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Review Article

EXPLORING THE BIOMEDICAL APPLICATIONS OF MEDICINAL PLANTS: A BRIEF OVERVIEW

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ABSTRACT

Medicinal plants have played a pivotal role in healthcare systems for centuries and continue to serve as a rich source of bioactive compounds with significant biomedical potential. This review provides a brief overview of the diverse applications of herbal plants in modern biomedicine, emphasizing their therapeutic, pharmacological, and preventive roles. Bioactive phytochemicals such as alkaloids, flavonoids, terpenoids, phenolics, and glycosides exhibit a wide range of biological activities including antimicrobial, anti-inflammatory, antioxidant, anticancer, and antidiabetic effects. The integration of traditional knowledge with modern scientific approaches has enabled the discovery of novel drug candidates and the development of plant-based formulations with improved efficacy and safety profiles. Additionally, advancements in biotechnology and nanotechnology have enhanced the delivery and bioavailability of herbal compounds. Despite promising outcomes, challenges such as standardization, toxicity evaluation, and clinical validation remain critical for their large-scale biomedical application. This concise review highlights the growing importance of medicinal plants as sustainable resources for drug discovery and biomedical innovation.

Keywords: Medicinal plants, Biomedical applications, Phytochemicals, Therapeutic potential, Drug discovery.

INTRODUCTION

Medicinal plants have been integral to human health and well-being since ancient times, forming the backbone of traditional medical systems such as Ayurveda, Traditional Chinese Medicine, and Unani. Their enduring relevance stems from the remarkable diversity of bioactive compounds they produce, many of which serve as prototypes or scaffolds for modern pharmaceuticals (Fabricant & Farnsworth, 2001; Newman & Cragg, 2020). Approximately one-quarter of currently approved drugs are derived directly or indirectly from plant sources, underscoring their pivotal role in global drug discovery and development (Cragg & Newman, 2013). The biomedical potential of medicinal plants arises from their rich phytochemical repertoire, including alkaloids, flavonoids, terpenoids, phenolics, tannins, and glycosides, which exhibit diverse pharmacological activities such as antimicrobial, antioxidant, anti-inflammatory, anticancer, and antidiabetic effects (Ríos & Recio, 2005; Kumar *et al*., 2023). These compounds not only provide therapeutic benefits but also serve as valuable molecular templates for synthetic modification and lead optimization in pharmaceutical research (Dehelean *et al*., 2021). Recent years have witnessed renewed scientific interest in medicinal plants, driven by the rise of multidrug-resistant pathogens, the need for safer anticancer therapies, and the global demand for natural and sustainable healthcare solutions (Vaou *et al*., 2021; Chassagne *et al*., 2021). Advances in analytical chemistry, molecular biology, and bioinformatics have facilitated the identification of novel phytochemicals and elucidation of their mechanisms of action. Simultaneously, nanotechnology has opened new avenues for improving the bioavailability and targeted

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delivery of herbal compounds (Jalili *et al*., 2023; Hashim *et al*., 2024).

Despite these promising developments, several challenges hinder the full biomedical exploitation of herbal resources. Variability in phytochemical composition, lack of standardization, limited clinical validation, and regulatory complexities continue to impede the translation of laboratory findings into approved therapeutics (Fabricant & Farnsworth, 2001; Dehelean *et al*., 2021). Moreover, unsustainable harvesting practices threaten biodiversity and disrupt traditional knowledge systems (Pirintsos *et al*., 2022; Davis *et al*., 2024). Medicinal plants have been central to traditional healing systems worldwide and remain an essential starting point for modern drug discovery because of their structural diversity and bioactivity (Fabricant & Farnsworth, 2001). Classic analyses emphasize that ethnobotanical leads often accelerate identification of therapeutically relevant scaffolds and that many approved drugs trace their origins to plant-derived compounds (Newman & Cragg, 2020; Cragg & Newman, 2013).

The literature highlights the dual value of preserving traditional knowledge and applying modern screening technologies to convert ethnomedical leads into validated therapeutics (Pirintsos *et al*., 2022; Davis *et al*., 2024). Phytochemicals such as alkaloids, flavonoids, terpenoids, phenolics and glycosides are repeatedly identified as the primary bioactive constituents responsible for antimicrobial, antioxidant, anti-inflammatory and anticancer effects (Kumar *et al*., 2023; Nwozo *et al*., 2023; Ríos & Recio, 2005). Reviews summarize structure–activity relationships showing, for example, how polyphenolic scaffolds contribute to radical scavenging and how certain alkaloids interact with mammalian targets relevant to oncology (Kumar *et al*., 2023; Dehelean *et al*., 2021). Understanding these classes provides a mechanistic basis for selecting plant extracts for further isolation and pharmacological evaluation (Cragg & Newman, 2013). Systematic and experimental studies document broad-spectrum antibacterial and antifungal activities across many plant species, often linked to specific secondary metabolites (Chassagne *et al*., 2020; Chassagne *et al*., 2021; Ríos & Recio, 2005). Mechanistic work suggests membrane disruption, enzyme inhibition and interference with quorum sensing as common antibacterial actions of plant compounds (Vaou *et al*., 2021; Manandhar, 2019). The literature also stresses methodological rigor standardized extraction, MIC reporting, and controls — to make results comparable across studies (Chassagne *et al*., 2020). Plant-derived molecules have a long and productive history in oncology research, with numerous reviews documenting cytotoxic natural products, their molecular targets, and preclinical models (Dehelean *et al*., 2021; Gahtori, 2023; Hashim *et al*., 2024). Reviews emphasize mechanisms including apoptosis induction, cell-cycle arrest, inhibition of angiogenesis, and modulation of key signaling pathways e.g., PI3K/AKT, MAPK and NF-κB — by plant-derived agents (Gahtori, 2023; Chunarkar-Patil, 2024). Importantly, translational obstacles such as bioavailability, off-target toxicity, and the need for clinical validation are recurrent themes (Hashim *et al*., 2024; Davis *et al*., 2024). A large body of work connects phytochemical antioxidant capacity with anti-inflammatory and metabolic benefits relevant to chronic diseases (Nwozo *et al*., 2023; Kumar *et al*., 2023). Reviews synthesize in vitro antioxidant assays and animal-model data showing reductions in oxidative stress markers, inflammatory cytokines, and improvements in metabolic end-points (Nwozo *et al*., 2023). Nevertheless, the literature cautions that in vitro antioxidant capacity does not always translate into in vivo efficacy without proper pharmacokinetic and dose–response studies (Ríos & Recio, 2005).

Bibliometric and perspective pieces argue for systematic integration of ethnopharmacological knowledge with biodiversity and genomic approaches to prioritize leads for drug discovery (Yeung *et al*., 2018; Pirintsos *et al*., 2022; Davis *et al*., 2024). Ethnobotanical records provide crucial context to focus screening efforts on species with historical therapeutic use, while modern genomics and metabolomics help deconvolute complex extracts and map biosynthetic pathways (Pirintsos *et al*., 2022; Davis *et al*., 2024). Authors encourage ethical benefit sharing and conservation-minded sourcing to preserve genetic resources (Pirintsos *et al*., 2022). Recent reviews highlight nanotechnology as a promising strategy to overcome solubility, stability, and bioavailability issues of phytochemicals (Jalili, 2023; Sandhiya, 2020; Hashim *et al*., 2024). Nanoencapsulation, liposomes, polymeric nanoparticles and other carrier systems increase circulation time, target delivery, and therapeutic index in preclinical models (Jalili, 2023; Hashim *et al*., 2024). However, researchers also point out regulatory, scalability, and toxicity evaluation challenges prior to clinical translation (Jalili, 2023; Sandhiya, 2020).

MATERIALS AND METHODS

The search utilized combinations of controlled vocabulary and free-text keywords such as “medicinal plants,” “phytochemicals,” “biomedical applications,” “natural products,” “antimicrobial activity,” “anticancer potential,” “antioxidant,” “nanotechnology,” *and* “drug discovery.” Boolean operators (*AND*, *OR*) and truncations were employed to refine the search results.Relevant information was extracted systematically, including study objectives, plant species investigated, bioactive constituents, experimental methods, pharmacological activities, and key outcomes. Extracted data were categorized into major biomedical themes: antimicrobial**,** anticancer**,** antioxidant**,** anti-inflammatory**,** and nanotechnology-based delivery applications**.** Qualitative synthesis was performed to identify research patterns, mechanistic insights, and emerging trends across studies (Fabricant & Farnsworth, 2001; Chassagne *et al*., 2021; Dehelean *et al*., 2021).

RESULTS AND DISCUSSION

Medicinal plants possess an extraordinary diversity of bioactive phytochemicals such as alkaloids, flavonoids, terpenoids, phenolics, tannins, and glycosides, which underpin their broad therapeutic potential. These compounds exhibit pharmacological activities including antimicrobial, antioxidant, anti-inflammatory, anticancer, and antidiabetic effects (Ríos & Recio, 2005; Kumar *et al*., 2023). Kumar *et al*. (2023) highlighted that phenolic compounds and flavonoids contribute significantly to free radical scavenging and immune modulation, while alkaloids and terpenoids exhibit pronounced cytotoxic and antimicrobial properties. The presence of multiple bioactive components allows synergistic effects, improving therapeutic outcomes and reducing side effects compared to synthetic drugs (Fabricant & Farnsworth, 2001). The antimicrobial activity of medicinal plants has been widely studied as an alternative to synthetic antibiotics, especially against multidrug-resistant pathogens**.** Chassagne *et al*. (2021) conducted a systematic review identifying plant species with potent antibacterial activity, attributing their efficacy to mechanisms such as cell wall disruption, enzyme inhibition**,** and interference with microbial signaling systems. Vaou *et al*. (2021) emphasized that essential oils, phenolic acids, and flavonoids disrupt bacterial membranes and biofilm formation, enhancing susceptibility to conventional antibiotics. Similarly, Manandhar (2019) demonstrated the inhibitory effects of ethanol and methanol plant extracts on both Gram-positive and Gram-negative bacteria. The synergy between plant-derived compounds and antibiotics represents a promising avenue to overcome resistance, though standardization of extraction and testing remains essential (Chassagne *et al*., 2020; Owusu *et al*., 2021).

Plant-derived compounds have played a critical role in anticancer drug discovery, contributing agents like paclitaxel, vincristine, and camptothecin (Newman & Cragg, 2020). Recent reviews by Dehelean *et al*. (2021) and Hashim *et al*. (2024) report that phytochemicals can modulate multiple cancer-associated pathways, including cell cycle arrest, apoptosis induction, anti-angiogenesis, and inhibition of metastasis**.** Gahtori (2023) described that compounds such as curcumin, resveratrol, and quercetin act via ROS-mediated apoptosis and suppression of oncogenic signaling pathways. Chunarkar-Patil (2024) emphasized the role of computational and structure-based drug design in identifying novel anticancer leads from natural products. However, challenges such as low bioavailability, poor solubility, and limited clinical data persist. Incorporating nanotechnology-based delivery systems is emerging as a key solution to these limitations (Jalili, 2023; Hashim *et al*., 2024). Oxidative stress and chronic inflammation are underlying mechanisms in numerous diseases, including diabetes, neurodegeneration, and cardiovascular disorders. Medicinal plants rich in phenolic and flavonoid compounds act as natural antioxidants, neutralizing reactive oxygen species and preventing cellular damage (Nwozo *et al*., 2023). Studies have demonstrated that extracts from green tea, turmeric, garlic, and Allium species significantly reduce oxidative biomarkers and inflammatory cytokines (Kumar *et al*., 2023; Ríos & Recio, 2005). Nwozo *et al*. (2023) noted that polyphenols modulate key signaling pathways such as NF-κB and MAPK, contributing to anti-inflammatory effects. Despite promising in vitro outcomes, further in vivo and clinical validations are necessary to confirm therapeutic efficacy and optimal dosage.

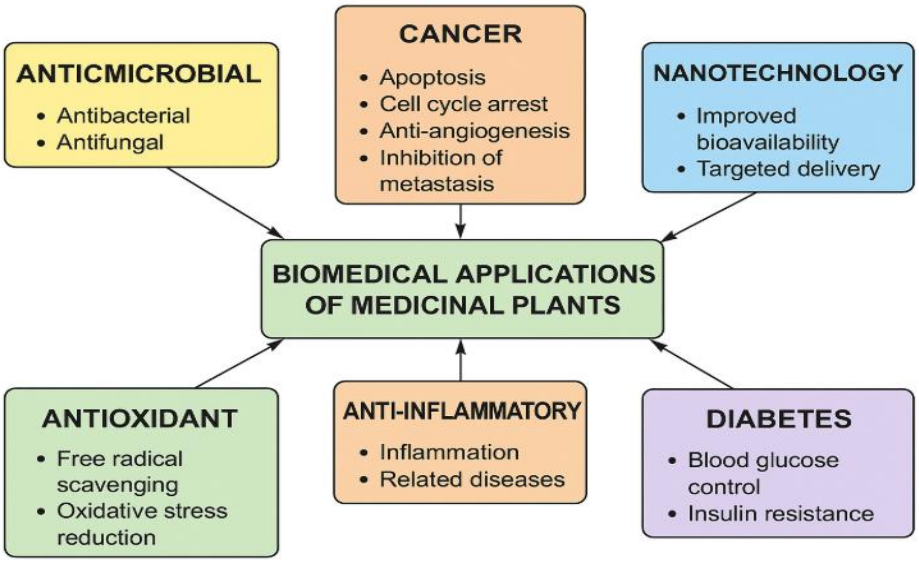

Figure 1. Overview of applications of medicinal plants.

CONCLUSION

Medicinal plants continue to represent an invaluable reservoir of bioactive compounds with diverse and potent biomedical applications**.** Their phytochemical constituents such as flavonoids, terpenoids, alkaloids, and phenolics exhibit significant antimicrobial, antioxidant, anticancer, and anti-inflammatory activities, offering a safer and more sustainable alternative to synthetic pharmaceuticals. The integration of traditional herbal knowledge with advanced biotechnological and pharmacological research has strengthened the foundation for natural product–based drug discovery. Moreover, studies demonstrate that the synergistic action of multiple plant-derived compounds enhances therapeutic efficacy and minimizes adverse reactions. The incorporation of nanotechnology and computational drug design has further improved the bioavailability, targeting, and clinical potential of phytochemicals. However, despite these promising findings, major challenges persist, including a lack of standardization, insufficient clinical validation**,** and limited toxicological data**.** Addressing these gaps through evidence-based approaches will be crucial for the transition of herbal formulations from traditional use to mainstream biomedicine. Future research should focus on a multidisciplinary approach combining ethnopharmacology, genomics, metabolomics, and nanotechnology to explore novel phytochemicals and mechanisms of action. Establishing standardized extraction and formulation protocols, along with comprehensive pharmacokinetic and toxicity studies**,** will be vital for ensuring consistency, efficacy, and safety in therapeutic applications. Furthermore, clinical trials and regulatory harmonization must be expanded to validate traditional claims under modern biomedical frameworks. Conservation of medicinal plant biodiversity and sustainable harvesting practices are equally essential to preserve these valuable natural resources for future generations. By bridging the gap between traditional herbal wisdom and modern scientific validation, medicinal plants can play a pivotal role in developing innovative, affordable, and eco-friendly healthcare solutions that address emerging global health challenges.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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