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ROLE OF HERBAL MEDICINE IN MODERN HEALTH CARE: EMPHASIS ON CHRONIC DISEASES, ANTIMICROBIAL ACTIVITY, AND IMMUNOMODULATION

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ABSTRACT

Herbal medicine has re-emerged as a significant component of modern health care systems worldwide, driven by increasing chronic disease burden, antimicrobial resistance, immune dysregulation disorders, and the demand for safer, cost-effective therapeutic alternatives. Traditional medical systems such as Ayurveda, Traditional Chinese Medicine, Unani, Kampo, and African ethnomedicine have contributed substantially to contemporary pharmacotherapy, with nearly 25% of modern drugs derived directly or indirectly from plant sources. Between 2020 and 2025, global interest in phytomedicine expanded significantly due to the COVID-19 pandemic, increasing awareness of immune health and antiviral botanicals. Herbal medicines demonstrate therapeutic potential through diverse mechanisms including antioxidant activity, modulation of inflammatory signaling pathways, regulation of cytokine expression, antimicrobial membrane disruption, apoptosis induction, and epigenetic modulation in chronic diseases such as diabetes, cardiovascular disorders, cancer, neurodegenerative diseases, autoimmune disorders, and metabolic syndrome, plant-derived bioactive compounds have shown clinically relevant benefits. Additionally, antimicrobial phytochemicals such as flavonoids, alkaloids, terpenoids, and phenolics exhibit broad-spectrum antibacterial, antifungal, and antiviral activities, addressing multidrug resistance concerns. Herbal medicines also play a crucial role in immune modulation by balancing Th1/Th2 responses, enhancing innate immunity, and regulating inflammatory mediators. However, safety concerns including hepatotoxicity, nephrotoxicity, contamination, adulteration, and herb–drug interactions remain significant challenges. Regulatory harmonization across global jurisdictions is evolving, yet variability persists in quality control, standardization, and pharmacovigilance frameworks. This review critically evaluates the global impact, mechanisms of action, clinical applications in chronic diseases, antimicrobial and antiviral activities, immunomodulatory properties, safety profiles, regulatory challenges, and future directions of herbal medicine in modern health care. Emphasis is placed on recent scientific advancements (2020–2025), evidence-based integration strategies, and translational opportunities for phytopharmaceutical development.

KEYWORDS: Herbal medicine; Chronic diseases; Immunomodulation; Phytochemicals; Regulatory science; Integrative medicine.

INTRODUCTION

Herbal medicine is among the oldest and most enduring systems of health care in human history. Archaeological findings indicate that medicinal plant use dates back more than 60,000 years, and current estimates suggest that nearly 80% of the global population depends on traditional plant-based remedies for primary health care.[1,29] In recent decades, scientific interest in herbal therapeutics has intensified due to the rising burden of chronic non-communicable diseases, increasing antibiotic resistance, adverse drug reactions, and the high economic costs associated with synthetic pharmaceuticals.[2,30]

The World Health Organization (WHO) has officially acknowledged traditional and complementary medicine

as a key component of universal health coverage strategies, particularly in low- and middle-income nations,[25,31] From 2020 to 2025, the COVID-19 pandemic markedly accelerated both public and scientific interest in plant-derived immunomodulatory and antiviral agents such as Andrographis paniculata, Glycyrrhiza glabra, Curcuma longa, and Withania somnifera.[3,32,34] This trend highlighted the potential role of phytomedicine in supportive as well as preventive therapeutic approaches.

Contemporary pharmacological research has validated several plant-derived compounds, including artemisinin, paclitaxel, vincristine, and morphine, underscoring the translational significance of ethnopharmacology.[2,35] Technological advancements in metabolomics, molecular docking, network pharmacology, and systems biology have enabled deeper insights into the multi-target mechanisms characteristic of herbal formulations.[6,36] Unlike many single-target synthetic drugs, herbal medicines frequently exhibit pleiotropic actions by modulating multiple signaling pathways concurrently.[5,37]

Despite encouraging evidence, notable challenges persist. Variations in phytochemical composition due to environmental, geographical, and post-harvest processing factors may influence therapeutic consistency and quality.[26,38] Furthermore, the limited availability of large-scale randomized controlled trials restricts broader integration into mainstream evidence-based practice.[39,40] Nevertheless, the global herbal medicine market surpassed USD 200 billion in 2023 and continues to demonstrate sustained growth.[41]

This review consolidates recent literature (2020–2025) to explore the expanding role of herbal medicine within modern health care systems, with particular focus on chronic disease management, antimicrobial properties, immune modulation, safety concerns, and evolving regulatory frameworks.

GLOBAL IMPACT OF HERBAL MEDICINE

Herbal medicine exerts substantial global influence across health, economic, and cultural domains. The worldwide phytopharmaceutical market continues to expand steadily, fueled by growing consumer preference for natural remedies, aging demographics, and the rising prevalence of chronic diseases.[41,42] Asia represents the largest share of herbal medicine utilization, particularly in China and India, where Traditional Chinese Medicine (TCM) and Ayurveda are formally incorporated into national health care frameworks.[43,44] In Europe and North America, herbal products are commonly used as complementary therapies, especially for stress-related conditions, metabolic disorders, and immune enhancement.[45,46]

The World Health Organization introduced the Global Traditional Medicine Strategy 2014–2023, prioritizing integration, regulatory strengthening, and research advancement.[25] Subsequently, many countries reinforced regulatory policies to enhance quality control and pharmacovigilance systems.[27,47] During the COVID-19 pandemic, several nations incorporated selected herbal formulations into national treatment protocols for mild cases or supportive care, reflecting increasing institutional acceptance.[3,48]

From an economic perspective, herbal medicine sustains the livelihoods of millions of small-scale farmers and indigenous populations.[49] At the same time, sustainable harvesting practices and biodiversity conservation have gained prominence, as excessive exploitation poses risks to medicinal plant species.[50]

In low-resource environments, herbal medicine provides affordable and accessible health care where conventional pharmaceuticals are scarce.[31,51] Conversely, in high-income countries, herbal therapies are progressively integrated into programs such as integrative oncology, cardiology, and mental health services.[52,53]

Globalization has further enabled cross-cultural exchange of traditional medical knowledge, facilitating the development of standardized phytopharmaceuticals and regulated botanical drugs.[54] Regulatory recognition is exemplified by the U.S. Food and Drug Administration approval of botanical products such as Veregen and Fulyzaq, demonstrating established pathways for plant-based therapeutics.[55]

MECHANISM OF ACTION OF HERBAL MEDICINES

Herbal medicines exert pharmacological effects through diverse and frequently synergistic mechanisms mediated by bioactive phytochemicals such as flavonoids, alkaloids, saponins, terpenoids, glycosides, tannins, and polyphenols.[5,13]

A central mechanism involves antioxidant activity. Oxidative stress plays a significant role in chronic inflammation, carcinogenesis, neurodegenerative conditions, and metabolic disorders.[56] Phytochemicals including quercetin, curcumin, and resveratrol scavenge reactive oxygen species (ROS) and upregulate endogenous antioxidant enzymes such as superoxide dismutase and catalase, thereby restoring redox balance.[57,58]

Anti-inflammatory effects constitute another major pathway. Numerous plant-derived compounds suppress NF-κB signaling, inhibit Cyclooxygenase-2 (COX-2), and reduce pro-inflammatory cytokines including TNF-α, IL-6, and IL-1β.[59,60] These actions contribute to clinical benefits observed in arthritis, inflammatory bowel disease, and autoimmune disorders.[61]

Herbal agents also influence metabolic regulation. Berberine, for instance, activates AMP-activated protein

kinase (AMPK), enhancing insulin sensitivity and improving lipid metabolism.[62] Additionally, polyphenols modulate glucose transporter expression and support pancreatic β-cell function.[63]

In oncology research, phytochemicals promote apoptosis through mitochondrial pathways, regulate cell cycle progression, and inhibit angiogenesis.[64,65] Emerging evidence also highlights epigenetic mechanisms, including modulation of histone acetylation and DNA methylation patterns.[66]

Antimicrobial activity commonly arises from disruption of microbial cell membranes, inhibition of nucleic acid synthesis, suppression of efflux pumps, and interference with quorum sensing mechanisms.[14,15] Antiviral actions include blocking viral entry, inhibiting replication enzymes, and preventing host receptor binding.[16,67]

Importantly, herbal formulations often demonstrate multi-target synergy, wherein multiple constituents enhance bioavailability or exert complementary pharmacodynamic effects.[36,68] Systems pharmacology and network-based approaches further substantiate these complex interactions.[6,69]

ROLE IN CHRONIC DISEASES

Chronic non-communicable diseases (NCDs)—including diabetes mellitus, cardiovascular diseases, cancer, chronic respiratory disorders, neurodegenerative conditions, autoimmune diseases, and metabolic syndrome—are the principal causes of global morbidity and mortality.[70] These complex, multifactorial disorders are commonly driven by oxidative stress, persistent inflammation, immune imbalance, mitochondrial dysfunction, and metabolic dysregulation. Owing to their multi-component and multi-target characteristics, herbal medicines present promising adjunctive strategies in chronic disease management.

In type 2 diabetes mellitus, numerous plant-derived bioactives exhibit antihyperglycemic, insulin-sensitizing, and pancreatic β-cell protective properties.[71] Compounds such as berberine, curcumin, gymnemic acids, and ginsenosides improve glycemic control through activation of AMP-activated protein kinase (AMPK), modulation of insulin receptor signaling, and enhanced GLUT4 translocation.[72,73] Meta-analyses published between 2020 and 2024 indicate that standardized herbal formulations can significantly reduce HbA1c levels when used alongside conventional therapy.[74]

Additionally, antioxidant phytochemicals decrease advanced glycation end-products and attenuate complications such as diabetic nephropathy and neuropathy.[75]

Cardiovascular diseases (CVDs) are strongly associated with inflammation, endothelial dysfunction, and abnormal lipid profiles. Botanical agents such as garlic (Allium sativum), hawthorn (Crataegus spp.), and green tea (Camellia sinensis) demonstrate lipid-lowering, antihypertensive, and vasodilatory actions.[76] Polyphenolic compounds enhance nitric oxide bioavailability and protect vascular endothelium from oxidative injury.[77] Clinical investigations report modest reductions in systolic and diastolic blood pressure with selected herbal extracts.[78] Furthermore, plant sterols and soluble fibers contribute to cholesterol management.[79]

In oncology, plant-derived compounds remain central both as chemotherapeutic agents and supportive therapies. Phytochemicals including curcumin, resveratrol, epigallocatechin gallate (EGCG), and withanolides exhibit antiproliferative and pro-apoptotic activities.[80] These agents regulate tumor suppressor pathways, inhibit angiogenesis, and modulate immune surveillance.[81] Integrative oncology increasingly incorporates herbal adjuncts to alleviate chemotherapy-related adverse effects such as nausea, fatigue, and mucositis.[82] Nevertheless, careful assessment of potential herb–drug interactions is essential.[83]

Neurodegenerative disorders such as Alzheimer's disease and Parkinson's disease involve neuroinflammation, amyloid aggregation, mitochondrial impairment, and oxidative damage.[84] Herbal constituents including bacosides, ginsenosides, and curcuminoids demonstrate neuroprotective properties by modulating cholinergic signaling, reducing amyloid deposition, and strengthening antioxidant defenses.[85] Emerging preclinical data suggest certain polyphenols may cross the blood–brain barrier and exert epigenetic regulatory effects.[86]

In autoimmune and inflammatory diseases like rheumatoid arthritis and inflammatory bowel disease, herbal formulations display immunomodulatory actions by balancing Th17/Treg cell responses and suppressing pro-inflammatory mediators.[87] Compounds such as boswellic acids and andrographolide inhibit leukotriene synthesis and inflammatory transcription factors.[88] Clinical trials report symptomatic improvement with specific standardized botanical preparations.[89]

Metabolic syndrome—characterized by central obesity, dyslipidemia, hypertension, and insulin resistance—is another domain where herbal interventions show therapeutic potential.[90] Polyphenol-rich extracts influence adipocyte differentiation, lipid metabolism, and gut microbiota composition.[91] Increasing evidence highlights modulation of the gut microbiome as a pivotal mechanism underlying systemic metabolic benefits of herbal medicines.[92]

ANTIMICROBIAL AND ANTIVIRAL ACTIVITY

Antimicrobial resistance (AMR) is widely acknowledged as a critical global health challenge, contributing to higher mortality rates, extended hospitalizations, and

escalating health care expenditures (94). The pressing demand for alternative antimicrobial strategies has renewed scientific attention toward plant-derived phytochemicals possessing antibacterial, antifungal, and antiviral activities.

Bioactive plant compounds such as alkaloids, flavonoids, terpenoids, tannins, and essential oils exhibit antimicrobial properties through multiple mechanisms.[95] These mechanisms include disruption of microbial cell membranes, inhibition of protein and nucleic acid synthesis, interference with quorum sensing pathways, and suppression of efflux pump activity.[96] Essential oils extracted from oregano, thyme, and eucalyptus demonstrate broad-spectrum efficacy against both Gram-positive and Gram-negative bacteria.[97]

Flavonoids like quercetin and kaempferol inhibit bacterial DNA gyrase and modify membrane permeability, thereby impairing microbial survival.[98] Alkaloids such as berberine compromise cell wall integrity and reduce biofilm formation.[99] Notably, certain phytochemicals exhibit synergistic effects when combined with conventional antibiotics, potentially restoring antimicrobial susceptibility in resistant strains.[100]

In antifungal therapy, plant extracts have demonstrated activity against pathogens including Candida, Aspergillus, and dermatophyte species.[101] Phenolic constituents disrupt fungal cell membranes and inhibit ergosterol biosynthesis, a key component of fungal membrane stability.[102] With increasing antifungal resistance, botanical alternatives represent promising avenues for therapeutic research.[103]

Antiviral research gained significant momentum during the COVID-19 pandemic. Several phytochemicals demonstrate inhibitory activity against viral proteases, RNA-dependent RNA polymerase, and host cell entry receptors.[104] Molecular docking investigations have identified compounds capable of interacting with the SARS-CoV-2 spike protein and Angiotensin-converting enzyme 2 binding sites.[105] Agents such as glycyrrhizin, quercetin, and catechins have shown antiviral potential in preclinical and early clinical evaluations.[106]

Beyond COVID-19, herbal medicines demonstrate activity against influenza viruses, herpes simplex virus, hepatitis viruses, and HIV.[107] Their mechanisms include inhibition of viral replication, prevention of viral attachment to host cells, and modulation of host immune responses.[108] Network pharmacology studies further emphasize the multi-target antiviral capacity of complex herbal formulations.[109]

For successful incorporation of phytochemicals into antimicrobial drug development, rigorous standardization of extraction methods, stringent quality control, and comprehensive toxicity assessments are essential.[110]

SAFETY AND TOXICITY

Although herbal medicines are often perceived as inherently safe due to their natural origin, growing evidence indicates that phytotherapeutics can produce adverse effects when misused, improperly dosed, contaminated, misidentified, or combined with conventional medications.[124] Safety risks may arise from intrinsic plant toxicity, excessive or prolonged administration, pharmaceutical adulteration, heavy metal contamination, pesticide residues, and microbial impurities.[125]

Hepatotoxicity is among the most commonly reported adverse reactions linked to certain herbal products.[126] Cases of herb-induced liver injury have been associated with kava, high-dose green tea extracts, and specific traditional multi-herb formulations.[127] Proposed mechanisms include reactive metabolite generation, mitochondrial dysfunction, and immune-mediated hepatic damage.[128] Likewise, nephrotoxicity has been documented with plants containing aristolochic acid, which may result in interstitial fibrosis and increased risk of urothelial malignancies.[129]

Variability in quality control significantly influences safety outcomes. Environmental factors such as soil composition, climate conditions, harvesting periods, and processing techniques can substantially alter phytochemical profiles.[130] Therefore, standardization methods—including chromatographic fingerprinting, metabolomic analysis, and implementation of good agricultural and collection practices (GACP)—are increasingly emphasized to ensure consistency and safety.[131]

Contamination and adulteration remain additional concerns. Investigations conducted between 2020 and 2024 identified herbal supplements adulterated with corticosteroids, nonsteroidal anti-inflammatory drugs, and phosphodiesterase inhibitors.[132] Furthermore, heavy metal contamination—particularly with lead, arsenic, and mercury—has been reported in certain traditional preparations.[133]

Despite these challenges, many herbal medicines demonstrate favorable safety profiles when properly standardized, quality-assured, and used appropriately, especially compared with long-term synthetic pharmacotherapy.[134] Strengthening pharmacovigilance systems, enhancing post-marketing surveillance, and conducting comprehensive toxicological evaluations remain essential to safeguard patient health and support responsible integration into modern medical practice.[135]

DRUG–HERB INTERACTIONS

Herb–drug interactions represent a critical concern in integrative medical practice, particularly among patients with chronic illnesses who require multiple medications (polypharmacy).[136] These interactions may occur

through pharmacokinetic or pharmacodynamic mechanisms.

Pharmacokinetic interactions commonly involve modulation of cytochrome P450 (CYP) enzymes and drug transporters such as P-glycoprote in.[137] For instance, St. John's Wort induces CYP3A4 and P-glycoprotein activity, potentially lowering plasma concentrations of immunosuppressants, oral contraceptives, and antiretroviral agents.[138] In contrast, certain flavonoids inhibit CYP enzymes, which may increase drug bioavailability and elevate toxicity risk.[139]

Pharmacodynamic interactions arise when herbal constituents either potentiate or counteract the effects of conventional drugs. Garlic and ginkgo, for example, may enhance anticoagulant effects and heighten bleeding risk when used concurrently with warfarin.[140] Likewise, hypoglycemic herbs can intensify the action of antidiabetic medications, increasing the likelihood of hypoglycemia.[141]

Undisclosed use of herbal supplements further complicates clinical risk assessment.[142] Evidence indicates that many patients do not report herbal product consumption to health care providers, highlighting the necessity for improved patient–physician communication and professional education.[143]

Emerging clinical decision-support systems and pharmacogenomic strategies aim to improve prediction and management of herb–drug interactions.[144] Effective integration of herbal medicine into mainstream health care therefore requires systematic interaction assessment, standardized product labeling, and comprehensive clinician training.[145]

REGULATORY ASPECTS

Regulatory governance of herbal medicines differs substantially across regions, reflecting variations in cultural traditions, legal frameworks, and health care infrastructures.[146] A comparative overview of developed and developing regions reveals both meaningful advancements and ongoing challenges.

In the United States, herbal products are regulated primarily as dietary supplements under the Dietary Supplement Health and Education Act (DSHEA).[147]

Manufacturers bear responsibility for product safety and labeling accuracy, while pre-market proof of efficacy is generally not required.[148] However, the U.S. Food and Drug Administration has established a botanical drug development pathway, permitting approval of certain plant-based prescription medicines following rigorous clinical evaluation.[149]

Within the European Union, herbal medicines may be registered under the Traditional Herbal Medicinal Products Directive (THMPD), which mandates documented traditional use for at least 30 years, including 15 years within the EU.[150] Compared to dietary supplement frameworks, EU regulations impose stricter standards for quality assurance, safety monitoring, and pharmacovigilance.[151]

China formally integrates Traditional Chinese Medicine into its national health system, supported by state-funded research institutions and hospital-based services.[152] Standardization and quality assurance are implemented through the Chinese Pharmacopoeia.[153] Similarly, India regulates Ayurveda, Siddha, and Unani systems under the Ministry of AYUSH, with increasing emphasis on scientific validation and international standardization.[154] In many African countries, traditional medicine remains a primary source of health care, although regulatory frameworks are often underdeveloped.[155] Collaborative initiatives led by the African Union and the World Health Organization aim to harmonize regulations, encourage research, and strengthen safety standards.[156]

Global harmonization efforts increasingly prioritize quality control, pharmacovigilance, biodiversity conservation, and ethical sourcing practices.[157] Nevertheless, discrepancies in regulatory strictness, labeling standards, and evidentiary requirements continue to exist across jurisdictions.[158] Future regulatory models must carefully balance preservation of traditional knowledge with robust scientific validation and consumer protection.[159]

FUTURE PERSPECTIVES

The future of herbal medicine within modern health care depends on integrative, evidence-driven, and technologically sophisticated strategies. Rapid progress in omics sciences—genomics, transcriptomics, proteomics, and metabolomics—has enabled more precise elucidation of phytochemical mechanisms and biological targets (160). Systems biology and network pharmacology further facilitate decoding of complex, multi-component herbal formulations and their multi-target interactions.[161]

Artificial intelligence and machine learning are increasingly applied in phytochemical screening, molecular docking, and drug discovery pipelines.[162] These computational tools accelerate identification and optimization of bioactive compounds with significant therapeutic promise.[163] Moreover, nanotechnology-based delivery platforms improve the solubility, stability, and bioavailability of poorly water-soluble phytochemicals such as curcumin and resveratrol.[164]

Personalized medicine represents another important frontier. Integration of pharmacogenomic insights may enable customization of herbal therapies according to individual genetic profiles.[165] Such precision-based phytotherapy holds potential to enhance therapeutic outcomes while minimizing adverse reactions.[166]

Sustainability considerations are equally vital. Climate change, habitat loss, and overharvesting threaten medicinal plant biodiversity worldwide.[167] Implementation of sustainable cultivation practices, conservation strategies, and ethical sourcing frameworks is essential to ensure long-term resource availability.[168]

Interdisciplinary collaboration among ethnobotanists, pharmacologists, clinicians, regulatory agencies, and public health specialists will shape the trajectory of herbal medicine integration.[169] Prioritizing high-quality randomized controlled trials and generating robust real-world evidence will further strengthen scientific credibility and clinical acceptance.[170]

CONCLUSION

Herbal medicine occupies a dynamic and progressively expanding role within contemporary global health systems. Escalating prevalence of chronic diseases, antimicrobial resistance, immune dysregulation, and patient preference for natural therapies have driven renewed interest in phytomedicine as a complementary therapeutic approach. Mechanistic research highlights antioxidant, anti-inflammatory, metabolic-regulatory, antimicrobial, antiviral, and immune modulatory properties of diverse phytochemicals. Clinical evidence supports promising adjunctive applications in diabetes, cardiovascular disease, oncology, neurodegenerative disorders, and autoimmune conditions.

Despite its therapeutic potential, challenges related to safety monitoring, quality standardization, herb–drug interactions, and regulatory variability demand systematic and coordinated attention. Strengthened pharmacovigilance systems, improved product standardization, and greater international regulatory harmonization are essential to enhance patient safety and public confidence. Technological innovations in systems biology, artificial intelligence, and nanomedicine provide unprecedented opportunities to translate traditional knowledge into scientifically validated phytopharmaceuticals.

Ultimately, herbal medicine is not intended to replace conventional therapy but to complement and strengthen it within a rigorously validated, patient-centered, and sustainable health care framework. Continued interdisciplinary research, policy development, and global collaboration will determine its enduring contribution to future health care systems.

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