activities, and therapeutic applications. The database also associates medicinal plants with a wide range of symptoms and diseases, making it a valuable tool for ethnopharmacological investigations and natural drug discovery programs[70].

The use of such databases facilitates the validation of traditional knowledge, supports scientific research on medicinal plants, and contributes to the identification of novel compounds with potential pharmaceutical value.

3.1 Digital Ethnobotanical Databases

The preservation of traditional medicinal knowledge has become more effective through the development of digital ethnobotanical databases. These platforms collect and organize information related to medicinal plants, including their traditional uses, methods of preparation, chemical constituents, and reported therapeutic effects. Such databases provide researchers with easy access to a vast amount of ethnomedical information, encouraging collaboration and reducing the risk of losing valuable indigenous knowledge. Furthermore, they support the identification of promising plant species for pharmacological investigations and drug development. Examples of widely used repositories include the Traditional Knowledge Digital Library (TKDL) and NAPRALERT[71]

3.2 Genomic Studies and Bioinformatics Applications

The application of genomics has transformed the understanding of medicinal plants at the molecular level. Advanced sequencing technologies enable researchers to examine genetic material in detail and identify genes responsible for the production of biologically active compounds. Bioinformatics tools assist in processing and interpreting large genomic datasets, allowing scientists to investigate biosynthetic pathways, genetic diversity, and evolutionary relationships among medicinal species. These approaches contribute to the scientific validation and standardization of traditional medicinal resources[72]

3.3 Gene Editing Technologies

Gene-editing methods, particularly CRISPR-Cas systems, have created new opportunities for enhancing the medicinal value of plants and microorganisms. Through precise modification of genetic material, researchers can increase the production of beneficial phytochemicals, improve resistance to environmental stress, and generate compounds with enhanced pharmacological properties. Such innovations support sustainable production and improve the efficiency of natural product-based drug development[73]

3.4 Metabolomics and Chemical Profiling

Metabolomics is a powerful analytical approach used to investigate the complete range of metabolites present within medicinal plants. Techniques such as mass spectrometry and nuclear magnetic resonance spectroscopy allow detailed characterization of plant-derived compounds. By studying metabolite profiles, researchers can identify bioactive constituents, understand their biological functions, and evaluate variations in chemical

composition among different plant species. This information is valuable for quality control, standardization, and the elucidation of therapeutic mechanisms[74]

3.5High-Throughput Screening Techniques

The discovery of biologically active natural compounds has been accelerated by high-throughput screening technologies. Automated screening systems can evaluate thousands of plant extracts and isolated compounds against specific biological targets within a short time. This rapid assessment enables researchers to identify promising candidates for further pharmacological studies and drug development. As a result, the efficiency and speed of natural product research have increased substantially[75]

3.6 Computational Approaches and Molecular Docking

Computational tools have become indispensable in modern ethnopharmacological investigations. Molecular docking and related computer-based techniques allow scientists to predict interactions between natural compounds and target proteins involved in disease processes. These simulations help estimate binding strength, biological activity, and therapeutic potential before conducting laboratory experiments. Consequently, computational methods reduce research costs and accelerate the identification of promising drug candidates derived from traditional medicinal sources[76]

4.CONCLUSION

Natural products derived from medicinal plants have long been recognized as valuable sources of therapeutic agents. For decades, pharmaceutical researchers have explored plant-based resources in search of novel compounds capable of treating human diseases. Plant selection may be guided either by traditional medicinal knowledge or by systematic screening programs designed to identify biologically active substances. Both approaches have contributed significantly to the discovery of important medicines and continue to support modern drug development efforts.

Several widely used pharmaceutical drugs originated from traditional medicinal plants. Compounds such as paclitaxel, vinblastine, quinine, and artemisinin were initially identified through observations of plant-based remedies and later validated through scientific research. These discoveries demonstrate how traditional knowledge can provide valuable leads for the development of effective modern medicines.

The advancement of analytical technologies has significantly changed the way natural products are investigated. Modern instruments enable the detection and characterization of complex chemical compounds with greater precision and efficiency than ever before. At the same time, the availability of extensive natural-product databases and sophisticated computational tools has accelerated the identification of promising drug candidates. Researchers can now rapidly analyze plant extracts and evaluate their potential therapeutic applications using advanced screening techniques.

Another important development has been the shift from a purely plant-centered approach to a target-based strategy. Traditionally, scientists began with a medicinal plant and searched for its active components. Today, researchers often start by identifying a specific disease-related target, such as a protein or molecular pathway, and then screen natural compounds to find those capable of interacting with that target. This approach has expanded the role of natural products in modern pharmaceutical research.

Computational methods, including molecular modeling and virtual screening, have become valuable tools in the early stages of drug discovery. These technologies allow researchers to predict how natural compounds may interact with biological targets and to estimate their therapeutic potential. By prioritizing the most promising molecules, computational approaches help reduce the time and resources required for experimental testing.

However, computational predictions alone cannot guarantee the success of a potential drug. Candidate compounds identified through computer-based analyses must undergo rigorous laboratory evaluation. Experimental validation through cell-based studies, animal testing, and human clinical trials remains essential to confirm efficacy, safety, and appropriate dosage. Therefore, computational methods should be viewed as supportive tools rather than replacements for traditional pharmacological research.

The development of new medicines is influenced not only by scientific discoveries but also by economic, legal, and social factors. Regulatory frameworks, intellectual property protection, research funding, healthcare policies, and market demands all contribute to shaping the pharmaceutical innovation process. These interconnected elements form a complex environment that determines how quickly new therapies can move from the laboratory to clinical use.

In conclusion, medicinal plants continue to provide an important foundation for drug discovery and development. The integration of traditional ethnopharmacological knowledge with modern analytical, computational, and biomedical technologies has strengthened the search for new therapeutic agents. By combining ancient wisdom with contemporary scientific methods, researchers can continue to uncover valuable natural compounds that contribute to the advancement of healthcare and medicine.

The field relies on collaboration among experts from diverse disciplines, including ethnobotany, pharmacology, phytochemistry, medicine, and molecular biology. Such

interdisciplinary efforts facilitate the identification of biologically active compounds, the validation of traditional remedies, and the exploration of their mechanisms of action. As scientific technologies continue to advance, ethnopharmacological research is becoming increasingly effective in uncovering novel therapeutic compounds and improving healthcare outcomes.

In addition to its contributions to medicine, ethnopharmacology plays a vital role in safeguarding traditional knowledge systems and promoting the conservation of medicinal plant diversity. International organizations and regulatory bodies have recognized the importance of establishing standards for herbal medicines to ensure their quality, safety, and effectiveness. These initiatives encourage the responsible use of natural resources while supporting the integration of evidence-based traditional medicine into modern healthcare practices.

Overall, ethnopharmacology offers significant potential for the discovery of innovative medicines while fostering respect for traditional healthcare systems and biodiversity. Its continued development is expected to contribute substantially to global health, sustainable drug development, and the preservation of valuable medicinal knowledge for future generations.

The understanding and evaluation of traditional medicines, herbal remedies, and indigenous healthcare practices require a broad and integrated perspective that combines scientific research with cultural and historical knowledge. Traditional medicinal systems have evolved over centuries through interactions between communities and their natural environments, making them valuable sources of information for healthcare and drug discovery. A comprehensive assessment of these practices involves examining ecological, social, economic, and pharmacological factors rather than relying solely on isolated observations or historical accounts.

The growing commercial demand for herbal medicines, nutraceuticals, and dietary supplements has created new opportunities for the utilization of natural products. However, the widespread availability of these products has also emphasized the importance of rigorous scientific evaluation. Many traditional remedies require further investigation to establish their safety, effectiveness, mechanisms of action, and quality standards. Therefore, evidence-based research remains essential for ensuring public confidence and patient safety.

The future of ethnopharmacology depends on strong collaboration among researchers, healthcare professionals, policymakers, and indigenous communities. Such cooperation can facilitate the preservation of traditional knowledge while supporting innovation in drug development and healthcare. Equally important is the implementation of ethical frameworks that protect intellectual property rights, encourage fair benefit-sharing, and recognize the contributions of local knowledge holder.

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