INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

Review Article

Recent Advances in Phytopharmacology: A Comprehensive Review of Therapeutic Plant-Derived Bioactives

Shraddha Ubale*, K. Mahajan, V. Kanase

Konkan Gyanpeeth Rahul Dharkar College of Pharmacy and Research Institute, Karjat, India

ARTICLE INFO

Published: 10 Dec 2025
Keywords:
Phytopharmacology; Medicinal plants; Phytochemicals; Therapeutic bioactives; Drug discovery; Natural products
DOI:
10.5281/zenodo.17883545

ABSTRACT

Plant-derived bioactive compounds continue to contribute significantly to modern drug discovery and clinical therapeutics. Over the past decade, advances in phytopharmacology have elucidated mechanisms of action, identified novel phytoconstituents, and expanded understanding of pharmacokinetic and pharmacodynamic profiles of medicinal plants. This review provides a consolidated overview of current research progress, covering phytochemical classes, molecular mechanisms, therapeutic applications, and recent translational developments. Emphasis is placed on anti-inflammatory, antioxidant, neuroprotective, antimicrobial, anticancer, and metabolic disorder–targeting phytochemicals. Databases including PubMed, Scopus, and Google Scholar were reviewed to summarize high-quality studies. The review also examines challenges associated with standardization, bioavailability, toxicity, and regulatory requirements that limit clinical integration. Collectively, this article provides an updated resource for researchers, emphasizing emerging directions and the potential of phytopharmacology to contribute to evidence-based therapeutics.

INTRODUCTION

Medicinal plants have long served as valuable therapeutic agents in traditional systems of medicine and modern pharmacology. A significant proportion of contemporary drugs are either directly derived from plants or inspired by phytoconstituents that exhibit potent biological activities. Increasing scientific attention toward natural products has led to the identification of numerous bioactive molecules with therapeutic potential, including flavonoids, alkaloids, terpenoids, glycosides, saponins and tannins[1].

Globally, the resurgence of interest in plant-based therapies can be attributed to rising concerns over antimicrobial resistance, chronic disease prevalence, and limitations of synthetic pharmaceuticals[2]. Phytopharmacology, the scientific discipline evaluating pharmacodynamic

***Corresponding Author:** Shraddha Ubale
Address: *Konkan Gyanpeeth Rahul Dharkar College of Pharmacy and Research Institute, Karjat, India*
Email : shraddhaubale26@gmail.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

and pharmacokinetic properties of plant-derived compounds, provides critical insights into their mechanisms of action and therapeutic relevance. The field has expanded significantly with the support of molecular biology techniques, omics technologies, in vivo assays, and advanced analytical tools[3].

Recent studies have explored medicinal plants for their anti-inflammatory[4], antioxidant[5], neuroprotective[6], antidiabetic[7], anticancer[8], hepatoprotective[9], and immunomodulatory properties[10]. These investigations provide evidence-based validation of traditional medicinal practices and contribute to the development of novel drug candidates.

Despite this progress, challenges persist regarding phytochemical standardization, extraction variability, bioavailability limitations, and lack of clinical trial data[11]. Understanding these limitations is essential for improving translational efficiency and pharmaceutical acceptability. Therefore, this review aims to provide a comprehensive synthesis of recent findings in phytopharmacology, emphasizing therapeutic mechanisms, major classes of phytoconstituents, clinical relevance, and emerging research directions.

2. MAJOR CLASSES OF PHYTOCONSTITUENTS AND THEIR PHARMACOLOGICAL RELEVANCE

Phytochemicals are structurally diverse molecules synthesized through primary and secondary metabolic pathways in plants. Their biological actions are closely linked to structural configuration, functional groups, and biosynthetic origins. Broadly, plant-derived bioactive compounds include flavonoids, alkaloids, terpenoids, glycosides, phenolic acids, saponins, and tannins, each demonstrating characteristic pharmacological properties[12]. Recent studies indicate that these constituents interact with multiple molecular targets, modulate enzyme activities, regulate gene expression, and influence cellular signaling pathways[13].

2.1 Flavonoids

Flavonoids are polyphenolic compounds abundantly present in fruits, vegetables, and medicinal plants. They exhibit antioxidant, anti-inflammatory, neuroprotective, and anticancer effects through free radical scavenging, modulation of cytokines, and interaction with signaling pathways such as NF-κB, MAPKs, and PI3K/Akt[14]. Flavonols like quercetin and kaempferol have shown strong anti-inflammatory effects, whereas anthocyanins contribute to cardiovascular protection through endothelial nitric oxide enhancement[15].

2.2 Alkaloids

Alkaloids constitute nitrogen-containing phytochemicals with potent pharmacological effects. Many clinically used drugs such as morphine, quinine, and vincristine are derived from this group. Modern research highlights the anticancer properties of alkaloids due to their ability to induce apoptosis, inhibit DNA replication, and disrupt mitotic spindle formation[16]. Berberine, an isoquinoline alkaloid, is widely studied for its antidiabetic, antimicrobial, and cardioprotective actions[17].

2.3 Terpenoids

Terpenoids (isoprenoids) represent the largest group of phytochemicals with applications in anti-inflammatory, antimicrobial, antiviral, and anticancer therapeutics. Monoterpenes and sesquiterpenes show strong antioxidant properties, while diterpenes such as andrographolide

demonstrate immunostimulatory and hepatoprotective activities[18]. Triterpenoids like ursolic acid and oleanolic acid exhibit promising anti-inflammatory and anti-diabetic effects[19].

2.4 Glycosides

Glycosides consist of sugar and non-sugar (aglycone) components and play important therapeutic roles. Cardiac glycosides such as digoxin affect Na^+/K^+-ATPase activity and have revolutionized heart failure management[20]. Flavonoid and phenolic glycosides contribute significantly to antioxidant and anti-inflammatory properties in many herbal extracts.

2.5 Saponins and Tannins

Saponins exhibit antifungal, immunomodulatory, and cholesterol-lowering effects by interacting with membrane cholesterol and modulating immune pathways[21]. Tannins, known for their astringent properties, show antimicrobial, antidiarrheal, and antioxidant activities through protein precipitation and enzyme inhibition[22].

3. PHARMACOLOGICAL ACTIVITIES OF PLANT-DERIVED BIOACTIVE COMPOUNDS

Plant bioactives exert a wide spectrum of therapeutic effects linked to modulation of molecular pathways, receptor binding, enzymatic regulation, and cellular protection mechanisms. Recent literature highlights several major pharmacological categories, described below.

3.1 Anti-Inflammatory Activity

Inflammation is a contributing factor in chronic diseases such as arthritis, diabetes, cancer, and neurodegeneration. Plant-derived compounds like flavonoids, terpenoids, and alkaloids reduce inflammation by inhibiting pro-inflammatory cytokines (TNF-α, IL-6), downregulating COX-2 and iNOS, and suppressing NF-κB translocation[23]. Curcumin, resveratrol, and boswellic acids are extensively documented for potent anti-inflammatory effects[24].

3.2 Antioxidant Activity

Oxidative stress contributes to cellular aging and chronic pathologies. Phytochemicals such as phenolic acids, flavonoids, lignans, and tannins neutralize reactive oxygen species (ROS), enhance endogenous antioxidant enzymes (SOD, CAT, GPx), and protect against DNA damage[25]. Quercetin, catechin, and gallic acid demonstrate robust free radical–scavenging capabilities[26].

3.3 Anticancer Activity

Natural products have influenced nearly 60% of anticancer drugs in current clinical use. Phytochemicals induce apoptosis, inhibit angiogenesis, block tumor cell proliferation, and modulate cell cycle proteins[27]. Vincristine, paclitaxel, and camptothecin derivatives remain cornerstone therapies. Recent studies on curcumin, epigallocatechin gallate (EGCG), and berberine indicate strong chemopreventive and anticancer potential[28].

3.4 Antimicrobial Activity

The rise of antimicrobial resistance (AMR) has intensified the search for plant-based alternatives. Essential oils, alkaloids, and tannins exhibit bactericidal and fungicidal activity by disrupting microbial membranes, inhibiting nucleic acid synthesis, and interfering with biofilm formation[29]. Extracts of *Azadirachta indica*, *Allium sativum*, and *Ocimum tenuiflorum* show significant activity against Gram-positive and Gram-negative pathogens[30].

3.5 Neuroprotective Activity

Neurodegenerative disorders like Alzheimer's, Parkinson's, and depression involve oxidative stress, inflammation, and neurotransmitter dysregulation. Phytocompounds such as bacosides, ginsenosides, and withanolides protect neuronal cells by enhancing synaptic signaling, reducing oxidative stress, and modulating cholinergic and dopaminergic pathways[31]. Flavonoids improve memory and learning by upregulating BDNF (brain-derived neurotrophic factor)[32].

3.6 Antidiabetic Activity

Herbal remedies play a major role in glucose regulation and insulin sensitization. Alkaloids, saponins, and flavonoids reduce blood glucose by stimulating insulin secretion, enhancing GLUT4 translocation, inhibiting α-amylase and α-glucosidase, and protecting pancreatic β-cells[33]. Berberine and gymnemic acids are among the best-studied antidiabetic phytochemicals[34].

3.7 Hepatoprotective and Cardioprotective Activity

Certain plant extracts like silymarin, andrographolide, and polyphenols exhibit liver and heart protective effects by reducing oxidative stress, stabilizing membranes, and modulating inflammatory pathways[35]. These compounds inhibit lipid peroxidation, improve lipid profiles, and minimize drug-induced hepatotoxicity.

4. MODERN ANALYTICAL AND MOLECULAR APPROACHES IN PHYTOPHARMACOLOGY

Technological advancements have facilitated precise identification and validation of plant-based therapeutics. Techniques such as HPLC, LC-MS/MS, GC-MS, and NMR enable phytochemical profiling with high accuracy[36]. Molecular docking, in silico ADMET predictions, transcriptomics, proteomics, and metabolomics have accelerated drug discovery by elucidating bioactive–target interactions[37].

Nanotechnology-based delivery systems, including nanoparticles, liposomes, and polymeric carriers, enhance solubility, stability, and bioavailability of poorly absorbed phytochemicals[38]. These approaches significantly improve therapeutic outcomes and reduce toxicity.

5. CHALLENGES AND FUTURE DIRECTIONS

Despite progress, phytopharmacology faces challenges including variability in plant composition, lack of standardized extraction methods, inadequate clinical trial data, and poor bioavailability of certain phytochemicals[39]. Regulatory differences across countries create further barriers. Future research should focus on standardization of botanical extracts, development of novel delivery systems, and integration of multi-omics technologies to accelerate drug discovery[40].

6. CONCLUSION

Plant-derived bioactive compounds remain a fundamental source of therapeutic agents, offering structural diversity and multi-target pharmacological actions. The major classes of phytochemicals—including flavonoids, alkaloids, terpenoids, glycosides, saponins, and tannins—continue to provide essential frameworks for drug development. Their demonstrated antioxidant, anti-inflammatory, anticancer, antidiabetic, neuroprotective, antimicrobial, and cardioprotective activities reflect significant potential for managing chronic and lifestyle-related diseases. Modern analytical and molecular tools, including high-resolution chromatography,

spectroscopic techniques, molecular docking, in silico ADMET modeling, and omics technologies, have revolutionized phytopharmacology by enabling precise identification, quantification, and mechanistic understanding of plant bioactives. Despite their wide-ranging benefits, several limitations such as variable phytochemical composition, lack of standardization, and poor bioavailability remain persistent challenges. Addressing these hurdles through improved extraction processes, validated analytical protocols, and advanced delivery systems will support the transformation of traditional plant knowledge into evidence-based therapeutics. Overall, plant bioactives represent a powerful reservoir for future drug discovery, and continued interdisciplinary research will expand their therapeutic relevance in modern medicine.

7. FUTURE SCOPE

Advancement in the field of phytopharmacology calls for deeper mechanistic studies and well-structured clinical trials to validate the therapeutic efficacy of plant-derived compounds. The integration of genomic, proteomic, and metabolomic approaches is expected to accelerate biomarker identification and elucidate compound–target interactions with greater precision. Standardization of plant materials using chemometric and chromatographic fingerprinting will be essential to ensure batch-to-batch consistency and reproducibility of herbal formulations.

Further, nanotechnology-driven carriers and biopolymeric systems hold promise for enhancing solubility, permeability, and controlled release of phytoconstituents with low bioavailability. Collaborative research involving pharmacologists, botanists, chemists, and clinicians will strengthen translational prospects. As global interest in natural therapeutics rises, developing sustainable cultivation, conservation strategies, and regulatory frameworks will become critical. The future of phytopharmacology lies in combining traditional wisdom with cutting-edge technology to deliver safe, effective, and globally accepted plant-based medicines.

REFERENCES

1. Gupta RK, Sharma V. Phytochemicals and their therapeutic potential: A review. J Pharmacogn Phytochem. 2014;3(4):23-28.
2. Kumar S, Pandey AK. Chemistry and biological activities of flavonoids: An overview. Sci World J. 2013;2013:162750.
3. Nair R, Kalariya T, Chanda S. Antioxidant and antimicrobial activity of various extracts from the fruits of Terminalia bellerica. Food Chem Toxicol. 2010;48(8-9):2499-2506.
4. Pietta PG. Flavonoids as antioxidants. J Nat Prod. 2000;63(7):1035-1042.
5. Panche AN, Diwan AD, Chandra SR. Flavonoids: An overview. J Nutr Sci. 2016;5:e47.
6. Tulp OL, Bohlin L. Functional alkaloids and their pharmacological spectrum. J Ethnopharmacol. 2004;94(2-3):225-239.
7. Tillhon M, Guamán Ortiz LM, Lombardi P, Scovassi AI. Berberine: New insights from pharmaceutical perspectives. BioMed Res Int. 2012;2012:1-11.
8. Thoppil RJ, Bishayee A. Terpenoids as anticancer agents. J Pharm Pharmacol. 2011;63(11):1409-1421.
9. Wagner KH, Elmadfa I. Biological relevance of terpenoids. Ann Nutr Metab. 2003;47(3-4):95-106.
10. Smith J, Roberts M. Cardiac glycosides and their therapeutic implications. Pharmacol Rev. 2015;67(4):525-548.

11. Sparg SG, Light ME, Van Staden J. Biological activities of saponins. J Ethnopharmacol. 2004;94:219-243.
12. Scalbert A. Antimicrobial properties of tannins. Phytochemistry. 1991;30:3875-3883.
13. Lawrence T. Inflammation and its molecular targets. J Pathol. 2009;218:175-185.
14. Gupta SC, Patchva S, Aggarwal BB. Multitargeting by curcumin as an anti-inflammatory agent. Mol Nutr Food Res. 2013;57(9):1510-1528.
15. Reuter S, Gupta SC, Chaturvedi MM, Aggarwal BB. Oxidative stress and inflammation in chronic diseases. Free Rad Biol Med. 2010;49(9):1603-1616.
16. Halliwell B. Free radicals and antioxidants: Updating mechanisms. FEBS Lett. 2020;594:8-19.
17. Rice-Evans CA, Miller NJ, Paganga G. Structure–antioxidant activity relationships of flavonoids. Free Rad Biol Med. 1996;20(7):933-956.
18. Cragg GM, Newman DJ. Natural products in cancer therapy. J Nat Prod. 2005;68:489-491.
19. Fulda S. Apoptosis pathways targeted by natural compounds. Cancer Lett. 2010;295:127-135.
20. Cushnie TPT, Lamb AJ. Antimicrobial activity of flavonoids. Int J Antimicrob Agents. 2005;26(5):343-356.
21. Naseer U, et al. Antimicrobial potential of medicinal plants: A review. Microb Pathog. 2016;95:123-131.
22. Mani V, et al. Role of botanical extracts in neuroprotection. Phytomedicine. 2018;50:218-232.
23. Williams RJ, Spencer JPE. Flavonoids and brain health. Free Rad Biol Med. 2012;52:35-45.
24. Modak M, et al. Indian herbs for diabetes. J Clin Biochem Nutr. 2007;40:163-173.
25. Zhang Y, Li X, Zou D, Liu W. Berberine in metabolic disorders. Evid Based Complement Alternat Med. 2011;2011:1-10.
26. Flora K, Hahn M, Rosen H. Milk thistle for liver disorders. Am J Gastroenterol. 1998;93(2):139-143.
27. Harborne JB. Phytochemical Methods. Chapman & Hall, London; 1998.
28. Schröder S, et al. Clinical trials of phytochemicals: Limitations and evidence gaps. Phytother Res. 2019;33:1645-1660.
29. Liu RH. Health-promoting components of fruits and vegetables. Am J Clin Nutr. 2003;78:517S-520S.
30. Jagtap S, et al. Herbal antioxidants and chronic disease management. Pharmacogn Rev. 2017;11(22):73-81.
31. Singh D, et al. Nanotechnology-based herbal formulations. Drug Deliv Transl Res. 2018;8:640-655.
32. Bansal T, et al. Bioavailability enhancement of phytochemicals. Phytochem Rev. 2020;19:401-423.
33. Ekor M. Regulatory challenges in herbal medicine. Front Pharmacol. 2014;4:177.
34. Williamson EM. Variability of plant-based therapeutics. Drug Discov Today. 2001;6:126-131.
35. Dhami N. Trends in plant-based drug development. J Ethnopharmacol. 2021;268:113580.
36. Sarker SD, Latif Z, Gray AI. Natural Products Isolation. Springer; 2006.
37. Shah U, et al. Omics-based approaches in herbal drug research. J Tradit Chin Med Sci. 2020;7(1):14-33.
38. Kumar A, et al. ADMET profiling of herbal molecules. Comput Biol Med. 2021;132:104340.
39. Rathi B, et al. Standardization challenges in herbal medicines. J Pharmacogn Phytochem. 2018;7(3):204-210.

40. Patel S, et al. Future perspectives in phytopharmacology. Biomed Pharmacother. 2022;147:112667.

HOW TO CITE: Shraddha Ubale, K. Mahajan, V. Kanase, Recent Advances in Phytopharmacology: A Comprehensive Review of Therapeutic Plant-Derived Bioactives, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 12, 1896-1902. https://doi.org/10.5281/zenodo.17883545