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Role of Traditional Herbal Systems in Modern Pharmacology

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Abstract

Traditional herbal systems represent millennia of accumulated therapeutic knowledge and constitute a foundational pillar of healthcare practice across diverse global civilisations. These systems, encompassing Ayurveda, Traditional Chinese Medicine (TCM), Unani, and numerous indigenous medicinal traditions, have long informed the therapeutic management of a broad spectrum of diseases. The objective of this review is to critically evaluate the role of traditional herbal systems in contemporary pharmacology, with particular emphasis on their historical foundations, pharmacological validation, and translational integration into modern drug development and clinical practice. Bioactive compounds derived from medicinal plants, including alkaloids, flavonoids, terpenoids, and polyphenols, have demonstrated significant pharmacological activities that underpin traditional therapeutic claims. Evidence-based validation through *in vitro*, *in vivo*, and clinical investigations has progressively transformed ethnopharmacological knowledge into scientifically credible therapeutic interventions. Landmark contributions such as artemisinin from *Artemisia annua* and paclitaxel from *Taxus brevifolia* illustrate the extraordinary capacity of traditional herbal knowledge to drive modern drug discovery. Furthermore, emerging technological platforms including metabolomics, network pharmacology, and high-throughput screening are accelerating the identification and optimisation of phytochemical leads. Despite these advances, significant challenges pertaining to standardisation, regulatory frameworks, and intellectual property protection remain. This review underscores the imperative of interdisciplinary collaboration and robust translational frameworks to harness the untapped therapeutic potential of traditional herbal systems, ultimately advancing global healthcare outcomes and promoting sustainable, evidence-based integrative medicine.

Keywords: Traditional medicine, Herbal systems, Ethnopharmacology, Drug discovery, Phytochemicals, Integrative medicine

1. Introduction

The utilisation of plants as therapeutic agents is one of the oldest and most universally documented practices in human history. Archaeological evidence suggests that medicinal plant use predates recorded history, with findings from Neanderthal burial sites indicating deliberate deposition of herbal materials, implying awareness of plant properties as far back as 60,000 years ago ^[1]. Across ancient civilisations in Mesopotamia, Egypt, India, China, Greece, and the Americas, herbal preparations formed the cornerstone of medical practice, codified in texts such as the Egyptian Ebers Papyrus, the Indian Charaka Samhita, and the Chinese Shennong Bencao Jing ^[2, 3]. These documents not only catalogued medicinal plants but also described preparation methods and clinical applications that continue to inform practice in the twenty-first century.

The global burden of disease, compounded by increasing antimicrobial resistance, the emergence of novel pathogens, and the escalating cost of synthetic drug development, has rekindled scientific and clinical interest in traditional herbal systems ^[4].

According to the World Health Organization (WHO), approximately 80% of the global population relies on traditional medicine for primary healthcare, particularly in low- and middle-income countries^[5]. This extraordinary dependency underscores both the relevance and the responsibility associated with scientifically evaluating and integrating traditional herbal knowledge into evidence-based medicine.

Over the past five decades, pharmacological research has demonstrated that many traditional remedies possess measurable biological activity attributable to discrete chemical entities. The isolation of morphine from *Papaver somniferum* in the early nineteenth century marked a pivotal transition from holistic botanical preparations to targeted pharmacotherapy^[6]. Subsequently, compounds such as quinine, digitalis glycosides, and reserpine emerged from traditional medicine to become foundational pharmaceutical agents. Today, estimates suggest that over 50% of approved drugs are derived from or inspired by natural products, with plants contributing disproportionately to this pharmacopoeia^[7]. This review synthesises current evidence regarding the pharmacological validation, translational applications, and integrative potential of traditional herbal systems within modern pharmacology.

2. Major Traditional Herbal Systems: Philosophical and Therapeutic Principles

Traditional herbal systems are not merely empirical compilations of plant use; they represent sophisticated epistemological frameworks that interpret health and disease through principles of balance, energy, and holism. Ayurveda, originating in the Indian subcontinent approximately 5,000 years ago, conceptualises health as a state of equilibrium among three biological humors known as doshas: Vata, Pitta, and Kapha^[8]. Therapeutic interventions, predominantly herbal in nature, aim to restore this balance through individualised formulations informed by the patient's constitutional type (Prakriti). Classical Ayurvedic texts such as the *Ashtanga Hridayam* describe thousands of plant-derived formulations, many of which have since been subjected to pharmacological investigation.

Traditional Chinese Medicine, practiced continuously for over 3,000 years, operates within a paradigm of Qi (vital energy) and the dynamic interplay of opposing forces, Yin and Yang^[9]. Herbal medicine within TCM employs complex polyherbal formulations designed to modulate specific organ systems and restore physiological homeostasis. The pharmacological complexity inherent in TCM preparations, which may contain ten or more plant species, poses both analytical and mechanistic challenges for modern investigators while simultaneously offering opportunities for synergistic therapeutic discovery.

Other significant traditional systems include Unani medicine, rooted in Greco-Arabic scholarship and widely practiced across the Middle East and South Asia; indigenous African healing traditions; and native American ethnobotanical practices^[10, 11]. Each system embodies a unique cultural and philosophical context yet shares a common reliance on botanical materials and an emphasis on holistic, patient-centred care. The recognition of these systems as legitimate sources of therapeutic knowledge is increasingly reflected in WHO's global strategy on traditional and complementary medicine, which calls for their rational integration into national health systems^[12].

3. Transition from Traditional Knowledge to Modern Pharmacological Research

The translation of traditional herbal knowledge into pharmacological research begins with the process of ethnopharmacological documentation, wherein the therapeutic practices of indigenous communities are systematically recorded and analysed^[13]. Ethnopharmacology, as a formal discipline, provides the essential intellectual bridge between traditional medicine and the natural sciences. By identifying plants with consistent therapeutic applications across independent cultural traditions, ethnopharmacologists can prioritise candidates for pharmacological investigation, substantially improving the efficiency of bioactive compound discovery compared to random screening approaches.

The subsequent step involves the phytochemical characterisation of prioritised plant materials, employing techniques such as solvent extraction, chromatographic separation, and spectroscopic identification including nuclear magnetic resonance spectroscopy and mass spectrometry^[14]. This process has led to the isolation of numerous pharmacologically active compounds across diverse chemical classes. Alkaloids such as morphine, codeine, and vincristine; terpenoids including artemisinin and taxol; flavonoids like quercetin and kaempferol; and polyphenols such as resveratrol and curcumin represent landmark phytochemical discoveries that have profoundly influenced modern pharmacotherapy^[15, 16].

The historical trajectory from plant to drug is exemplified by the discovery of artemisinin. Traditional Chinese texts documented the use of *Artemisia annua* for febrile illness for over two millennia. In the 1970s, Chinese scientist Tu Youyou and colleagues isolated artemisinin and demonstrated its potent antimalarial activity, a contribution that ultimately earned the Nobel Prize in Physiology or Medicine in 2015^[17]. This example illustrates the transformative potential of systematic engagement with traditional herbal knowledge and reinforces the scientific legitimacy of ethnopharmacology as a drug discovery paradigm.

4. Pharmacological Validation of Herbal Medicines

The pharmacological validation of traditional herbal medicines encompasses the characterisation of bioactive compounds, elucidation of mechanisms of action, and assessment of efficacy and safety through rigorous experimental approaches. *in vitro* studies employing cell culture models have been instrumental in identifying molecular targets for phytochemical compounds. Curcumin from *Curcuma longa*, for instance, has been shown to inhibit nuclear factor kappa B (NF- κ B) signalling, modulate cyclooxygenase-2 (COX-2) expression, and induce apoptosis in cancer cell lines, providing mechanistic support for its traditional anti-inflammatory applications^[18].

In vivo animal studies provide the next tier of evidence, enabling evaluation of pharmacokinetics, bioavailability, and therapeutic efficacy within complex physiological systems. Rodent models of inflammation, neurodegeneration, diabetes, and infection have been employed extensively to validate herbal preparations and isolated compounds^[19]. However, the translation of animal data to human pharmacology requires careful consideration of species differences in metabolism, receptor pharmacology, and disease pathophysiology.

Clinical evidence for herbal medicines has accumulated substantially over recent decades, though methodological heterogeneity and small sample sizes continue to limit conclusions in many areas. Randomised controlled trials have demonstrated efficacy for St. John's Wort (*Hypericum perforatum*) in mild to moderate depression, *Echinacea* preparations in reducing the duration and severity of upper respiratory infections, and ginkgo biloba extracts in cognitive function and peripheral vascular disease [20, 21]. The pharmacological basis for these effects has been partially elucidated, with hypericin and hyperforin identified as key active constituents in *Hypericum*, acting primarily through inhibition of monoamine reuptake [22].

5. Preclinical and Translational Research

The translation of phytochemical leads into clinically viable therapeutics requires a structured preclinical development programme that mirrors those applied to synthetic drug candidates. This includes comprehensive assessment of acute and chronic toxicity, genotoxicity, reproductive toxicity, and carcinogenicity in accordance with internationally recognised guidelines from regulatory bodies such as the International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) and the Organisation for Economic Co-operation and Development (OECD) [23].

Bioavailability represents a critical translational challenge for many phytochemical compounds, which frequently exhibit poor aqueous solubility, rapid first-pass metabolism, and limited membrane permeability. Formulation science has responded to this challenge through the development of nanotechnology-based delivery systems including liposomes, polymeric nanoparticles, and self-emulsifying drug delivery systems, which have been shown to significantly enhance the oral bioavailability of compounds such as curcumin and quercetin [24]. Solid dispersion techniques and phospholipid complexation have also been applied with demonstrable success in improving phytochemical pharmacokinetics.

Network pharmacology represents an emerging translational framework that is particularly well-suited to the multi-target, multi-component nature of herbal medicines. By constructing interaction networks between phytochemical compounds, their protein targets, and associated disease pathways, researchers can generate systems-level hypotheses regarding mechanisms of action and identify novel therapeutic applications [25]. This approach has been applied productively to complex TCM formulations, revealing that the therapeutic activity of polyherbal preparations frequently depends upon synergistic interactions among multiple chemical constituents acting on interconnected pathways.

6. Clinical Applications, Safety, and Standardisation Challenges

The integration of herbal medicines into clinical practice is increasingly supported by evidence-based guidelines and systematic reviews published by authoritative bodies including the Cochrane Collaboration, the European Medicines Agency (EMA), and national regulatory authorities [26]. Clinical applications span a wide range of therapeutic areas including oncology, where plant-derived compounds such as vinblastine, vincristine, paclitaxel, and camptothecin derivatives have become indispensable chemotherapeutic agents; neurology, where compounds like galantamine (derived from *Galanthus* species) are used for

Alzheimer's disease; and infectious diseases, where artemisinin-based combination therapies remain first-line treatment for uncomplicated *Plasmodium falciparum* malaria [27].

Safety considerations represent a paramount concern in herbal pharmacotherapy. Adverse effects attributable to herbal preparations include hepatotoxicity associated with pyrrolizidine alkaloids in *Symphytum* species, nephrotoxicity from aristolochic acids in *Aristolochia* species, and clinically significant pharmacokinetic herb-drug interactions mediated through cytochrome P450 enzyme induction or inhibition [28]. St. John's Wort, for example, is a potent inducer of CYP3A4 and P-glycoprotein, substantially reducing plasma concentrations of concomitantly administered immunosuppressants, antiretrovirals, and oral contraceptives [29]. These interactions necessitate careful clinical monitoring and underscore the importance of comprehensive herbal medicine histories in all patient encounters.

Standardisation of herbal preparations constitutes one of the most formidable challenges confronting the field. The chemical composition of medicinal plant materials is inherently variable, influenced by factors including geographical origin, soil composition, climate, harvesting season, post-harvest handling, and preparation methods [30]. Without rigorous standardisation, reproducibility of therapeutic effects across different batches and manufacturers cannot be assured. Modern analytical approaches including high-performance liquid chromatography coupled with diode array and mass spectrometric detection, along with metabolomic fingerprinting, are being employed to establish quality standards and validate herbal product authenticity.

7. Technological Advancements in Herbal Medicine Research

The application of advanced analytical and computational technologies has transformed the scientific investigation of traditional herbal medicines. Metabolomics, the comprehensive profiling of low-molecular-weight metabolites in biological matrices, enables the characterisation of the complete chemical complexity of herbal preparations and facilitates the identification of marker compounds for quality control and standardisation [31]. High-resolution mass spectrometry platforms, including Fourier-transform ion cyclotron resonance and Orbitrap-based instruments, provide the mass accuracy and sensitivity required to annotate hundreds of phytochemical constituents simultaneously.

High-throughput screening technologies, originally developed for synthetic compound libraries, have been adapted for phytochemical investigation, enabling rapid evaluation of plant extracts and isolated compounds against panels of pharmacological targets and cellular disease models [32]. Coupled with robotics and miniaturised assay formats, these platforms substantially accelerate the identification of bioactive constituents from complex herbal matrices. Virtual screening and molecular docking approaches, applied within computational drug discovery frameworks, allow the *in silico* assessment of phytochemical binding affinities to therapeutic targets and the prioritisation of compounds for experimental validation.

Artificial intelligence and machine learning are increasingly being applied to ethnopharmacological datasets to identify

patterns and predict pharmacological activity from chemical structure. Natural language processing algorithms have been deployed to extract and analyse traditional medicine knowledge from historical texts, creating structured databases that facilitate hypothesis generation and drug discovery [33]. These technological convergences represent a transformative frontier in herbal medicine research, offering unprecedented capacity to decode the pharmacological complexity of traditional healing systems.

8. Regulatory, Ethical, and Intellectual Property Considerations

The commercialisation of traditional herbal knowledge raises profound ethical, legal, and intellectual property concerns that cannot be disentangled from scientific investigation. Biopiracy, defined as the exploitation of indigenous biological resources and associated traditional knowledge without appropriate authorisation, acknowledgement, or benefit-sharing, has been extensively documented [34]. High-profile cases, such as attempts to patent the wound-healing properties of turmeric and the pesticidal uses of neem, both of which are longstanding elements of Indian traditional knowledge, have galvanised international advocacy for intellectual property protections for traditional knowledge holders.

The Convention on Biological Diversity and its Nagoya Protocol on Access and Benefit Sharing provide an international legal framework governing access to genetic resources and the equitable sharing of benefits arising from their utilisation [35]. However, implementation remains inconsistent across national jurisdictions, and indigenous communities frequently lack the legal capacity or institutional support to assert their rights effectively. The Traditional Knowledge Digital Library (TKDL) of India represents a notable initiative in this regard, having documented thousands of traditional formulations in patent-searchable formats to prevent fraudulent patent claims.

Regulatory frameworks for herbal medicines vary considerably across countries, creating challenges for international harmonisation and market access. In the European Union, the Traditional Herbal Medicinal Products Directive provides a simplified registration pathway for herbal preparations with established traditional use, while in the United States, herbal products are regulated as dietary

supplements with comparatively minimal pre-market requirements [36]. Strengthening regulatory harmonisation, establishing robust pharmacovigilance systems for herbal medicines, and ensuring that safety data requirements are proportionate yet scientifically rigorous represent key priorities for international regulatory authorities.

9. Conclusion and Future Directions

Traditional herbal systems represent an extraordinarily rich repository of therapeutic knowledge accumulated over millennia, and their integration into modern pharmacology offers transformative potential for global healthcare. The evidence reviewed herein demonstrates that traditional herbal medicines have contributed immensely to pharmaceutical development, and continue to provide viable leads for drug discovery across a spectrum of therapeutic domains. Pharmacological validation, enhanced by sophisticated analytical technologies and translational research frameworks, has begun to bridge the epistemological distance between traditional practice and evidence-based medicine.

Future progress will depend upon sustained investment in ethnopharmacological documentation, particularly in regions of exceptional biodiversity and rich indigenous medical traditions that remain underexplored. Interdisciplinary collaboration among ethnobotanists, pharmacologists, clinicians, computational scientists, and regulatory specialists is essential to maximise the scientific and therapeutic returns from traditional herbal systems. Furthermore, the ethical dimensions of this enterprise must be addressed with equal rigour; the benefits of traditional knowledge commercialisation must flow equitably to the communities whose intellectual and biological heritage has enabled these discoveries.

In conclusion, the integration of traditional herbal systems into modern pharmacology is neither a nostalgic retreat from scientific rigour nor a superficial concession to cultural sentiment. It is, rather, a scientifically compelling, ethically imperative, and clinically promising frontier that has the capacity to substantially expand the therapeutic armamentarium available to address the global burden of disease. The next decade holds considerable promise for evidence-based integrative medicine frameworks that honour both the wisdom of traditional knowledge and the exacting standards of modern pharmacological science.

Figures

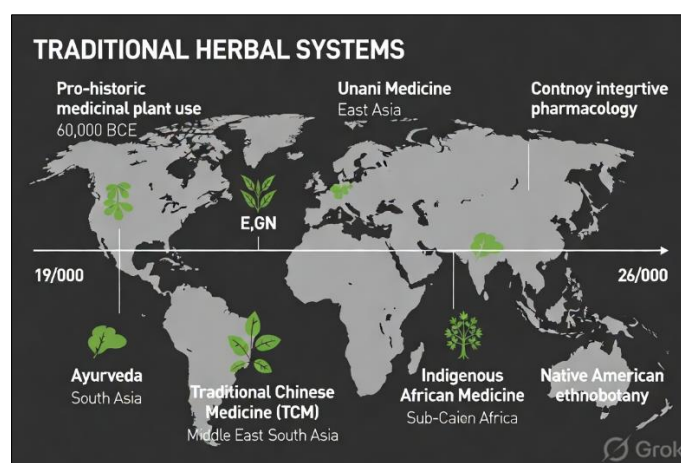


Fig 1: Historical evolution and global distribution of traditional herbal systems.

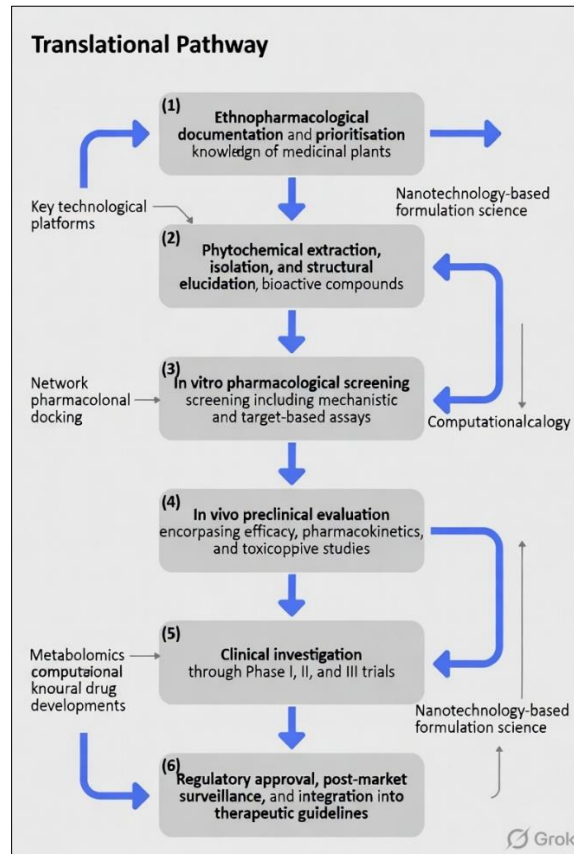


Fig 2: Translational pathway from traditional herbal knowledge to modern pharmacological research and drug development.

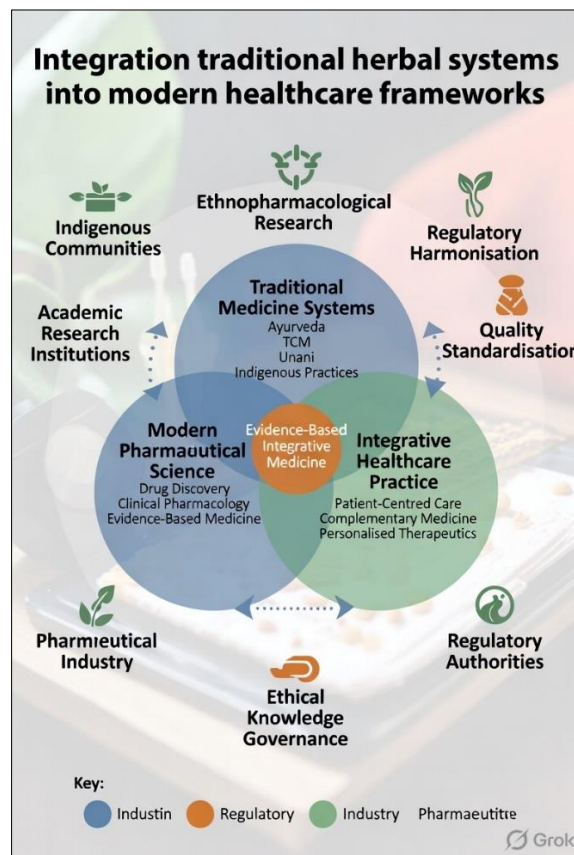


Fig 3: Integration of traditional herbal systems into modern healthcare frameworks.

Tables

Table 1: Comparison of Major Traditional Herbal Systems, Principles, and Therapeutic Approaches

Traditional System	Region of Origin	Foundational Principles	Therapeutic Philosophy	Representative Medicinal Plants
Ayurveda	Indian Subcontinent	Balance of Vata, Pitta, and Kapha doshas; Prakriti constitution	Individualised herbal formulations to restore doshic equilibrium and promote Ojas	Ashwagandha, Turmeric, Triphala, Brahmi, Shatavari
Traditional Chinese Medicine	China and East Asia	Qi (vital energy), Yin-Yang balance, Five Elements theory	Polyherbal formulations targeting organ systems to restore Qi flow and Yin-Yang harmony	Ginseng, Astragalus, Coptis, Artemisia annua, Ligustrum
Unani Medicine	Greco-Arabic, Middle East, South Asia	Four humors (blood, phlegm, yellow bile, black bile); Mizaj (temperament)	Herbal and mineral preparations to rebalance humoral constitution	Senna, Galbanum, Myrrh, Black seed (Nigella sativa), Liquorice
Indigenous African Medicine	Sub-Saharan Africa	Spiritual and physical balance; ancestral and community healing	Plant preparations combined with spiritual and ritual practices for holistic wellbeing	Devil's Claw, African Potato, Hoodia, Moringa, Rooibos
Native American Ethnobotany	North, Central, and South America	Harmony with nature; spiritual healing and community medicine	Plant-based rituals, poultices, teas, and preparations guided by healers	Echinacea, Goldenseal, Cascara sagrada, Passionflower, Saw palmetto

Table 2: Bioactive Compounds Derived from Traditional Medicines and Their Pharmacological Activities

Compound	Plant Source	Traditional System	Pharmacological Activity	Clinical Application
Artemisinin	Artemisia annua	TCM	Antimalarial; inhibits haem polymerisation; generates reactive oxygen species	First-line treatment for Plasmodium falciparum malaria (WHO-endorsed ACT)
Curcumin	Curcuma longa	Ayurveda	Anti-inflammatory (NF- κ B inhibition); antioxidant; anti-proliferative	Investigational in inflammatory diseases, colorectal cancer (Phase II/III trials)
Paclitaxel (Taxol)	Taxus brevifolia	Native American	Mitotic spindle stabilisation; tubulin polymerisation promotion	Approved for breast, ovarian, and lung carcinomas
Morphine	Papaver somniferum	Multiple ancient systems	μ -Opioid receptor agonist; central and peripheral analgesia	Severe pain management; palliative care; post-operative analgesia
Galantamine	Galanthus species	Traditional European	Reversible acetylcholinesterase inhibitor; allosteric nicotinic modulator	Approved for mild to moderate Alzheimer's disease
Reserpine	Rauwolfia serpentina	Ayurveda	Depletion of vesicular monoamine stores; sympatholytic	Historical antihypertensive; psychiatric applications
Quercetin	Multiple sources (Allium cepa, Camellia sinensis)	Multiple	Antioxidant; anti-inflammatory; anti-viral; kinase inhibition	Investigational in cardiovascular disease and cancer chemoprevention
Hypericin/Hyperforin	Hypericum perforatum	Traditional European	Monoamine reuptake inhibition; neurotransmitter modulation	Mild to moderate depression (EMA-registered herbal medicinal product)

Table 3: Advantages, Limitations, and Challenges in Integrating Traditional Herbal Systems into Modern Pharmacology

Domain	Advantages	Limitations	Challenges and Mitigation Strategies
Drug Discovery	Rich ethnopharmacological lead prioritisation; chemical diversity; multi-target bioactivity; historical safety profile in human populations	Variable bioactivity; complex matrices; poor <i>in vitro</i> -to- <i>in vivo</i> translation for polyherbal preparations	Systematic ethnopharmacological databases; bioassay-guided fractionation; network pharmacology approaches
Pharmacological Validation	Mechanistic insights into multi-target effects; clinical validation through traditional use; lower preliminary risk	Insufficient standardisation of extracts used in studies; limited pharmacokinetic data; dose-response inconsistencies	Standardised extract preparation protocols; ICH-compliant preclinical packages; robust PK-PD modelling
Clinical Evidence	Growing body of randomised controlled trials; meta-analyses available for select indications; patient acceptance and adherence	Methodological heterogeneity; small trial sizes; absence of long-term safety data; publication bias toward positive outcomes	Pre-registered multi-centre trials; CONSORT-compliant reporting; systematic reviews; active pharmacovigilance systems
Regulatory Integration	Established registration pathways (EU THMPD, WHO monographs); increasing regulatory literacy among manufacturers	Jurisdictional inconsistency; inadequate post-market surveillance; low barrier to entry for substandard products	International regulatory harmonisation; WHO global benchmarks; mandatory quality standards and GMP compliance
Safety and Herb-Drug Interactions	Long history of human use provides empirical safety signals; well-characterised major interactions available	CYP450 and P-glycoprotein-mediated interactions; adulterants; heavy metal contamination in some markets	Mandatory herb-drug interaction screening in clinical development; quality assurance programmes; consumer education
Ethical and Intellectual Property	Recognition of traditional knowledge as prior art; TKDL and similar databases protect against biopiracy	Inequitable benefit-sharing; inadequate legal capacity of indigenous communities; risk of cultural appropriation	Full implementation of Nagoya Protocol; community benefit-sharing agreements; co-development models with originating communities

Table 4: Current Research Status and Clinical Applications of Selected Traditional Herbal Medicines

Herbal Medicine / Compound	Indication	Research Phase	Level of Evidence	Regulatory Status
Artemisinin (ACT formulations)	Plasmodium falciparum malaria	Post-approval surveillance	Level I: Multiple RCTs and systematic reviews	WHO Essential Medicine; approved in >100 countries
Paclitaxel (Taxol)	Breast, ovarian, lung cancers	Post-approval; ongoing combination trials	Level I: Phase III RCTs; regulatory approval	FDA and EMA approved; multiple generic formulations available
Galantamine	Mild-moderate Alzheimer's disease	Post-approval; Phase IV studies	Level I: Cochrane systematic review confirming modest cognitive benefit	FDA, EMA, and TGA approved
Hypericum perforatum (St. John's Wort)	Mild-moderate depression	Approved in EU; investigational in others	Level I: Multiple meta-analyses supporting efficacy vs. placebo	EMA traditional use registration; not FDA-approved as drug
Curcumin (various formulations)	Inflammatory bowel disease; colorectal cancer; osteoarthritis	Phase I/II clinical trials; ongoing Phase III for IBD	Level II-III: Multiple small RCTs with heterogeneous outcomes	Not approved as drug; available as supplement; formulation optimisation ongoing
Echinacea preparations	Upper respiratory tract infections	Post-marketing studies; Phase III trials	Level II: Cochrane review supports modest reduction in duration	EU traditional use registered; widely available as OTC supplement
Berberine (Coptis chinensis)	Type 2 diabetes; dyslipidaemia	Phase II/III clinical trials	Level II: Multiple RCTs demonstrating HbA1c and lipid reduction	Approved as drug in China; supplement in Europe and USA
Ashwagandha (Withania somnifera)	Stress; anxiety; fatigue; cognitive function	Phase I/II pilot studies; emerging Phase III	Level II-III: Small RCTs showing anxiolytic and adaptogenic effects	Traditional use registered in EU; supplement status in USA

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