



Integrating Pharmacology and Traditional Medicine: Evaluating the Safety and Efficacy of Herbal Remedies in Modern Therapeutics

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Abstract

The integration of pharmacology and traditional medicine, particularly herbal remedies, presents a promising avenue for enhancing modern therapeutics. This article explores the historical context, current trends, and future directions in the evaluation of herbal medicines' safety and efficacy. Traditional medicine has deep roots in ancient civilizations, with significant contributions from cultures such as those in China, India, and the Islamic Golden Age. Recent scientific advancements have led to a resurgence in interest in herbal remedies, particularly in light of the growing demand for natural therapies. However, challenges such as standardization, quality control, and regulatory frameworks persist. Evidence-based medicine (EBM) has emerged as a critical approach to validate traditional practices, yet many herbal remedies remain inadequately studied. Future directions include the need for rigorous clinical trials, interdisciplinary collaboration, and the application of advanced technologies such as artificial intelligence and network pharmacology. By addressing these challenges, the integration of pharmacology and traditional medicine can enhance therapeutic options, ensuring patient safety and efficacy in healthcare.

Keywords: Pharmacology; Traditional Medicine; Herbal Remedies; Safety; Efficacy; Evidence-Based Medicine; Clinical Trials; Regulatory Frameworks

Introduction

The integration of pharmacology and traditional medicine represents a dynamic and evolving field that seeks to harmonize ancient healing practices with contemporary scientific methodologies. Traditional medicine, particularly herbal remedies, has been a cornerstone of healthcare for centuries, with its roots tracing back to ancient civilizations such as those in China, Egypt, and Greece. These cultures developed extensive pharmacopoeias that documented the medicinal properties of local flora, laying the groundwork for modern pharmacological practices. Notable figures from history, including Dioscorides and Hippocrates, contributed significantly to the understanding of medicinal plants, with their works continuing to influence contemporary medicine [1].

The Islamic Golden Age further advanced medical knowledge, as scholars translated and expanded upon Greco-Roman texts, integrating traditional practices with empirical observations. This period saw the establishment of hospitals and the development of pharmacology as a distinct field, which would later influence European medicine during the Middle Ages. Traditional Chinese Medicine (TCM), with its holistic approach and emphasis on balance, has also gained recognition globally, prompting scientific inquiry into the safety and efficacy of its herbal components [2].

The 19th and 20th centuries marked a pivotal shift in the field of pharmacology, characterized by significant advancements in drug development and the isolation of active compounds from plants [3].

This transition from empirical use of herbal remedies to a rational, scientific approach has led to the creation of modern pharmaceuticals, yet the resurgence of interest in herbal medicine—especially during the World Wars—highlighted the need for rigorous evaluation of these traditional remedies. Despite the growing popularity of herbal medicines, challenges remain, including the need for standardized regulatory frameworks and evidence-based practices to ensure their safety and efficacy.

In recent years, the integration of evidence-based medicine (EBM) has facilitated the validation of traditional herbal treatments, bridging the gap between ancient practices and modern medical standards [4]. This shift towards a more holistic approach to healthcare recognizes the importance of individual patient characteristics and the potential for personalized treatment strategies. As public interest in natural and alternative therapies continues to rise, healthcare providers are increasingly called upon to consider the role of traditional medicine in their practice.

This article aims to explore the historical context, current trends, and future directions in the integration of pharmacology and traditional medicine, with a particular focus on the safety and efficacy of herbal remedies in modern therapeutics. By examining the interplay between ancient practices and contemporary scientific advancements, we seek to contribute to a more comprehensive understanding of health and wellness in a globalized.

Historical context

The historical context of integrating pharmacology and traditional medicine is rich and multifaceted, reflecting the evolution of medical practices across various cultures and eras. Traditional medicine, particularly herbal remedies, has been a cornerstone of healthcare for centuries, with roots tracing back to ancient civilizations.

Origins of traditional medicine

- **Ancient Civilizations:** The use of plants for medicinal purposes has a rich history dating back thousands of years across various civilizations. Ancient cultures in China, Egypt, and Greece developed extensive pharmacopoeias documenting the medicinal properties of local flora. Archaeological findings and ancient manuscripts from the Middle East, India, and China reveal a vast body of knowledge regarding medicinal

plants [1]. The Ayurvedic system in India and TCM are examples of ancient healing systems that emphasize the use of herbs for maintaining health. Notable herbalists like Dioscorides, Hippocrates, and Galen contributed significantly to the documentation of medicinal plants, with works such as *De Materia Medica* providing valuable information that is still relevant today [1].

- **Islamic Golden Age:** During the Islamic Golden Age (7th-15th centuries), scholars made significant contributions to medicine, translating and expanding upon Greco-Roman texts. Notable figures like Ibn Sina (Avicenna) compiled encyclopedic works such as “The Canon of Medicine,” integrating Greek knowledge with original observations. Islamic physicians advanced various medical fields, including pharmacology, developing theories on medicinal qualities and experimental approaches. They introduced innovations like the discovery of the immune system and the separation of pharmacology from medicine. Hospitals were established, providing universal care and medical education. The Islamic world’s medical knowledge, including herbal remedies, greatly influenced European medicine during the Middle Ages and beyond [5]. This transfer of knowledge occurred through the translation of Arabic texts into Latin, forming the foundation for Western medical education.
- **Chinese Medicine:** TCM is an ancient healing system with a history spanning over 3000 years [2]. It is based on fundamental theories such as yin-yang and five elements, which explain natural phenomena and human health. TCM encompasses various modalities, including herbal medicine, acupuncture, massage, and dietary therapy. Chinese herbal medicine (CHM), a core component of TCM, is rooted in Chinese philosophy and religion, emphasizing balance and holism in the body. TCM has gained popularity not only in China but also in Western countries [2]. In Japan, a similar system called *Kampo*, adapted from TCM, has been integrated into the modern healthcare system. Recent research has focused on scientifically assessing the safety and efficacy of Chinese herbal medicines.

Development of pharmacology

- **Scientific Advancements:** The 19th and 20th centuries marked significant advancements in pharmacology and drug development, with the isolation and synthesis of active compounds from plants leading to the development of modern pharmaceuticals. The field evolved from empirical use of

plant-based remedies to a rational, scientific approach based on molecular targets and mechanisms [3]. This progression led to the development of antibiotics, local anesthetics, and drugs for chronic conditions like glaucoma. Compounds like morphine from opium poppy and aspirin from willow bark illustrate the transition from traditional remedies to standardized medications. The pharmaceutical industry grew alongside biochemistry and molecular biology, enabling the isolation, characterization, and manipulation of drug receptors. The number of available drugs increased dramatically, from 91 in 1940 to over 22,000 by the end of the century. Early textbooks emphasized pharmacology's historical context and relationship with industry and society, though these aspects were minimized in later editions. The field continues to evolve, with promising new approaches like photodynamic therapy and genetic-based therapies emerging for the 21st century.

- **World Wars and Herbal Medicine:** The two World Wars saw a resurgence in the use of herbal medicines due to shortages of synthetic drugs. This period highlighted the efficacy of traditional remedies and led to a renewed interest in herbal pharmacology. The renewed interest has led to advancements in quality control, analysis, and clinical research to evaluate the safety and efficacy of herbal products [6]. Modern pharmacology is increasingly exploring the therapeutic potential of herbal medicines, integrating traditional knowledge with contemporary scientific methodologies. However, challenges remain, including the need for standardized regulatory frameworks and evidence-based practices. Despite these challenges, herbal medicine continues to gain popularity due to its perceived efficacy, affordability, and cultural acceptability, with the World Health Organization recognizing its importance in global healthcare. Herbal medicine has experienced a resurgence in recent years, driven by concerns over synthetic drug side effects and a renewed interest in traditional remedies. This trend is evident in both developed and developing countries, with global demand for medicinal plants projected to reach US \$5 trillion by 2050 [7].
- **Regulatory Developments:** The regulation of herbal medicines has evolved significantly since the mid-20th century, with varying approaches across different countries. In Europe, the EU Directive 2004/24/EC established a framework for herbal medicinal products, balancing traditional knowledge with scientific evidence [8]. Australia and Canada have created specialized committees to address herbal medicine

regulation. The United States classifies these products as dietary supplements, with specific labeling requirements. Despite regulatory efforts, concerns persist regarding the quality, safety, and efficacy of herbal medicines. The complexity of herbal products, potential for contamination, and interactions with conventional medicines pose challenges for regulators and healthcare providers. Improving product quality, enhancing research, and educating both healthcare providers and consumers are crucial steps in addressing these concerns.

Modern integration

- **Evidence-Based Medicine:** The integration of traditional herbal medicine into modern healthcare systems has been facilitated by growing research supporting its efficacy. Systematic reviews and clinical trials have begun to validate the safety and effectiveness of various herbal treatments, bridging the gap between traditional practices and contemporary medical standards. EBM has become the standard for evaluating medical practices, including TCM and Western herbal medicine [4]. While traditional knowledge has long guided herbal medicine, there is a shift towards using EBM criteria to validate its effectiveness. Researchers have conducted systematic reviews and clinical trials to assess the safety and efficacy of herbal treatments, although challenges remain in applying EBM models to traditional practices [4]. Some studies have provided convincing evidence for the efficacy of certain TCM treatments, but many purported benefits remain unvalidated by EBM criteria. Improved methodology in clinical trials is essential for establishing the role of traditional herbal medicine in contemporary healthcare and complementing Western medical treatments.
- **Holistic Approaches:** There is a growing recognition of the importance of holistic approaches to health that consider individual patient characteristics, including genetic, environmental, and lifestyle factors. This aligns with traditional medicine's emphasis on personalized treatment based on an individual's constitution and health status. The holistic approach to healthcare emphasizes treating patients as whole individuals, considering their physical, mental, and spiritual well-being [9]. This approach recognizes the importance of integrating various factors, including genetic, environmental, and lifestyle aspects, in determining health outcomes and treatment strategies. Holistic medicine aims to address the fragmentation of medical knowledge and patient care by

reconciling physical, mental, social, and spiritual aspects of health. It promotes a respectful partnership between physicians and patients, incorporating techniques from diverse healing traditions. This approach aligns with non-Western perspectives that view health as a balance between complementary opposites and emphasize restoring proper relationships. The precision medicine paradigm, particularly in cancer treatment, exemplifies the application of personalized approaches based on individual patient characteristics.

- **Public Interest and Usage:** Increasing public interest in natural and alternative therapies has led to a rise in the use of herbal remedies alongside conventional treatments. Patients often seek integrative approaches that combine the best of both worlds, prompting healthcare providers to consider traditional medicine in their practice. The growing popularity of herbal medicines is driven by increasing health consciousness, perceived safety, and affordability. Over 80% of people in developing countries rely on traditional medicines for primary healthcare due to lower costs and cultural acceptance [10]. The global herbal product market has expanded significantly, reaching an estimated \$60 billion annually [10]. However, concerns persist regarding quality control, potential contamination, and interactions with conventional drugs. The integration of traditional wisdom with modern science is crucial for ensuring the safety and efficacy of herbal remedies. Healthcare providers, especially pharmacists, play a vital role in monitoring herbal medicine use and educating patients about potential risks and benefits. As interest in integrative approaches grows, there is a need for standardization, rigorous clinical trials, and open communication between patients and healthcare providers to maximize the potential of herbal medicines in contemporary healthcare.

The historical context of integrating pharmacology and traditional medicine reveals a complex interplay between ancient practices and modern scientific advancements. As the field continues to evolve, the challenge remains to evaluate the safety and efficacy of herbal remedies rigorously while respecting the cultural significance and historical roots of traditional medicine. This integration not only enriches therapeutic options but also fosters a more comprehensive understanding of health and wellness in a globalized world.

Current trends

The integration of traditional herbal medicines with pharmacological studies is an evolving field that aims to enhance the safety and efficacy of herbal remedies in modern therapeutics. Phytomedicine development has gained renewed interest in modern drug research, focusing on standardized herbal preparations with proven efficacy and safety [11]. This approach emphasizes the synergistic effects of multiple plant constituents, which are believed to offer enhanced therapeutic outcomes compared to isolated compounds. High-throughput screening methods and “reverse pharmacology” techniques are being employed to investigate these complex plant mixtures and their modes of action [11]. However, challenges remain, including reproducibility, toxicity, standardization, and herb-drug interactions. Despite these obstacles, recent phytopharmacological and clinical studies have demonstrated the therapeutic superiority of many plant extracts over single isolated constituents, as well as the bioequivalence of some phytopharmaceuticals with synthetic drugs. The future of phytomedicine research requires collaboration between various scientific disciplines to rationalize the multidrug and multitarget concept in therapy.

This section focusing on standardization, mechanisms of action, drug development, and the use of advanced technologies.

Standardization and scientific validation of herbal medicines

One of the primary trends is the standardization of herbal medicines. Standardization of herbal medicines is crucial for ensuring consistent quality, safety, and efficacy. This process involves identifying active compounds, establishing dosage guidelines, and evaluating safety and efficacy. Standardization guarantees the content of active constituents and marker compounds, addressing challenges posed by genetic and environmental factors affecting plant biochemistry. Various techniques are employed for extraction and characterization of herbal medicines, including spectroscopic, chromatographic, and thermogravimetric methods. The World Health Organization has established guidelines for assessing safety, efficacy, and quality of herbal medicines to promote global harmonization. Advanced technologies like nanotechnology and metabolomics are being utilized to improve bioavailability and develop better phytotherapeutic agents. These standardization efforts aim

to produce safe, potent, and affordable herbal medicines with consistent quality and effects. The process standardization involves:

- **Identifying Active Compounds:** Determining the bioactive compounds in herbal medicines is crucial for understanding their therapeutic effects.
- **Establishing Dosage Guidelines:** Standardizing dosages ensures consistent therapeutic outcomes and minimizes adverse effects.
- **Safety and Efficacy Evaluation:** Rigorous evaluation of the safety and efficacy of herbal remedies is essential, as many traditional formulations lack scientific validation.

For instance, recent studies on saffron (*Crocus sativus*) have highlighted its neuroprotective and antidepressant effects, emphasizing the need for standardized extracts to ensure consistent therapeutic benefits [12].

Mechanisms of action

Recent research has focused on understanding the mechanisms of action and pharmacokinetics of herbal medicines. Studies have explored how herbal compounds are absorbed, metabolized, and excreted, which is crucial for determining their therapeutic potential and safety. Researchers have investigated the influence of herbal constituents on cellular pathways, including inflammation and apoptosis [13]. The pharmacokinetics-pharmacology disconnection observed in many herbal medicines has led to the development of cellular pharmacokinetic-pharmacodynamic strategies, which focus on intracellular drug fate rather than plasma concentrations [13]. Drug-metabolizing enzymes, transporters, and non-coding RNAs play significant roles in determining pharmacokinetics and inter-individual variations in response to herbal medicines. Many herbal compounds undergo Phase I and/or Phase II metabolism, with cytochrome P450s and UGTs playing major roles. Despite increasing pharmacokinetic studies, data on the disposition and biological fate of many herbal remedies in humans remain limited.

Research has focused on:

- **Cellular Pathways:** Herbal compounds can influence various cellular pathways, impacting processes such as inflammation and apoptosis.
- **Pharmacokinetics:** Studies have examined how herbal constituents are absorbed, metabolized, and excreted, which is vital for determining their therapeutic potential and safety.

For example, curcumin, a compound found in turmeric, has been shown to modulate inflammatory pathways, enhancing its efficacy as an anti-inflammatory agent.

Development of combination therapies

The development of combination therapies integrating herbal medicines with conventional pharmaceuticals is gaining traction in medical research. This approach aims to enhance efficacy and reduce side effects of treatments. Combining phytochemicals with synthetic drugs can lead to synergistic effects, potentially improving therapeutic outcomes while minimizing adverse reactions [14]. For instance, in breast cancer treatment, the combination of piperine, sulforaphane, and thymoquinone with conventional therapies has shown promise in enhancing efficacy and reducing drug resistance. Similarly, in diabetes management, combining commercial drugs with phytochemicals may reduce side effects while effectively combating hyperglycemia. The introduction of “omic” technologies is opening new perspectives for rationalizing these synergistic effects and developing a new generation of phytopharmaceuticals. This approach could lead to more rational, evidence-based interventions for multifactorial diseases and aims to:

- **Enhance Efficacy:** Combining herbal remedies with synthetic drugs can improve therapeutic outcomes.
- **Reduce Side Effects:** Herbal components may mitigate the side effects of conventional drugs, leading to better patient compliance.

Research has indicated that combining ginseng with standard treatments for conditions like Alzheimer’s disease can enhance cognitive function while reducing adverse effects.

Utilization of advanced technologies

The application of modern technologies such as nanotechnology and artificial intelligence is revolutionizing the integration of pharmacology and traditional medicine. Nanoparticles are being explored to enhance the bioavailability, stability, and targeted delivery of herbal compounds [15]. Various nanocarriers, such as liposomes and polymeric nanoparticles, are being developed to improve the efficacy of herbal therapeutics. These advanced technologies address challenges like poor bioavailability and non-specific targeting in traditional herbal medicine. Nanotechnology enables the encapsulation of herbal medicines, allowing for controlled re-

lease and reduced side effects. Additionally, data analytics and artificial intelligence are being applied to develop personalized herbal therapies. The combination of nanotechnology and herbal medicine shows promise in treating various conditions, including cancer and neurodegenerative disorders. Continued research in this field is crucial for unlocking the full potential of these innovative approaches in healthcare. The trend includes:

- **Artificial Intelligence and Machine Learning:** These technologies are being used to identify potential herbal compounds and predict their interactions with other drugs.
- **Nanotechnology:** Nanoparticles are being explored for their ability to enhance the bioavailability of herbal extracts, improving their therapeutic efficacy.

For instance, the use of nanoparticles to deliver curcumin has shown promise in increasing its absorption and effectiveness in cancer treatment [16].

Clinical trials and evidence-based research

Clinical trials and evidence-based research are increasingly important in validating herbal medicines. Randomized controlled trials (RCTs) are considered the gold standard for establishing efficacy. However, herbal drug trials face unique challenges in scientific validity and risk assessment, requiring careful ethical considerations. Key issues include quality of raw materials, appropriate assessment methodologies, standardization, pharmacokinetics, and clinical study designs. Researchers must address these challenges to ensure data quality and safeguard participants. Despite the growing interest in herbal supplements worldwide, limited data exist on their safety and efficacy. Evidence-based botanical research can help validate traditional uses and facilitate new drug development. However, obstacles remain, including procurement of study agents, regulatory hurdles, and funding issues. Continued efforts from governmental agencies and industry are essential to support high-quality research in this field. The trend includes:

- **RCTs:** RCTs are being utilized to provide robust evidence for the therapeutic claims of herbal medicines.
- **Ethical considerations:** Ensuring ethical standards in research, including informed consent and transparency, is paramount.

The increasing number of clinical trials focusing on herbal medicines, such as studies on the efficacy of licorice (*Glycyrrhiza glabra*) for gastrointestinal disorders, reflects this trend.

Regulatory frameworks

Regulatory frameworks for herbal medicines are crucial for ensuring safety, efficacy, and quality control [17]. While many countries lack stringent regulations, some nations like Canada, Europe, Australia, the USA, and Japan have implemented strict guidelines. The European Union has established a complex but clear legal framework for herbal medicinal products, focusing on safeguarding public health. Quality control measures, including Good Manufacturing Practices, are essential for maintaining consistency and safety. Despite the perception that herbal medicines are safe, they can have side effects, emphasizing the need for well-controlled clinical trials. Cuba has integrated traditional medicine into its national health system and established regulatory policies to ensure quality, safety, and efficacy of herbal medicines. Harmonization of regulatory guidelines is necessary to promote the safe and effective use of herbal medicines globally. The trend includes

- **Quality Control Standards:** Implementing stringent quality control measures to ensure the consistency and safety of herbal products.
- **Legal and Ethical Guidelines:** Developing legal frameworks that protect traditional knowledge and ensure ethical practices in herbal medicine research.

Countries like Germany have made significant strides in integrating traditional herbal medicines into their healthcare systems, establishing standards that align with modern pharmacological practices.

The integration of pharmacology and traditional medicine is a promising field that holds the potential to enhance the therapeutic landscape. Current trends emphasize the importance of standardization, understanding mechanisms of action, developing combination therapies, utilizing advanced technologies, conducting clinical trials, and establishing regulatory frameworks. Continued research and collaboration between traditional medicine practitioners and pharmacologists are essential to fully realize the benefits of herbal remedies in modern therapeutics.

Methodological challenges

The methodological challenges based on the context and general knowledge includes

Cultural resistance

Herbal medicine, rooted in traditional practices, faces challenges in gaining universal acceptance and integration into modern healthcare systems [18]. Despite its long-standing use and perceived efficacy, cultural resistance from educational institutions and healthcare professionals hinders its widespread adoption. This resistance can hinder the acceptance and integration of herbal remedies into modern therapeutic practices. It stems from a lack of confidence in traditional medicine's effectiveness and a reluctance to engage in related research [18]. Many healthcare professionals and students may lack confidence in the efficacy of traditional medicine, leading to a reluctance to engage in research or clinical application of herbal remedies. However, there has been a resurgent trend towards herbal medicine usage, driven by concerns over synthetic drug side effects and contraindications. The integration of herbal medicines into mainstream healthcare requires addressing challenges such as inadequate standardization, societal stigma, and divergent stakeholder perspectives. Proposed strategies include collaborative research, international endorsements, and education initiatives to promote evidence-based practices and enhance regulations [19].

Complexity of herbal formulations

Traditional medicine frequently employs polypharmacological approaches, utilizing complex herbal mixtures rather than single compounds. This complexity complicates the understanding of how various components interact within the body. Unlike conventional drugs that target specific pathways, herbal remedies may exert synergistic effects through multiple active metabolites, making it difficult to isolate individual effects or establish standardized dosages. While there is an assumption that synergy derives from interactions between multiple bioactive components, evidence remains limited due to methodological challenges and the complex nature of herbal medicines [20]. Metabolomics coupled with multivariate statistical tools offers a promising approach to address the complexities of polypharmacokinetics, integrating the analysis of bioavailable xenobiotic molecules and human metabolic responses. The multi-target therapeutic concept of phytotherapy suggests that the combined action of multiple constituents may be more effective in treating multifactorial diseases than single-target drugs. Synergistic or antagonistic interactions between phytochemicals can occur through various mechanisms, including effects on bioavailability, cellular transport processes, and multi-target effects

on signaling cascades. Further research using advanced technologies may help unravel the complexities of herbal medicine interactions.

Lack of standardization

Herbal remedies often lack standardization in terms of preparation, dosage, and quality control. This variability can complicate the assessment of their safety and efficacy. The lack of standardization in herbal remedies poses significant challenges in assessing their safety, efficacy, and quality [21]. Standardization is crucial for confirming identity, purity, and content of herbal drugs. Without standardized protocols, it becomes challenging to conduct rigorous clinical trials that yield reliable data. Various methods are employed for standardization, including macroscopic, microscopic, physical, chemical, and biological techniques. Advanced chromatographic and hyphenated techniques like HPLC-MS and GC-MS are also utilized. The absence of standardized protocols complicates the conduct of rigorous clinical trials and quality control. To address these issues, there is a growing need to develop standardization parameters and implement proper integration of modern scientific techniques with traditional knowledge. This standardization is essential to meet the demands of the global herbal market and ensure consumer safety.

Insufficient scientific evidence

Many traditional herbal remedies have not been subjected to the same level of scientific scrutiny as conventional pharmaceuticals. The absence of robust clinical trials and scientific validation makes it difficult to evaluate their therapeutic potential and safety profiles. This gap in evidence can lead to skepticism among healthcare providers and regulatory bodies. While herbal medicines are popular among the public, healthcare professionals often view them critically due to insufficient clinical trials demonstrating efficacy and safety [22]. The complex nature of herbal products, with their numerous bioactive components, makes it difficult to extrapolate results from one product to another. Although some standardized herbal extracts have undergone extensive clinical investigation, evidence of efficacy is often extract-specific. Current regulations allow manufacturers to produce and sell herbal products without first demonstrating safety and efficacy, unlike pharmaceutical drugs. This lack of standardization and rigorous testing contributes to the skepticism among healthcare providers and regulatory bodies. To improve the acceptance and integration of herbal medicines

into mainstream healthcare, there is a need for more comprehensive clinical trials and stricter regulatory standards.

Inadequate regulatory framework

The regulatory landscape for herbal medicines is often less stringent than that for conventional drugs. The regulatory landscape for herbal medicines varies globally, with some countries having stricter guidelines than others. Many nations lack adequate quality control measures for herbal products, leading to concerns about safety and efficacy [23]. Ethiopia, for instance, faces challenges in regulating traditional herbal medicines due to weak legal enforcement and resource constraints. Iran faces challenges such as counterfeit with conventional medications. To address these issues, the World Health Organization developed guidelines for assessing herbal medicines in 1991. This can result in the marketing of unproven or unsafe products. A lack of clear guidelines for the evaluation and approval of herbal remedies poses significant challenges for researchers and practitioners aiming to integrate these treatments into modern medicine. Implementing standardized practices, such as Good Agricultural Practice and Good Manufacturing Practice, is crucial for ensuring product quality. While some countries like Germany and Japan have advanced regulatory systems, others like the United States and South Africa struggle with inadequate or ineffective policies. Overall, there is a global need for harmonization of regulatory guidelines to ensure the safe and effective use of herbal medicines.

Pharmacovigilance challenges

Monitoring the safety of herbal products post-approval poses another challenge. Establishing effective systems for pharmacovigilance-tracking adverse effects and interactions-remains difficult due to the informal nature of many traditional practices and the lack of comprehensive data collection systems. Pharmacovigilance of herbal medicinal products (HMPs) faces unique challenges due to their complex composition, widespread self-medication, and perceived safety. Despite their popularity, HMPs can pose risks through inherent toxicity, contamination, adulteration, misidentification, and interactions with other substances [24]. Current pharmacovigilance models, designed for synthetic drugs, are inadequate for monitoring herbal medicine safety. Underreporting of adverse reactions, variable product quality, and lack of comprehensive toxicity data further complicate safety assessments. To address these issues, researchers suggest integrating novel information sources, such as poison control data and advanced toxico-

logical techniques like predictive toxicology and omics [24]. Developing effective pharmacovigilance systems for HMPs is crucial to detect, assess, and prevent adverse effects, ensuring their safe use in traditional and complementary medicine.

Poor public awareness and misinformation

Public awareness and understanding of traditional and complementary medicine are often compromised by misinformation and inadequate regulation. This can lead to misconceptions about the efficacy and safety of herbal remedies, further complicating their acceptance in mainstream healthcare. Studies have shown that information available to the public, including online sources and media reports, can be unreliable and misleading [25]. This issue is compounded by the lack of knowledge among conventional healthcare professionals and the tendency of some alternative practitioners to overestimate treatment efficacy. The problem extends to traditional medicine systems worldwide, with pseudoscientific practices and unsubstantiated claims prevalent in various contexts, such as traditional Iranian medicine. Even well-established systems like TCM face scrutiny regarding the scientific basis of their core concepts and diagnostic methods. Despite these challenges, traditional medicine remains widely used globally, highlighting the need for improved public health research and education to address the social, cultural, and economic factors influencing its use and integration into healthcare systems.

Interdisciplinary collaboration

Interdisciplinary collaboration between various disciplines, including pharmacology, ethnobotany, and cultural studies, is crucial for effective integration of pharmacology and traditional medicine, but challenges persist. The rigid discipline-oriented framework of academia often impedes interdisciplinarity in ethnopharmacology, hindering comprehensive research efforts [26]. Ethnobotany plays a valuable role in pharmacological research by providing cultural perspectives and insights into plant chemistry. However, the impact of ethnobotanical studies on public health in local communities remains limited. There is a need for more applied and interdisciplinary approaches to improve healthcare in underserved and minority communities. Integrative pharmacology-based traditional Chinese medicine (TCMIP) has emerged as a paradigm shift, employing systems biology and data integration to establish pharmacokinetics-pharmacodynamics correlations. This approach aims to improve quality control, clarify molecular mechanisms, and discover potential new drugs, particularly TCM-related combination therapies.

Ethical considerations

Research involving traditional medicine must navigate ethical considerations, particularly regarding informed consent and the use of indigenous knowledge. Ensuring that traditional knowledge holders are respected and compensated for their contributions is crucial for ethical research practices. Traditional herbal medicine research is gaining attention globally, with significant investments from governments and industry [27]. However, this research faces unique ethical challenges, particularly in international collaborations. Key issues include determining shared concepts of social value, scientific validity, and favorable risk-benefit ratios across cultures [27]. Ethical considerations also encompass patient autonomy, informed consent, justice, and the patient-physician relationship. Institutional review boards (IRBs) play a crucial role in addressing these challenges, but they often struggle with cultural differences and competing stakeholder interests. To promote ethically sound research, collaborative partnerships and democratic deliberation are recommended. Additionally, “cross-training” investigators and investing in safety-monitoring infrastructure can help address ethical concerns. As traditional herbal medicine research continues to expand, it is essential to apply comprehensive ethical frameworks to ensure responsible and beneficial outcomes.

Methodological rigor

The methodological rigor in herbal medicine research is often inadequate, with many studies lacking standardization, proper clinical evidence, and safety assessments. Many studies may rely on anecdotal evidence or small sample sizes, which can lead to biased results. Common issues include poor allocation concealment, insufficient reporting of dropouts, and small sample sizes [28]. While RCTs are considered the gold standard, herbal interventions face unique challenges in patient selection, blinding, and endpoint selection. To improve the quality of ethnopharmacological field studies, researchers should adhere to ethical and legal standards, collect and present data transparently, and ensure proper plant documentation linked to voucher specimens. Rigorous scientific approaches are necessary for the development and clinical use of herbal medicines, including standardization of products, proof of clinical efficacy, and safety assessments through well-designed clinical research. Addressing these methodological weaknesses is crucial for advancing the field of herbal medicine research. There is a need for well-designed, large-scale clinical trials that adhere to rigorous scientific standards to provide credible evidence for the efficacy and safety of herbal remedies.

Addressing these methodological challenges is essential for the successful integration of pharmacology and traditional medicine. By fostering a collaborative environment that values both scientific inquiry and traditional knowledge, researchers can enhance the understanding and application of herbal remedies in modern therapeutics. This will ultimately contribute to a more holistic approach to healthcare that respects cultural practices while ensuring patient safety and efficacy.

Case studies

The integration of pharmacology and traditional medicine, particularly in evaluating the safety and efficacy of herbal remedies, can be effectively illustrated through various case studies. These studies provide empirical evidence and contextual understanding of how traditional herbal medicines can be harmonized with modern therapeutic practices.

Ginger

Ginger (*Zingiber officinale* Roscoe) contains various bioactive compounds, primarily phenolic compounds like gingerols and shogaols, which contribute to its diverse biological activities. These compounds exhibit antioxidant, anti-inflammatory, antimicrobial, and anticancer properties [29]. Ginger has shown potential in managing neurological disorders, cardiovascular diseases, obesity, and diabetes. It is also effective in treating nausea, vomiting, and pain, including arthritis. The bioavailability of ginger's active compounds is limited due to low solubility, and the use of nanoparticles for drug delivery is recommended to enhance its therapeutic effects. Ongoing research aims to develop ginger-based functional foods and nutraceuticals for chronic disease prevention and management.

Ginger has shown promising results in treating various pain conditions, particularly dysmenorrhea and migraines. Multiple studies have demonstrated that ginger is as effective as conventional medications like mefenamic acid and ibuprofen in relieving menstrual pain. For migraines, ginger powder exhibited comparable efficacy to sumatriptan, with fewer side effects. The pain-reducing effects of ginger are attributed to its anti-inflammatory properties, inhibition of prostaglandin synthesis, and modulation of pain pathways [30]. Ginger has also shown potential in treating delayed onset muscle soreness, osteoarthritis, and chronic low back pain. Both oral and

topical applications of ginger have demonstrated effectiveness in pain management. While these findings are encouraging, further research is needed to establish optimal dosages for long-term therapy.

Turmeric

Curcumin, the primary bioactive compound in turmeric, exhibits its diverse therapeutic properties, including anti-inflammatory, antioxidant, and anticancer effects [31]. Despite its potential, curcumin's clinical application is hindered by poor bioavailability due to low solubility, rapid metabolism, and elimination. Various strategies have been developed to enhance curcumin's bioavailability, including the use of adjuvants like piperine, which increases absorption twofold. Nanoparticle formulations have shown promise in improving bioavailability and efficacy. For instance, polymer-based nanocurcumin demonstrated similar *in vitro* activity to free curcumin in pancreatic cell lines. Additionally, curcumin-loaded solid lipid nanoparticles applied topically showed improved efficacy compared to free curcumin. Despite bioavailability challenges, curcumin has demonstrated therapeutic potential against various diseases, including cancer, cardiovascular diseases, and arthritis.

Clinical studies have explored turmeric's potential in treating various conditions such as arthritis, diabetes, liver disorders, and Alzheimer's disease. Curcumin's low toxicity and broad therapeutic potential make it an attractive candidate for drug development. Recent research has focused on curcumin's role in managing obesity and metabolic disorders. While traditional uses of turmeric are largely attributed to curcumin, further clinical studies with larger sample sizes are needed to fully elucidate its efficacy in treating various diseases.

Ginseng

Ginseng, a medicinal plant with a long history of use, contains various bioactive compounds including ginsenosides, polysaccharides, and other phytochemicals. These components contribute to ginseng's diverse pharmacological effects, such as immunomodulation, anti-inflammatory, and anti-cancer properties [32]. Ginseng has demonstrated efficacy in improving cardiovascular health, combating diabetes, enhancing brain function, and promoting sexual health. Notably, ginseng leaf-stem extracts contain similar or

higher concentrations of active ingredients compared to the root, offering a more cost-effective and readily available alternative. Korean ginseng, in particular, has been found to contain a greater variety of ginsenosides and non-saponin compounds than American ginseng, potentially contributing to its wide range of therapeutic effects. While generally safe, excessive consumption may lead to adverse effects, warranting careful dosage consideration.

Ginseng has shown potential therapeutic applications across various health conditions. It demonstrates antidiabetic effects, potentially benefiting type II diabetics by protecting beta-cells and improving glucose metabolism. Ginseng also exhibits cardiovascular benefits, including antioxidant properties, vasomotor function modification, and platelet adhesion reduction [33]. In cancer treatment, ginseng may serve as an adjuvant to enhance immune activity and life quality during chemotherapy and radiation. Ginsenoside-Rg5 has shown anti-cancer effects in ovarian carcinoma by reducing tumor volume and metastasis. Ginseng's effects on cognitive function and potential for treating Parkinson's disease have been observed in rat models. Clinical applications include ameliorating subjective symptoms and preventing quality of life deterioration in chronic diseases. A clinical trial demonstrated ginseng's efficacy in reducing HIV-associated fatigue. However, more rigorous investigations are needed to fully assess ginseng's efficacy and safety in clinical settings.

Milk thistle

Milk thistle (*Silybum marianum*) extract contains flavonolignans collectively known as silymarin, with silybin being the main component. These compounds exhibit liver-protective properties but have low bioavailability [34]. After oral administration, silymarin flavonolignans are rapidly absorbed and metabolized, reaching peak plasma concentrations within 1-3 hours. They undergo extensive phase II metabolism, forming primarily glucuronide and sulfate conjugates. The conjugated forms have 4-30 times higher plasma concentrations than free forms, with short half-lives of 3-8 hours for conjugates and 1-3 hours for free compounds. Silybin-phosphatidylcholine complexes (phytosomes) show enhanced bioavailability compared to conventional silymarin [34]. While pre-clinical data are promising, further well-designed clinical trials are needed to fully establish the efficacy of milk thistle preparations in liver diseases.

Milk thistle has been traditionally used for liver and biliary disorders, with recent research exploring its potential in oncology. Clinical studies have demonstrated its efficacy in treating various liver diseases through antioxidative, anti-inflammatory, and liver-regenerating effects. Milk thistle extracts have shown promise in protecting against chemotherapy-induced toxicity and may have anticancer, antidiabetic, and cardioprotective properties. The active component, silymarin, has exhibited hepatoprotective and anticarcinogenic effects in preclinical studies, inhibiting cancer cell growth in multiple human cell types. While milk thistle is generally considered safe and well-tolerated, more rigorous clinical trials are needed to fully evaluate its potential in treating liver toxicity, chronic liver disease, and various cancers. Overall, milk thistle shows promise as a complementary therapy in oncology and liver-related conditions.

Licorice

Licorice root, derived from *Glycyrrhiza* species, has been traditionally used for various ailments including gastrointestinal issues, respiratory infections, and skin diseases. Its main bioactive compound, glycyrrhizin, exhibits anti-inflammatory, antiviral, antimicrobial, and antioxidative properties. Recent studies have explored licorice's potential in improving oral health, showing promise in treating dental caries, periodontitis, and other oral diseases [35]. Clinical studies have demonstrated its efficacy in managing mucositis, pharyngitis, asthma, peptic ulcer disease, and menopausal symptoms. While licorice demonstrates therapeutic benefits, chronic use can lead to adverse effects such as hypokalemia and hypertension. Glycyrrhizin inhibits 11β -hydroxysteroid dehydrogenase and binds to mineralocorticoid receptors, contributing to its pharmacological effects and potential risks. Despite its wide applications in food, medicine, and cosmetics, further research is needed to fully understand licorice's efficacy and safety in clinical settings.

The integration of pharmacology and traditional medicine through case studies of herbal remedies like ginger, turmeric, ginseng, milk thistle, and licorice highlight their potential efficacy and safety in modern therapeutics. While these herbal remedies offer numerous health benefits, understanding their bioavailability, mechanisms of action, and potential side effects is crucial for their effective application in clinical settings. Further research and clinical trials are necessary to substantiate these findings and optimize their use in healthcare.

Regulatory perspectives

The integration of pharmacology and traditional medicine, particularly concerning herbal remedies, necessitates a thorough understanding of the regulatory frameworks governing these products across different countries. This section outlines the regulatory perspectives on herbal medicines, focusing on safety, efficacy, and quality control as mandated by various health authorities worldwide.

Global regulatory landscape

The World Health Organization (WHO) recognizes the importance of traditional and complementary medicine (T and CM) in global healthcare systems, with approximately 170 countries utilizing some form of traditional medicine. The WHO has drafted guidelines to ensure the safety, efficacy, and quality control of herbal medicines, emphasizing the need for evidence-based approaches. However, regulation of T and CM varies widely between countries due to different cultural, historical, and medical backgrounds. The WHO encourages countries to inventory and assess their traditional medicinal plants, promote cooperation between traditional and modern healthcare providers, and integrate T and CM into national healthcare systems. Despite these efforts, countries face challenges in developing and implementing regulations due to the diversity and complexity of T and CM practices [36]. International cooperation and coordination are essential for the conservation and sustainable use of medicinal plants.

Diverse regulatory models

Different countries adopt various regulatory models for herbal medicines, which can include [37]

- **Prescription Drugs:** Some herbal products are regulated similarly to prescription medications, requiring rigorous clinical trials for safety and efficacy.
- **Over-the-Counter (OTC) Products:** Others may be classified as OTC products, which have less stringent requirements but still need to meet basic safety standards.
- **Dietary Supplements:** In some regions, herbal remedies are categorized as dietary supplements, which often have minimal regulatory oversight.

Regulatory frameworks by region

- **United States:** In the U.S., herbal products are classified as “dietary supplements” under the Federal Food, Drug, and Cosmetic Act (FD and C). Unlike pharmaceuticals, dietary supplements do not require pre-market approval for safety and efficacy. The FDA oversees post-market surveillance, and manufacturers are responsible for ensuring their products are safe for consumption. Only two herbal medicines have received FDA approval for specific therapeutic claims; Veregen in 2006 and Fulyzaq (Mytesi) in 2012.
- **Australia:** Herbal products are categorized as “complementary medicines” and are regulated under the Therapeutic Goods Administration (TGA). Products can be listed or registered, with registered products undergoing more rigorous evaluation for quality, safety, and efficacy. The regulatory framework aims to ensure that all therapeutic goods available to the public meet high standards.
- **Canada:** Health Canada regulates natural health products (NHPs), which include herbal medicines. NHPs must demonstrate safety and efficacy through evidence, which can include clinical trials or published studies. Products require pre-market approval, Post-market surveillance, and manufacturers must adhere to strict labeling and quality control standards.
- **European Union:** In the EU, herbal medicines are classified as medicinal products and must comply with the European Medicines Agency (EMA) regulations. The Traditional Herbal Medicinal Products Directive allows for simplified registration for products with at least 30 years of traditional use, 15 of which must be within the EU. This directive emphasizes the need for quality, safety, and efficacy in herbal products.
- **China:** TCM is well-integrated into the healthcare system, with specific regulations governing the production and sale of herbal products. The Chinese materia medica (CMM) market has grown significantly, representing 31% of the total pharmaceutical industry in China by 2014. The Chinese Food Safety Law mandates rigorous testing for safety and efficacy, especially for new herbal ingredients.
- **Japan:** In Japan, herbal medicines (Kampo) are regulated similarly to pharmaceuticals. Manufacturers must provide evidence of safety and efficacy, and Kampo products are often covered by national health insurance, reflecting their acceptance in mainstream medicine.

Quality control and safety measures

Quality control and safety measures are crucial in herbal medicine production to ensure efficacy and consumer safety. Regulatory bodies worldwide emphasize the importance of standardized processes, contaminant detection, and adherence to good manufacturing practices. Despite their widespread use, herbal remedies can pose health risks, including toxic contaminants, adverse reactions, and interactions with conventional medications [38]. The increasing demand for herbal products necessitates stringent quality control measures to maintain consistency and safety. Challenges in monitoring herbal medicine safety include inadequate knowledge of their mode of action, potential adverse reactions, and interactions with pharmaceuticals. To address these concerns, collaboration between academia, government, and industry is essential to develop practical methods for improving herbal remedy safety. Regulatory authorities must implement appropriate measures to protect public health and ensure the safe use of herbal medicines [38].

The regulatory landscape for herbal remedies and traditional medicine is complex and varies significantly across different regions. While there is a growing recognition of the role of herbal medicines in modern therapeutics, ensuring their safety, efficacy, and quality remains a critical challenge. Regulatory frameworks must continue to evolve, incorporating scientific evidence and traditional knowledge to facilitate the safe integration of herbal remedies into contemporary healthcare practices.

Future directions

Combining pharmacology with traditional medicine, especially regarding herbal remedies, offers a promising pathway to improve modern therapeutics. As this field progresses, several important directions are emerging to ensure the safe and effective use of herbal medicines alongside conventional treatments, enhancing their safety, efficacy, and acceptance in contemporary healthcare.

Clinical trials and evidence-based research

The necessity for rigorous clinical trials to establish the safety and efficacy of herbal remedies is paramount. RCTs are considered the gold standard for evaluating herbal interventions [39]. However, the overall methodological quality of RCTs in CHM has been found to be poor, with issues in randomization, blinding, and

sample size calculation. To improve the quality of herbal medicine research, three fundamental principles must be adhered to: standardization and regulation of the product, scientific proof of clinical benefit, and evidence of safety. Recommendations for enhancing RCT quality include formal training for investigators, conducting pilot studies, trial registration, and collaboration with academic research centers. These rigorous scientific approaches are essential for the development and clinical use of herbal medicines, as well as their potential integration into mainstream healthcare.

Research on herbal medicines faces several challenges in establishing evidence-based practices. These include the need for standardization of herbal products to ensure consistent therapeutic effects and reduce adverse interactions. Quality control and authenticity of herbal products are crucial for conducting meaningful clinical trials. Long-term studies are necessary to monitor the efficacy and safety of herbal medicines over time. The complexity of herbal products requires advanced research approaches, such as network pharmacology based on omic tools. Practitioners are advised to select high-quality herbal products with product-specific evidence and consider traditional knowledge when evaluating their use. Key challenges in herbal medicine research include raw material quality, appropriate assessment methodologies, standardization, pharmacokinetics, and clinical study designs. Addressing these issues is essential for improving the quality of herbal medicine research and its integration into evidence-based practice.

Integration with modern pharmacology

Network pharmacology has emerged as a powerful approach for understanding the complex interactions between bioactive compounds in medicinal plants and their biological targets. This method integrates traditional knowledge with modern analytical techniques to explore the pharmacological properties of herbal medicines. It enables researchers to investigate the synergistic effects of traditional medicines by analyzing multiple targets and pathways simultaneously. Network pharmacology has been particularly useful in studying TCM, providing insights into herb combinations, herbal formulae actions, and TCM syndromes [40]. The approach employs various computational tools, including network-based and machine learning algorithms, to conduct research and analyze data [40]. Systems pharmacology, which integrates systems biology and pharmacology, further advances drug

discovery and therapeutic understanding for herbal medicines by combining large-scale statistical analysis, exploration of active ingredients and targets, and the development of specific informatics methods. This approach can help elucidate the mechanisms of action behind complex herbal formulations. Also, emphasizing ethnopharmacological studies that combine traditional knowledge with scientific inquiry to identify potential new drugs derived from herbal sources.

Standardization and quality control

Standardization and quality control of herbal medicines are crucial for ensuring consistency, safety, and efficacy [41]. The complex nature of herbal products poses challenges due to potential contamination, variability in composition, and batch-to-batch differences. Standardization encompasses the entire process from plant cultivation to clinical application, involving measures such as moisture content, foreign matter assessment, ash content, extractive values, and chemical assays. Quality control of herbal medicines requires rigorous protocols, including authentication of plant species, quantification of biomarkers, and selection of desired chemotypes. Implementing good manufacturing practices and adhering to regulatory guidelines are essential for producing consistent and reproducible herbal products. The development of comprehensive quality control parameters and standardization techniques is necessary to improve the safety and efficacy of herbal medicines in the global market. Future efforts should prioritize the development of rigorous quality control measures, including the establishment of guidelines for the cultivation, harvesting, and processing of medicinal plants. This will help mitigate risks associated with contamination and variability in active ingredient concentrations.

Pharmacogenomics and personalized medicine

Pharmacogenomics plays a crucial role in personalized medicine by studying how genetic variations influence drug responses, metabolism, and side effects. This field has evolved from focusing on single gene-drug pairs to encompassing multiple “-omics” disciplines, including proteomics and metabolomics [42]. By incorporating genetic information into clinical decision-making, healthcare providers can optimize drug therapy, minimize adverse reactions, and improve patient outcomes. Despite significant progress in identifying genetic factors affecting treatment outcomes, current biomarker panels still rely largely on single gene tests, with much

genetic influence yet to be discovered. Future research should focus on exploring combined effects of multiple genetic variants, gene-gene interactions, and non-protein coding functional variants across diverse populations to develop more comprehensive and accurate biomarker tests for improving individual clinical care. Future research should focus on identifying specific genetic markers that influence the efficacy and safety of herbal remedies. This will enable personalized treatment plans that consider both pharmacological and herbal interventions, optimizing therapeutic outcomes.

Understanding herb-drug interactions

The increasing use of herbal supplements alongside conventional medications has raised concerns about potential herb-drug interactions. These interactions often involve cytochrome P450 (CYP) enzymes, which play a crucial role in drug metabolism [43]. Inhibition or induction of CYP enzymes by herbal compounds can significantly alter the pharmacokinetics of prescribed drugs, potentially leading to toxicity or reduced efficacy. Common herbal medicines such as St. John's wort, garlic, ginseng, and ginkgo have been associated with clinically significant interactions when co-administered with prescription drugs. The complex nature of herbal preparations, containing multiple active ingredients, complicates the study of these interactions. As the global use of herbal remedies continues to rise, there is an urgent need for more clinical data on herb-drug interactions to ensure patient safety and inform healthcare professionals. Future studies should explore the pharmacokinetic and pharmacodynamic interactions between herbal remedies and conventional medications. This includes investigating the role of cytochrome P450 enzymes in metabolizing both herbal and pharmaceutical compounds, which can significantly impact therapeutic efficacy and safety.

Regulatory frameworks

Pharmacovigilance of herbal medicines is crucial for ensuring their safe use, but faces several challenges. These include inadequate regulatory measures, weak quality control systems, and uncontrolled distribution channels [44]. Under-reporting of adverse effects is a significant issue, as users often don't seek professional advice or report side effects. To address these challenges, there's a need for stronger national regulation, registration, and quality control of herbal medicines [44]. Cooperation between orthodox physicians and traditional practitioners is essential for compre-

hensive case evaluations. Future directions should include developing global standards for herbal product regulation and integrated pharmacovigilance systems. Additionally, improving botanical identity verification, traceability, and addressing over-the-counter herbal medicines are crucial for enhancing global safety. These efforts can lead to better risk management and increased availability of safe herbal products. Advocating for global standards in the regulation of herbal products to ensure quality control and safety, similar to those applied to conventional pharmaceuticals. Developing integrated pharmacovigilance systems to monitor adverse effects and interactions associated with herbal medicines, thereby enhancing patient safety. Future directions should include collaboration between regulatory bodies, healthcare professionals, and traditional medicine practitioners to create policies that govern the use of herbal remedies. This will help in monitoring adverse effects and ensuring that herbal products meet safety standards.

Education, training and awareness

The integration of herbal medicines into modern healthcare systems faces challenges despite their widespread use and potential benefits. Studies have shown that while many physicians accept herbal remedies, there is a significant knowledge gap regarding their safety and interactions [45]. This lack of awareness extends to health professionals in various regions, with only about half demonstrating good knowledge of herbal medicine safety. To address these issues, strategies such as implementing training programs, launching public awareness campaigns, and integrating traditional medicine education into medical curricula have been proposed. Additionally, there is a need for standardization, quality control, and evidence-based practices to enhance the acceptance and safe use of herbal medicines. Collaborative research, international endorsements, and improved regulatory frameworks are crucial steps towards effectively integrating traditional medicine into mainstream healthcare systems. Future initiatives should focus on integrating traditional medicine education into pharmacology and medical curricula. This will equip practitioners with the knowledge to make informed decisions about incorporating herbal remedies into patient care. Implementing training programs for healthcare providers on the integration of traditional medicine into modern practice, emphasizing evidence-based approaches. Launching campaigns to educate the public about the safe use of herbal remedies, including potential interactions with conventional treatments.

Interdisciplinary collaboration

The integration of traditional herbal medicine with modern pharmacology has gained significant attention in recent years. Researchers emphasize the importance of interdisciplinary collaboration between pharmacologists and herbal medicine practitioners to advance the field [46]. This collaboration aims to bridge traditional knowledge with contemporary scientific methodologies, focusing on botanical diversity, phytochemical analysis, therapeutic applications, safety assessments, and regulatory considerations. The journey of herbal medicines from traditional practices to modern pharmacological applications involves exploring their mechanisms, therapeutic potentials, and safety profiles. However, ethical challenges arise in international herbal medicine research, particularly in determining shared concepts of social value, scientific validity, and favorable risk-benefit ratios. To address these challenges, collaborative partnerships and democratic deliberation are recommended, along with cross-training investigators and investing in safety-monitoring infrastructure. These efforts can promote ethically sound research that contributes to global health. Promoting interdisciplinary collaboration between pharmacologists, herbalists, and researchers will foster a more comprehensive understanding of herbal medicines. Future research should encourage partnerships that facilitate knowledge exchange and innovation in the development of safe and effective herbal therapies.

Patient-centered approaches

Patient-centered care and cultural competence are complementary approaches to improving healthcare quality [47]. Both concepts have evolved from focusing on interpersonal interactions to considering the entire healthcare system. Patient-centered care emphasizes treating patients as unique individuals, respecting their beliefs and preferences. Cultural competence expands on this by providing healthcare providers with skills to navigate cultural conflicts and deliver effective care. Rather than relying on stereotypical cultural traits, a cross-cultural approach focuses on universal human needs and communication skills. Future directions in patient-centered care should address bio-psycho-spiritual concerns within the family's socio-cultural context. Integrating multidisciplinary teams and evidence-based complementary practices into conventional care can help develop patient-tailored treatment approaches. These strategies can lead to improved health outcomes and quality of life for patients. Future directions should emphasize patient-centered approaches that respect cultural beliefs

and practices related to traditional medicine. Engaging patients in discussions about their use of herbal remedies can lead to better adherence to treatment plans and improved health outcomes.

Technological Innovations

Advancements in technology can significantly impact the study and application of traditional medicine. Artificial Intelligence (AI) is revolutionizing TCM by enhancing diagnostic accuracy, treatment efficacy, and standardization. AI technologies, particularly machine learning, are improving the objectivity and reliability of TCM diagnoses through pattern recognition and data analysis. This integration is bridging the gap between TCM and modern medicine, promoting evidence-based practices and potentially leading to new therapeutic discoveries. AI applications in TCM include analyzing tongue images for syndrome differentiation, exploring herbal compound mechanisms, and constructing signaling pathways for specific treatments. However, challenges such as data quality and ethical concerns persist. Despite these obstacles, the combination of AI and TCM holds promise for advancing global healthcare by leveraging ancient wisdom with cutting-edge technology, potentially leading to more systematic, effective, and accessible medical practices [48]. Leveraging AI for data analysis can help in identifying patterns and trends in traditional medicine practices, potentially leading to new therapeutic discoveries. Also, employing biotechnological methods to isolate active compounds from herbs can improve drug formulation processes and enhance therapeutic efficacy.

Comprehensive safety evaluations

Traditional herbal medicines, despite their long history of use, require comprehensive safety evaluations similar to those for chemical drugs. This includes in vitro and in vivo toxicity tests, such as cytotoxicity, genotoxicity, acute and repeated dose toxicity, carcinogenicity, and reproductive toxicity studies. Animal experimentation plays a crucial role in these assessments, with rodents, guinea pigs, rabbits, cats, and dogs commonly used. Standardization of herbal materials is essential for quality control and reproducibility of results, encompassing species identification, extraction procedures, and chemical analysis. The U.S. Food and Drug Administration has developed a framework for advancing botanicals into new drugs based on the same standards as small molecule drugs [49]. These rigorous evaluations are necessary to ensure the safety and efficacy of traditional medicines by modern standards.

In the best of our study, the integration of pharmacology and traditional medicine requires a multifaceted approach that prioritizes safety, efficacy, and patient well-being. By focusing on these future directions, the healthcare community can harness the potential of herbal remedies while ensuring they complement modern therapeutic practices effectively.

Conclusions

The integration of pharmacology and traditional medicine offers significant potential for improving healthcare outcomes through the validation of herbal remedies. However, rigorous scientific evaluation and standardization are essential to ensure their safety and efficacy.

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Conflict of Interest

The authors declare there is no conflict of interests.

Author Contributions

Study concept and design (AG), data acquisition (A, B, C, D, E, F), manuscript drafting (G). All authors have significantly contributed to this and approved the manuscript.

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