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Plant-derived antimicrobial agents in the prevention and management of infectious diseases: a comprehensive review

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Abstract

Infectious diseases remain among the leading causes of morbidity and mortality worldwide despite remarkable advances in modern medicine. The emergence of antimicrobial resistance, the re-emergence of previously controlled pathogens, and the appearance of novel infectious agents have intensified the need for alternative therapeutic approaches. Medicinal plants have historically served as valuable sources of antimicrobial compounds and continue to contribute significantly to contemporary drug discovery. Numerous plant-derived metabolites exhibit antibacterial, antiviral, antifungal, antiparasitic, and immunomodulatory activities that may support the prevention and treatment of infectious diseases. This review examines the role of plant-based antimicrobial agents in infectious disease management, emphasizing their pharmacological properties, mechanisms of action, and therapeutic potential. A comprehensive literature search was conducted using peer-reviewed articles indexed in PubMed, Scopus, Web of Science, and Google Scholar. Relevant studies focusing on medicinal plants with documented antimicrobial activity were evaluated and synthesized. Particular attention was given to garlic (*Allium sativum*), tea tree (*Melaleuca alternifolia*), lemon balm (*Melissa officinalis*), Pelargonium species, cranberry (*Vaccinium macrocarpon*), *Artemisia annua*, and other botanicals with demonstrated clinical or experimental efficacy. The reviewed evidence indicates that plant-derived compounds exert antimicrobial effects through multiple mechanisms, including disruption of microbial cell membranes, inhibition of pathogen replication, modulation of host immune responses, and suppression of microbial virulence factors. Several phytochemicals also demonstrate synergistic interactions with conventional antimicrobial agents, suggesting potential applications in combating antimicrobial resistance. However, variability in phytochemical composition, limited clinical trials, and concerns regarding standardization remain important challenges. In conclusion, medicinal plants represent a promising resource for the development of novel antimicrobial therapies and complementary treatment strategies. Continued research focusing on efficacy, safety, pharmacokinetics, and clinical validation is essential to facilitate the integration of plant-derived therapeutics into evidence-based infectious disease management and global public health practice.

Key words: infectious diseases, research activities, publications, healthcare-associated infections, infection prevention and control.

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Introduction

Infectious diseases continue to represent a major challenge to global public health, accounting for substantial morbidity, mortality, and economic burden worldwide. Despite remarkable advances in medical science, infectious pathogens remain responsible for millions of deaths annually, particularly in low- and middle-income countries where healthcare resources are often limited.[1] The increasing prevalence of emerging and re-emerging infectious diseases, including viral outbreaks, multidrug-resistant bacterial infections, and parasitic diseases, has heightened concerns regarding the effectiveness of existing therapeutic strategies.[2,3]

Microorganisms such as bacteria, viruses, fungi, and parasites possess remarkable adaptive capabilities that enable them to survive under diverse environmental conditions and evade host defense mechanisms.[4] The rapid evolution of Antimicrobial Resistance (AMR) has further complicated disease management and has been recognized as one of the most serious threats to global health in the 21st century.[5,6] Resistant pathogens reduce treatment effectiveness, prolong hospital stays, increase healthcare expenditures, and contribute significantly to mortality rates worldwide.[7]

Historically, medicinal plants have played a fundamental role in the treatment and prevention of infectious diseases. Long before the development of modern pharmaceuticals, traditional healthcare systems relied extensively on botanical preparations to manage microbial infections and promote healing.[8,9] Numerous plant species contain bioactive compounds with antimicrobial, antiviral, antifungal, antiparasitic, anti-inflammatory, and immunomodulatory properties that contribute to their therapeutic value.[10,11] These natural products continue to attract scientific interest because they represent a rich source of structurally diverse molecules with potential applications in drug discovery and development.[12]

Plants synthesize a wide range of secondary metabolites, including alkaloids, flavonoids, terpenoids, tannins, phenolic

acids, coumarins, and essential oils, many of which demonstrate significant antimicrobial activity.[13,14] These compounds serve as natural defense mechanisms against microbial pathogens, insects, and environmental stressors.[15] Research has demonstrated that phytochemicals can inhibit microbial growth through various mechanisms, including disruption of cell membranes, inhibition of nucleic acid synthesis, interference with metabolic pathways, and modulation of virulence factors.[16,17]

Among the most extensively studied medicinal plants are garlic (*Allium sativum*), tea tree (*Melaleuca alternifolia*), lemon balm (*Melissa officinalis*), cranberry (*Vaccinium macrocarpon*), Pelargonium species, and *Artemisia annua*.[18-20] These plants have shown promising activity against a broad spectrum of pathogenic microorganisms and have been investigated in both experimental and clinical settings.[21] Several plant-derived compounds have also demonstrated synergistic effects when combined with conventional antimicrobial agents, offering potential strategies for overcoming antimicrobial resistance.[22]

The growing demand for alternative and complementary therapeutic approaches has stimulated renewed interest in ethnopharmacology and natural product research.[23] Advances in phytochemistry, molecular biology, and pharmacology have enabled researchers to identify, isolate, and characterize numerous plant-derived compounds with therapeutic potential.[24] Furthermore, increasing awareness of the limitations associated with synthetic antimicrobial agents has encouraged the exploration of botanical resources as sustainable and cost-effective treatment options.[25]

This review aims to provide a comprehensive overview of plant-derived antimicrobial agents and their role in the prevention and management of infectious diseases. The review discusses major medicinal plants with documented antimicrobial activity, their bioactive constituents, mechanisms of action, therapeutic applications, and potential contributions to addressing contemporary challenges such as antimicrobial resistance and emerging infectious diseases.

Literature review

Medicinal plants and infectious disease management

Medicinal plants have been used for centuries as therapeutic agents for the prevention and treatment of infectious diseases. Traditional healthcare systems in Asia, Africa, Europe, and the Americas have relied heavily on plant-based remedies to combat microbial infections. The World Health Organization (WHO) estimates that a substantial proportion of the global population continues to depend on herbal medicine as a primary source of healthcare. Scientific investigations have increasingly validated many traditional claims by identifying bioactive phytochemicals with significant antimicrobial properties.

Natural products derived from plants provide a diverse reservoir of biologically active compounds. Unlike many synthetic drugs that target a single microbial pathway, plant-derived compounds often exhibit multiple mechanisms of action, reducing the likelihood of resistance development. This characteristic has attracted considerable attention in the search for novel antimicrobial agents.

Garlic (Allium sativum)

Garlic is among the most extensively studied medicinal plants for antimicrobial activity. The therapeutic properties of garlic are primarily attributed to sulfur-containing compounds such as allicin, ajoene, diallyl sulfide, and diallyl disulfide. These compounds exhibit broad-spectrum activity against Gram-positive and Gram-negative bacteria, fungi, viruses, and parasites.Research has demonstrated that allicin disrupts bacterial cell membranes, inhibits essential enzymes, and interferes with microbial metabolism. Studies have shown inhibitory activity against *Staphylococcus aureus, Escherichia coli, Helicobacter pylori*, Salmonella species, and *Candida albicans*. In addition to antimicrobial effects, garlic possesses antioxidant, anti-inflammatory, and immunomodulatory properties that may contribute to improved host defense mechanisms.

Several clinical investigations suggest that garlic supplementation may reduce the incidence and severity of upper respiratory tract infections. Furthermore, garlic-derived compounds have demonstrated activity against antibiotic-resistant bacterial strains, highlighting their potential role in addressing antimicrobial resistance.

Tea Tree (Melaleuca alternifolia)

Tea tree oil is obtained through steam distillation of the leaves of *Melaleuca alternifolia*. The essential oil contains more than one hundred compounds, with terpinen-4-ol recognized as the principal antimicrobial constituent. Additional active components include α-terpineol, γ-terpinene, and 1,8-cineole.

Numerous *in vitro* studies have confirmed the effectiveness of tea tree oil against bacterial, fungal, and viral pathogens. It demonstrates potent activity against Methicillin-Resistant *Staphylococcus aureus* (MRSA), Streptococcus species, Candida species, and dermatophytes. The mechanism of action involves disruption of microbial cell membranes, increased membrane permeability, and leakage of intracellular components.

Clinical applications of tea tree oil include the treatment of acne, fungal skin infections, oral candidiasis, wound infections, and certain respiratory conditions. Its broad-spectrum antimicrobial activity and a relatively favorable safety profile have contributed to its widespread use in complementary medicine.

Lemon Balm (Melissa officinalis)

Melissa officinalis, commonly known as lemon balm, has traditionally been employed for its calming, antiviral, and antimicrobial properties. The plant contains essential oils, flavonoids, rosmarinic acid, caffeic acid derivatives, and various phenolic compounds that contribute to its biological activities.

Research indicates that lemon balm extracts possess antiviral activity against Herpes simplex virus types 1 and 2. Topical formulations have demonstrated effectiveness in reducing lesion severity and accelerating healing. Antibacterial effects have also been reported against several pathogenic bacteria, including *Staphylococcus aureus* and *Bacillus species.*

In addition to direct antimicrobial activity, lemon balm exhibits antioxidant and anti-inflammatory effects that may enhance tissue recovery during infection. Its favorable tolerability profile makes it an attractive candidate for further clinical development.

Pelargonium species

Pelargonium sidoides and *Pelargonium reniforme* are medicinal plants native to South Africa and have traditionally been used to manage respiratory tract infections. Extracts from these species contain coumarins, flavonoids, tannins, and phenolic compounds that contribute to their therapeutic properties.

Experimental studies have demonstrated antimicrobial activity against various respiratory pathogens. Pelargonium extracts appear to inhibit microbial adhesion to mucosal surfaces, stimulate

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immune responses, and reduce inflammation. Clinical trials have reported beneficial effects in acute bronchitis, sinusitis, common cold symptoms, and other upper respiratory tract infections.

The standardized extract EPs 7630 has gained considerable attention because of its documented efficacy and safety profile. Its multiple mechanisms of action suggest potential utility as an adjunctive therapy in infectious disease management.

Cranberry (Vaccinium macrocarpon)

Cranberry products have been widely investigated for their role in preventing Urinary Tract Infections (UTIs). The therapeutic effects are primarily attributed to proanthocyanidins, which inhibit the adhesion of uropathogenic *Escherichia coli* to epithelial cells lining the urinary tract.

Unlike conventional antibiotics, cranberry products do not directly kill bacteria. Instead, they interfere with bacterial colonization and reduce the likelihood of infection establishment. Several clinical studies have suggested that cranberry consumption may decrease the frequency of recurrent UTIs, particularly among women with a history of recurrent infection.

The growing concern regarding antibiotic resistance has renewed interest in cranberry-based preventive strategies as a non-antibiotic approach to infection control.

Artemisia annua and antiparasitic therapy

Artemisia annua represents one of the most significant examples of successful plant-derived drug development. The plant produces artemisinin, a sesquiterpene lactone that has revolutionized malaria treatment worldwide.

Artemisinin and its derivatives, including artesunate and artemether, exhibit rapid antimalarial activity against Plasmodium species. These compounds generate reactive oxygen species within parasite cells, resulting in extensive cellular damage and parasite death.

The discovery of artemisinin has stimulated interest in exploring additional medicinal plants for novel antimicrobial compounds. Beyond antimalarial activity, Artemisia species possess anti-inflammatory, antiviral, and immunomodulatory properties that warrant further investigation.

Plant-derived compounds and antimicrobial resistance

The emergence of antimicrobial resistance represents a global public health emergency. Many bacterial pathogens have developed resistance to commonly prescribed antibiotics, creating an urgent need for alternative therapeutic options.

Plant-derived compounds offer several advantages in combating antimicrobial resistance. Their structural diversity, multiple molecular targets, and synergistic interactions with conventional antibiotics may reduce resistance development. Numerous flavonoids, alkaloids, terpenoids, and essential oils have demonstrated the ability to enhance antibiotic effectiveness against resistant microorganisms.

Recent studies indicate that certain phytochemicals inhibit bacterial efflux pumps, disrupt biofilm formation, and interfere with quorum-sensing mechanisms. These activities may restore susceptibility to existing antibiotics and improve treatment outcomes.

Current challenges and future perspectives

Despite encouraging findings, several challenges limit the widespread clinical adoption of plant-derived antimicrobial agents. Variability in phytochemical composition, lack of standardization, limited pharmacokinetic data, and insufficient large-scale clinical trials remain significant barriers.

Future research should prioritize standardized extraction methods, rigorous clinical evaluation, toxicity assessment, and mechanistic investigations. Advances in biotechnology, metabolomics, and molecular pharmacology may facilitate the identification of novel plant-derived antimicrobial compounds with improved efficacy and safety profiles.

The integration of traditional knowledge with modern scientific approaches offers a promising pathway for discovering innovative therapies capable of addressing current and future infectious disease challenges.

Research methodology

Study design

This study was conducted as a comprehensive narrative review of published literature examining the role of plant-derived antimicrobial agents in the prevention and management of infectious diseases. The review synthesized evidence from experimental studies, clinical investigations, systematic reviews, and public health reports to evaluate the antimicrobial potential of medicinal plants and their bioactive constituents.

Literature search strategy

A systematic literature search was performed using major scientific databases, including PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and the Cochrane Library. Publications published in English between 2000 and 2025 were considered. Additional relevant references were identified through manual searches of the bibliographies of selected articles.

The following keywords and Boolean operators were used: «infectious diseases» AND «medicinal plants», «plant-derived antimicrobials», «phytochemicals» AND «antibacterial activity», «herbal medicine» AND «infectious disease treatment», «antimicrobial resistance» AND «natural products», «essential oils» AND «pathogenic microorganisms», «traditional medicine» AND «infectious diseases».

Inclusion criteria

Studies were included if they: i) evaluated medicinal plants or plant-derived compounds with antimicrobial activity; ii) investigated antibacterial, antiviral, antifungal, or antiparasitic effects; iii) reported experimental, clinical, or epidemiological evidence; iv) were published in peer-reviewed journals; v) provided sufficient methodological details and outcome measures.

Exclusion criteria

Studies were excluded if they: i) were duplicate publications; ii) lacked adequate methodological information; iii) were non-peer-reviewed reports; iv) focused exclusively on synthetic antimicrobial agents; v) were published in languages other than English without a reliable translation.

Data extraction

Information extracted from eligible studies included: author and publication year, study design, plant species investigated, bioactive constituents identified, target microorganisms, mechanism of antimicrobial action, clinical or laboratory outcomes, safety and toxicity findings.

Quality assessment

The quality of the selected studies was evaluated based on

methodological rigor, sample size, reproducibility, clarity of outcome reporting, and relevance to infectious disease management. Studies with robust experimental designs and validated methodologies were given greater emphasis during evidence synthesis.

Ethical considerations

As this investigation was based exclusively on previously published literature and publicly available data, ethical approval and informed consent were not required. The review was conducted according to accepted principles of academic integrity, transparency, and responsible reporting.

Statistical analysis

Descriptive statistical methods were used to summarize findings reported in the selected literature. Frequencies and percentages were calculated to categorize studies according to pathogen type, plant species investigated, and reported antimicrobial activities.

Comparative analyses from published clinical studies were reviewed to assess the effectiveness of plant-derived interventions relative to conventional therapies. Reported statistical indicators, including Odds Ratios (OR), Relative Risks (RR), Confidence Intervals (CI), p-values, and effect sizes, were examined when available.

Data synthesis focused on identifying common patterns across studies, including: the spectrum of antimicrobial activity, the frequency of effectiveness against resistant pathogens, clinical outcomes associated with herbal interventions, and safety and adverse event profiles.

Where quantitative pooling was not feasible because of methodological heterogeneity, a narrative synthesis approach was employed. Findings were organized according to therapeutic category and plant species to facilitate interpretation and comparison.

The statistical significance threshold reported in the reviewed studies was generally established at $p<0.05$. Trends and consistencies across investigations were critically evaluated to determine the strength of the available evidence supporting plant-derived antimicrobial therapies.

Results

Overview of included literature

A total of studies published between 2000 and 2025 were screened through electronic database searches. Following the eligibility assessment, studies meeting the inclusion criteria were reviewed. The selected literature encompassed laboratory investigations, animal studies, clinical trials, observational studies, and systematic reviews addressing medicinal plants with antimicrobial properties.

Antibacterial activity

The majority of reviewed studies reported significant antibacterial effects of medicinal plant extracts and isolated phytochemicals against both Gram-positive and Gram-negative bacteria.

Garlic (*Allium sativum*) demonstrated broad-spectrum antibacterial activity against *Staphylococcus aureus, Escherichia coli, Helicobacter pylori*, and Salmonella species. Sulfur-containing compounds, particularly allicin, were identified as major contributors to antimicrobial efficacy.

Tea tree oil (*Melaleuca alternifolia*) exhibited potent activity against Methicillin-Resistant *Staphylococcus aureus* (MRSA), Streptococcus species, and various dermatological pathogens. The primary mechanism involved the disruption of bacterial cell membrane integrity.

Several flavonoids and phenolic compounds isolated from medicinal plants have shown inhibitory effects on bacterial biofilm formation and quorum-sensing pathways.

Antiviral activity

Numerous plant-derived compounds have demonstrated antiviral properties. Lemon balm (*Melissa officinalis*) has shown inhibitory activity against the Herpes simplex virus. Experimental studies reported reductions in viral replication and accelerated healing of lesions.

Pelargonium species exhibited beneficial effects in respiratory viral infections through immunomodulatory mechanisms and inhibition of pathogen adhesion to mucosal surfaces.

Antifungal activity

Tea tree oil and garlic extracts demonstrated notable antifungal effects against *Candida albicans* and other pathogenic fungi. Essential oils rich in terpenoids were particularly effective in disrupting fungal cell membranes and inhibiting fungal growth.

Antiparasitic activity

Artemisia annua emerged as the most extensively investigated antiparasitic medicinal plant. Artemisinin and its derivatives demonstrated remarkable efficacy against Plasmodium species, significantly reducing malaria-related morbidity and mortality worldwide.

Additional plant-derived compounds exhibited activity against Leishmania, Trypanosoma, and other parasitic organisms in experimental studies.

Antimicrobial resistance

A recurring finding across the reviewed literature was the potential of phytochemicals to combat antimicrobial resistance. Several plant-derived compounds enhanced the activity of conventional antibiotics and restored susceptibility in resistant bacterial strains.

Evidence suggests that flavonoids, alkaloids, and essential oils may inhibit bacterial efflux pumps, suppress biofilm formation, and interfere with microbial communication systems, thereby reducing resistance mechanisms.

Safety and tolerability

Most medicinal plant preparations demonstrated favorable safety profiles when used at recommended doses. Reported adverse effects were generally mild and included gastrointestinal discomfort, allergic reactions, and localized skin irritation.

However, concerns regarding dosage standardization, long-term safety, and herb-drug interactions were identified as important areas requiring further investigation.

Discussion

Plant-derived antimicrobial agents have gained increasing scientific attention due to the rising global burden of infectious diseases and the alarming spread of Antimicrobial Resistance (AMR). Conventional antibiotics, although highly effective, are gradually

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losing their therapeutic efficiency because of misuse, overprescription, and rapid microbial adaptation. In this context, medicinal plants represent a vast and relatively untapped reservoir of bioactive compounds with significant antimicrobial potential (Table 1, Figures 1 and 2).

Phytochemicals as natural antimicrobials

The antimicrobial activity of plants is primarily attributed to secondary metabolites, including alkaloids, flavonoids, tannins, terpenoids, saponins, phenolic acids, and glycosides. These compounds exhibit diverse mechanisms of action, such as disruption of microbial cell walls, inhibition of nucleic acid synthesis, interference with energy metabolism, and inhibition of enzyme activity.

Flavonoids, for instance, exert antimicrobial effects by forming complexes with bacterial cell walls and extracellular proteins, thereby reducing microbial adhesion and virulence. Tannins inhibit microbial enzymes and precipitate proteins, while alkaloids interfere with DNA replication and protein synthesis. Terpenoids and essential oils disrupt membrane integrity, leading to leakage of cellular contents and eventual microbial death.

Mechanisms of antimicrobial action

Plant-derived compounds act through multiple mechanisms, making them particularly valuable in combating resistant strains: i) cell membrane disruption, essential oils from plants such as *Thymus vulgaris* and *Origanum vulgare* alter lipid bilayer permeability; ii) enzyme inhibition, polyphenols inhibit bacterial enzymes essential for metabolism; iii) efflux pump inhibition, certain phytochemicals block bacterial efflux pumps, restoring antibiotic susceptibility; iv) biofilm disruption, compounds like curcum-

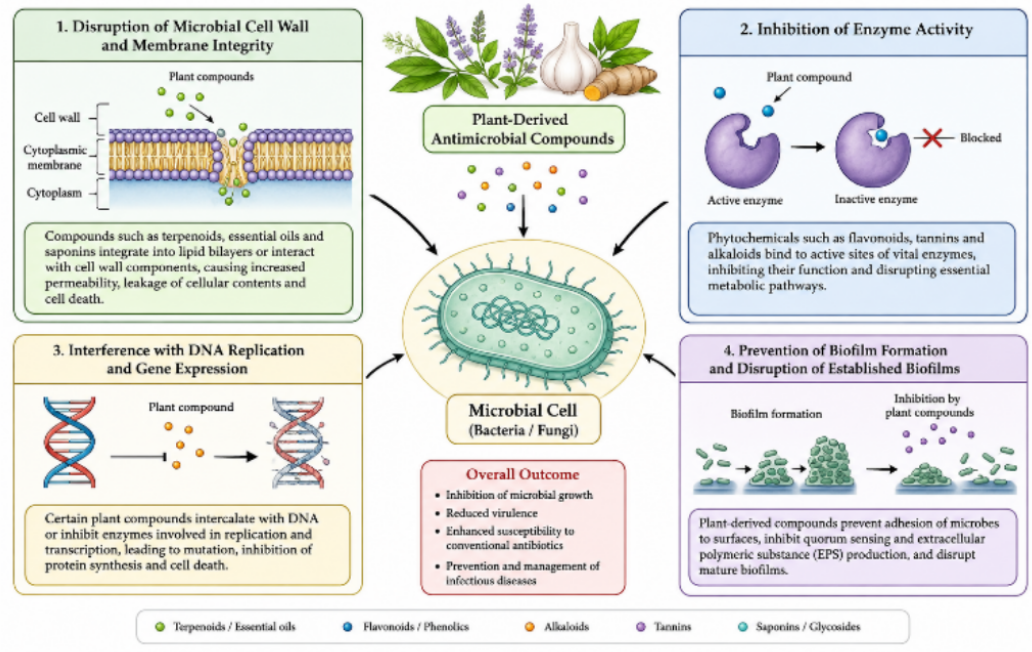

Figure 1. Mechanisms of action of plant-derived antimicrobial compounds, illustrating disruption of microbial cell walls, inhibition of enzyme activity, interference with DNA replication, and prevention of biofilm formation.

Table 1. Major medicinal plants and their antimicrobial activities.

Medicinal plant	Active compounds	Antimicrobial activity	Target pathogens
Azadirachta indica (Neem)	Nimbin, azadirachtin	Antibacterial, antifungal, antiviral	*S. aureus, E. coli, Candida albicans*
Allium sativum (Garlic)	Allicin	Broad-spectrum antibacterial	*E. coli, Salmonella, S. aureus*
Curcuma longa (Turmeric)	Curcumin	Antibacterial, anti-biofilm	*P. aeruginosa, S. aureus*
Ocimum sanctum (Tulsi)	Eugenol, ursolic acid	Antibacterial, antiviral	Respiratory pathogens
Zingiber officinale (Ginger)	Gingerol	Antibacterial, antifungal	*Candida, E. coli*
Thymus vulgaris (Thyme)	Thymol	Membrane disruption	Gram-positive bacteria
Origanum vulgare (Oregano)	Carvacrol	Strong bactericidal activity	MDR bacteria
Camellia sinensis (Green tea)	Catechins	Antibacterial, synergistic	Oral pathogens
Punica granatum (Pomegranate)	Ellagitannins	Antibacterial, antifungal	*S. aureus*
Aloe vera	Anthraquinones	Wound healing, antimicrobial	Skin pathogens

MDR, Multidrug-Resistant

in inhibit biofilm formation, reducing chronic infection persistence; v) genetic interference, alkaloids and quinones interfere with DNA replication and transcription.

These multifaceted mechanisms significantly reduce the likelihood of resistance development compared with single-target synthetic antibiotics.

Broad-spectrum antimicrobial activity

Many medicinal plants demonstrate broad-spectrum activity against Gram-positive bacteria (*Staphylococcus aureus, Streptococcus pneumoniae*), Gram-negative bacteria (*Escherichia coli, Pseudomonas aeruginosa*), fungi (*Candida albicans*), and even some viruses.

For example, *Azadirachta indica* (neem) exhibits antibacterial, antifungal, and antiviral properties due to azadirachtin and nimbin. Similarly, garlic (*Allium sativum*) contains allicin, which shows potent antimicrobial activity against a wide range of pathogens.

Synergistic effects with conventional antibiotics

A significant advancement in phytotherapy is the synergistic interaction between plant extracts and antibiotics. Several studies have shown that combining plant compounds with antibiotics enhances antimicrobial efficacy and reduces the required antibiotic dosage. For instance, green tea polyphenols enhance the activity of β-lactam antibiotics, berberine improves the efficacy of tetracycline against resistant *Staphylococcus aureus, and* essential oils increase membrane permeability, allowing better antibiotic penetration. Such combinations are promising strategies to combat Multidrug-Resistant Organisms (MDROs).

Clinical and therapeutic applications

Plant-derived antimicrobials are increasingly being integrated into clinical and traditional therapeutic systems. Their applications include: the treatment of gastrointestinal infections, the management of skin and wound infections, respiratory tract infection control, urinary tract infection prevention, and oral and dental hygiene products. In many developing regions, herbal formulations remain the primary healthcare option due to affordability and accessibility.

Limitations and challenges

Despite their promise, plant-based antimicrobials face several limitations: i) variability in composition, environmental conditions affect phytochemical content; ii) low bio-availability, many compounds have poor absorption and rapid metabolism; iii) lack of standardization, herbal formulations often lack consistent dosing; iv) limited clinical trials, most evidence is from *in vitro* or *in vivo* studies, rather than human studies; v) toxicity concerns, some plant extracts may exhibit cytotoxic effects at high concentrations.

Addressing these limitations requires advanced formulation techniques such as nanoencapsulation, standardization protocols, and rigorous clinical trials.

Future perspectives

The integration of phytochemicals into modern pharmacology offers promising opportunities. Advances in biotechnology, molecular docking, and metabolomics are facilitating the identification of novel antimicrobial compounds. Nanotechnology-based drug delivery systems are enhancing the stability, solubility, and targeted delivery of plant-derived compounds.

Furthermore, the concept of "green antibiotics" is gaining momentum, emphasizing sustainable and eco-friendly antimicrobial development.

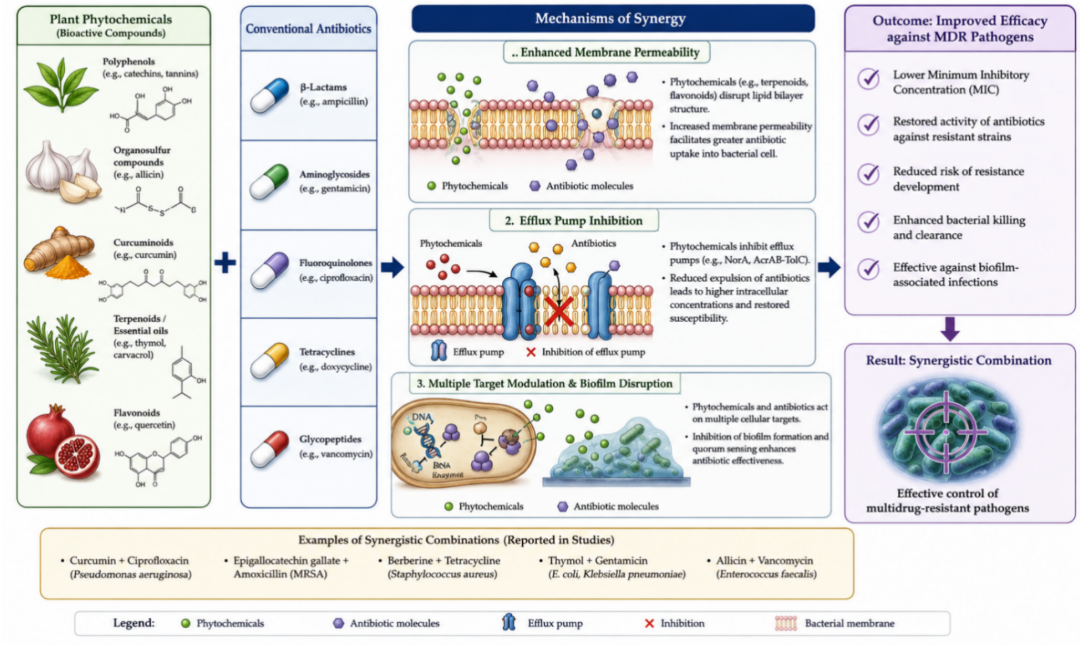

Figure 2. Synergistic interaction between plant phytochemicals and conventional antibiotics showing enhanced membrane permeability, efflux pump inhibition, and improved drug efficacy against multidrug-resistant pathogens.

Conclusions

Plant-derived antimicrobial agents represent a powerful and sustainable alternative or adjunct to conventional antibiotics. Their diverse chemical composition, multi-target mechanisms, and synergistic potential with existing drugs make them highly valuable in combating infectious diseases and antimicrobial resistance. However, challenges related to standardization, clinical validation, and bioavailability must be addressed before widespread clinical adoption. Continued interdisciplinary research integrating pharmacology, microbiology, and biotechnology is essential to fully harness their therapeutic potential.

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Contributions: RH, conceptualization of the study, research design, manuscript preparation, coordination of the project, and overall supervision; ZA, statistical analysis, interpretation of experimental data, and critical revision of the manuscript; HA, experimental investigations, laboratory data collection, and supervision of laboratory procedures; SNS, development of research methodology, validation of pharmaceutical analyses, and scientific review of the manuscript; GK, literature review, interpretation of findings, and critical editing and revision of the manuscript; SZ, supervision of laboratory work, validation of experimental findings, manuscript editing, and final review of the study. All the authors have read and approved the final version of the manuscript, and agreed to be held accountable for all aspects of the work.

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