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A REVIEW ARTICLE

Antimicrobial activity of Medicinal plant extracts: A Review Article

Fitua M. Al-Saedi [a,b], Suzan Yousif Jasim [b], Mayssaa E. Abdalah [b], Amer Saleh Mahdi [c]

[a] Polymers research unit, college of Science, Mustansiriyah University, Baghdad, Iraq.
[b] Clinical Laboratory Sciences, college of Pharmacy , Mustansiriyah University, Baghdad, Iraq.
[c] Department of Chemistry, College of Science, Mustansiriyah University, Baghdad, Iraq.

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Correspondent author:

Fitua M. Al-Saedi, Polymers research unit, college of Science, Mustansiriyah University, Baghdad, Iraq.

Abstract

The inappropriate use of antibiotics has accelerated the emergence of antimicrobial resistance, reducing the effectiveness of many conventional therapies and creating an urgent need for alternative antimicrobial agents. This review aims to critically evaluate the antimicrobial activity of medicinal plant extracts, focusing on their phytochemical composition, mechanisms of action, and evidence from in vitro, in vivo, and clinical studies.

A structured literature search was conducted using major scientific databases, and studies were categorized according to experimental model and methodological quality. Medicinal plants contain diverse bioactive compounds, including alkaloids, flavonoids, terpenoids, tannins, and polyphenols, which exhibit antimicrobial effects through multiple mechanisms such as membrane disruption, inhibition of nucleic acid and protein synthesis, and interference with microbial virulence factors.

While numerous in vitro studies report strong antimicrobial activity—often with low minimum inhibitory concentrations—evidence from animal models and clinical trials remains limited. Furthermore, variability in extract composition, lack of standardization, and insufficient toxicity data represent major challenges for clinical translation.

In conclusion, medicinal plant extracts represent promising sources of novel antimicrobial agents; however, further well-designed in vivo and clinical studies, along with standardized extraction and safety evaluation protocols, are required to support their therapeutic application.

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1. Introduction

The inappropriate uses of antibiotics have led to antimicrobial resistance, making various currently used antibiotics ineffective [1,2,3]. Antimicrobial resistance threatens the capability to effectively treat microbial infections worldwide [4]. This global health challenge threatens the effective treatment of infectious diseases and is associated with increasing morbidity and mortality worldwide. It is estimated that antimicrobial resistance may cause up to 10 million deaths annually by 2050 if no effective interventions are implemented [5]. Consequently, there is an urgent need to develop novel antimicrobial agents that are both effective and safe. Medicinal plants have gained considerable attention as potential sources of such agents due to their rich content of bioactive compounds [6,7,8,9].

Approximately 30–50% of currently available pharmaceuticals are derived from plant sources, highlighting their importance in drug discovery [10]. Plant materials are natural, safe, available and cheap.They contain diverse secondary metabolites, including alkaloids, flavonoids, terpenoids, tannins, and phenolic compounds [11,12], which are responsible for their antimicrobial, antioxidant, and anti-inflammatory properties [13,14,15]. However, the biological activity of these compounds depends strongly on extraction methods, solvent polarity, plant species, and environmental conditions [16].

Despite extensive research, most evidence regarding the antimicrobial activity of medicinal plants remains limited to laboratory studies, with insufficient validation in animal models and clinical settings. Therefore, a critical evaluation of existing evidence is necessary to assess their potential for clinical application.

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2. Methodology

The current study was conducted as a narrative review of published literature on the antimicrobial activity of medicinal plant extracts. A comprehensive search was done using electronic databases including PubMed, Scopus, and Google Scholar using key words search terms included "medicinal plants," "plant extracts," "antimicrobial activity," and "phytochemicals." Articles published between 2010 and 2025 were considered, with inclusion criteria focusing on peer-reviewed studies reporting antimicrobial activity, mechanisms of action, or safety assessments, while non-peer-reviewed sources were excluded.

The selected literature was systematically examined to obtain detailed information relevant to the antimicrobial activity of medicinal plant extracts. Data extraction focused on the plant species investigated and the specific parts utilized. The methods of extraction employed, including aqueous, ethanol, and methanol techniques. The microorganisms tested in each study were recorded to determine the breadth of antimicrobial evaluation. In addition, the antimicrobial assay techniques applied. Finally, the reported outcomes and effectiveness of the extracts were synthesized to provide a comprehensive and critical overview of their antimicrobial potential.

3. Phytochemical Classes and Mechanisms of Action

Medicinal plants contain diverse bioactive compounds that exert antimicrobial effects through multiple mechanisms.

3.1. Major Phytochemical Classes

Major phytochemical classes include: alkaloids, which interfere with DNA replication and enzyme activity; flavonoids, which disrupt cellular membranes and inhibit microbial enzymes; terpenoids, which alter membrane permeability; tannins, which precipitate proteins and inhibit enzymes; and phenolics, which induce oxidative stress and damage cellular components.

3.2. Mechanisms of Antimicrobial Action

The bioactive components of medicinal plants are primarily secondary metabolites that can combat resistant pathogens These compounds exert their antimicrobial effects through multiple mechanisms, including inhibition of bacterial cell wall synthesis, disruption of cell membrane integrity, inhibition of protein and nucleic acid synthesis, efflux pump inhibition, generation of reactive oxygen species, and interference with quorum sensing and biofilm formation [17,18,19] (Figure 1).

Plant-derived compounds affect microorganisms in various ways. For instance, saponins interact with sterols in microbial cell membranes, forming complexes that lead to membrane damage [20]. Alkaloids generally act by inhibiting efflux pumps; for example, berberine, an isoquinoline alkaloid, functions as a DNA intercalator and interferes with enzymes such as topoisomerase IV, DNA gyrase, and RNA polymerase [21,22].

Phenolic compounds, including flavonoids, phenolic acids, and tannins, exhibit strong antimicrobial activity against bacteria, fungi, and protozoa [23,24,25]. These compounds inhibit microbial efflux pumps, alter cytoplasmic membrane permeability, and disrupt essential cellular processes by binding to key enzymes or damaging the cell wall [26,27,28,29,30,31].

Flavonoids such as luteolin, quercetin, naringin, morin, and rutin demonstrate antimicrobial effects against a wide range of pathogens, including *Staphylococcus aureus, Streptococcus oralis, Streptococcus sanguinis, Escherichia coli, Enterococcus faecalis, Lactobacillus casei, Actinomyces viscosus, Aggregatibacter actinomycetemcomitans,* and *Candida albicans* [32]. Their activity is attributed to their ability to form complexes with extracellular proteins and cell membranes, leading to inhibition of microbial enzymes, disruption of quorum sensing receptors, increased membrane permeability, and loss of essential molecules required for microbial growth [33,34].

Tannic acid is known for its antibacterial and antiviral properties. It has been shown to inhibit the growth of S*. aureus, S. pyogenes, E. coli, E. faecalis, Yersinia enterocolitica, Pseudomonas aeruginosa,* and *Listeria innocua,* as well as viruses such as influenza A, herpes simplex virus, noroviruses, human immunodeficiency virus (HIV), and papillomaviruses [35]. Tannins act by disrupting microbial cell membranes and walls, inhibiting oxidative phosphorylation, functioning as

DNA intercalators [36], and interacting with essential proteins such as enzymes to inhibit their activity [37].

Coumarins also exhibit antimicrobial activity against various pathogens, including *Enterobacter aerogenes, Bacillus subtilis, Klebsiella pneumoniae, Staphylococcus aureus, Enterobacter cloacae, Helicobacter pylori,* and *Salmonella enterica* serovar Typhi. [38,39,40,41]. Their mechanisms include inhibition of DNA gyrase [42], suppression of quorum sensing systems, and prevention of biofilm formation [43, 44].

Terpenes exert their antimicrobial effects mainly due to their lipophilic nature, which facilitates their penetration into microbial cell walls and membranes, leading to structural and functional disruption [45].

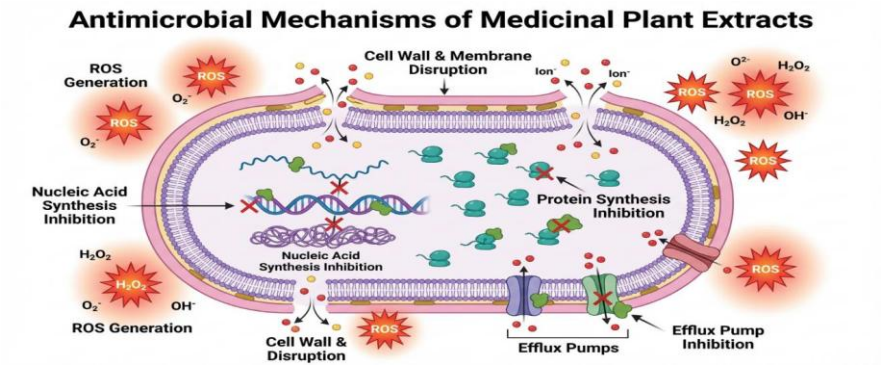

Figure 1. Schematic representation of the major antimicrobial mechanisms of medicinal plant extracts. Plant-derived compounds target multiple cellular structures and processes including cell wall and membrane disruption, inhibition of protein and nucleic acid synthesis, reactive oxygen species (ROS) generation, and efflux pump inhibition

4. Studied on Antimicribial Activty of Medicinal Plants Extracts

4.1. Antibacterial Activity

Several medicinal plants, including, tea tree oil (*Melaleuca alternifolia*) [46], turmeric (*Curcuma longa*)[47], and garlic (*Allium sativum*) [48], have demonstrated antimicrobial activity against both Gram-positive and Gram-negative bacteria, their activity attributed to the effects of bioactive compounds such as alkaloids, flavonoids, terpenoids, and tannins [49]. Another study reported that seeds and leaves extracts of *Zizyphus spina-christi* has antibacterial effects against pathogenic bacteria isolated from skin lesions [50]. Methanol extract of *Saussurea costus* roots contains bioactive composites, which include coumarins, alkaloids, phenols/polyphenols, quinines, flavonoids, steroids terpenoids, tannins, glycosides and resins, has antibacterial effect against *Bacillus cereus, Staphylococcus saprophyticus*, *Staphylococcus epidermidis* and *Staphylococcus aureus*, *Aspergillus niger* [51].

The methanol extracts of *Juglans regia* and *Thymus vulgaris* seeds showed inhibitory activity against *Listeria monocytogenes*, *Bacillus subtilis, Escherichia coli*, *Staphylococcus aureus, Proteus vulgaris, Klebsiella pneumoniae* , *Streptococcus pyogenes* and *Pseudomonas aeruginosa* [52]. *Myristica fragrans seed extracts have demonstrated antibacterial activity against several pathogens, including Escherichia coli, Salmonella enterica serovar Typhi, Bacillus subtilis, and Helicobacter pylori.* [53,54]. Methanol extracts of *Cinnamomum tamala, Oxalis corniculata, Ageratina adenophora* and *Artemisia vulgaris* have shown antimicrobial activities against *Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Salmonela Typhi*, and *Citrobacter koseri* [55]. Thyme peppermint, fennel,lavender contain essential oils and volatile oils, like monoterpenes, phenylpropanoids and sesquiterpenes, have been exhibited antimicrobial activity against viruses, fungi and bacteria [56,57].Ethanolic extract of roselle (*Hibiscus sabdariffa*) displayed antibacterial activity against *S. aureus*, *B. cereus*, *E. coli*, *P. aeruginosa*, *V. parahaemolyticus* and *S. enteritidis* [58]. The methanolic extract of Syzygium aromaticum (syn. Caryophyllus aromaticus) has shown inhibitory effects against Staphylococcus aureus, Enterococcus spp., Escherichia coli, and Salmonella enterica serovar Typhimurium [59]. *Croton marostachyus Del. Dodonea angustifolia L.f.* and

Calpurnia aurea (Ait.) Benth extracts displayed antimicrobial activity against *Candida albicans ,S. aureus, E. coli, K. pneumonia* and *P. aeruginosa* [60].

The essential oils extracted from of cumin, cinnamon, black seeds, marjoram and cloves have antibacterial activity against wide range of pathogens [61].*Prosopis laevigata* extract inhibited the growth of *K. pneumoniae*, *E. coli*, *E. faecalis*, *Stenotrophomonas maltophilia* and *S. aureus* [62]. Further studies confirmed that plant extracts have antimicrobial properties, as shown in table (1). In spite of the beneficial effects of medicinal plants, there is a challenge in the using them as antibacterial agents, the great limitation correlated with concentrations of bioactive compounds which differ according to the plant species, geographical area, harvesting conditions, and preparation methods [63]. Future studies should direct toward development of the extraction methods, studying the synergistic effects between plant compounds, and focusing on the safety and efficacy of such plants in treating bacterial infections.

4.2. Antifungal activity

Medicinal plants also play important roles as antifungal agents specially because the rise in antifungal resistance. Many plants have active compounds with antifungal properties, making them good choice for fungal treatment. The effect of medicinal plants as antifungal may carried out by cell wall disruption and interfere with enzyme activity of fungal cells [64]. The common medicinal plants which are used as antifungal include Neem (*Azadirachta indica*) which reported to exhibit antifungal effects by inhibiting fungal growth and spore germination, especially against dermatophytes. [65]; Turmeric (*Curcuma longa*) exhibit their effects as antifungal by disrupting mitochondrial function, this belongs to the effects of bioactive compound (Curcumin) [66]; while Garlic (Allium sativum) has shown significant antifungal activity against Candida and Aspergillus species, and this activity is mainly attributed to the bioactive compound allicin [67]. In addition to that, medicinal plant can enhance the activity of traditional antifungal drugs when used in combination. For example, tea tree oil (*Melaleuca alternifolia*) can increase the efficacy of fluconazole (synergistic effects) against *Candida albicans* [68].

Table 1. Antimicrobial activity of selected medicinal plant extract

Plant (Scientific name)	Part used	Extract / Study type	Microorganisms tested	MIC (units)	Antimicrobial effects	Ref.
Neem (Azadirachta indica)	Leaves	Aqueous, Ethanolic *In vitro*	*S. aureus*(MRSA), *E. faecalis*, *P. aeruginosa*, *S. mutans*, Candida spp.	125–500 µg/mL	Inhibits Gram-positive/negative bacteria and Candida ; antibiofilm vs MRSA.	69
Oregano (Origanum vulgare)	Aerial parts	Essential oil (carvacrol-rich) *In vitro*	*S. aureus, E. coli,*	*0.25–0.5 mg/mL*	Strong activity;	70
Clove (Syzygium aromaticum)	Buds	Essential oil / ethanolic extract *In vitro*	*B. cereus, S. aureus, E. coli, P. aeruginosa, S. pneumoniae, S. aureus, S. epidermidis, A. hydrophila, K. pneumoniae, P. gingivalis, and P. mirabilis. V. inaequalis, C. albicans, C. glabrata, and C. tropicalis.*	*0.05–0.2 mg/mL*	Broad antibacterial/antifungal	71
Rosemary (Rosmarinus officinalis)	Leaves	Essential oil extracts / *In vitro*	Oral and foodborne bacteria; some fungi	0.2–1 mg/mL	antibacterial activity vs oral pathogens.	72,73
Eucalyptus (Eucalyptus globulus)	Leaves	Essential oil *In vitro*	*S. aureus, E. coli*	*0.5–2 mg/mL*	Essential oil active vs Gram-positive/negative;	74
Green tea (Camellia sinensis)	Leaves	Aqueous / ethanolic (catechins) *In vitro*	*P. aeruginosa, S. aureus*(MRSA)	64–256 µg/mL	Active vs MRSA and P. aeruginosa	75
Pomegranate (Punica granatum)	Peel	Methanol *In vivo*	Candida spp. (oral)	Not reported	Antifungal comparable to nystatin in models.	76
Black cumin (Nigella sativa)	Seeds	Fixed oil / thymoquinone *In vitro* and *in vivo*	broad pathogens including bacteria/fungi	8–64 µg/mL	broad antimicrobial spectrum including Gram-negative, Gram-positive bacteria, viruses, parasites, schistosoma and fungi.	77
Henna (Lawsonia inermis)	Leaves	Water/alcoholic/oily extracts *In vitro*	*S. aureus, S. epidermidis*, ß-hemolytic streptococci and *P. aeruginosa*	250–1000 µg/mL	Leaf extracts effective vs clinical isolates.	78
Aloe (Aloe vera)	Leaf gel / juice	Ethanolic extract of Aloe vera leaf gel *In vitro*	*S. aureus, Ps.aeruginosa, E. coli* and *K. pneumoniae*	200–800 µg/mL	Bacteriostatic/antibacterial vs pathogens.	79

4.3. Antiviral activity

As a results of resistance, side effects, and limitation of antiviral drugs, there is great interest in using medicinal plants as alternative or complementary treatments [80]. The medicinal plant works by different mechanisms to exhibit the antiviral effects, they can exert their effects by modulate the host immune response, suppress the entrance of the virus into the cells, interfere with viral replication or suppress the viral protein synthesis [81]. Licorice (Glycyrrhiza glabra); this plant contain Glycyrrhizin, which has antiviral activity against hepatitis viruses and SARS-associated coronaviruses by modulating the immune responses [82]. Sambucus nigra (elderberry) contains anthocyanins and flavonoids that exhibit antiviral activity against influenza viruses, potentially by interfering with viral entry through inhibition of hemagglutinin-mediated attachment to host cells [83]. For Andrographis (Andrographis paniculata); this plant improves immune response and inhibit viral replication as in influenza and these effects belong to the presence of andrographolide [84].

In addition, some plants can enhance the effect of antiviral treatments, minimize the dose and reduce the side effects. For example, green tea (Camellia sinensis) synergist the effect of acyclovir against herpes simplex virus due to the presence of catechins [85]. Medicinal plants represent a good source of antimicrobial agents that can be used as alternative or traditional treatment. More clinical studies are necessary to evaluate their effects and safety in human.

5. The Invitro and Invivo Effects of Medicinal Plants

In vitro and in vivo studies are indispensable for estimating the antimicrobial efficiency of medicinal plants. In vitro studies involve investigating plant extracts activity and mechanism of action against different pathogens using culture media. These studies have revealed that the active composites of medicinal plants such as tannins, alkaloids, flavonoids and terpenoids display antimicrobial efficacy in vitro [86]. Conversely, in vitro outcomes may not always show directly the antimicrobial efficacy within living organisms because of the complexities within living systems. In vivo studies include investigating the activity and safety of medicinal plants within the organism. Thus, whereas in vitro research provides preliminary evidence of antimicrobial effects, in vivo studies is essential for confirming efficiency and safety of medicinal plants extracts before clinical application [87].

6. Safety and Contamination Risks in Medicinal Plants Extracts

The safety of medicinal plant extracts represents a critical challenge for their therapeutic application. Several studies have reported cytotoxic effects at concentrations similar to those required for antimicrobial activity, suggesting a potentially narrow therapeutic index. In addition, improper storage conditions can lead to microbial contamination, particularly by fungi such as Aspergillus and Fusarium, which produce mycotoxins including aflatoxins and ochratoxins. These compounds are associated with hepatotoxicity and carcinogenicity [88]. Furthermore, Ergot alkaloids (from Claviceps spp.) cause vasoconstriction and gangrene [89].

The optimal temperature must be below 25°C to prevent fungal proliferation. The humidity should be below 60% to avoid moisture absorption. The Packaging involve airtight, UV-protected containers to reduce oxidation and microbial contamination [90].

Chemical contamination is another concern, as plant extracts may contain residual organic solvents, pesticide residues, or heavy metals such as lead, cadmium, and arsenic due to environmental pollution. These contaminants pose significant health risks and limit the safe use of herbal products [91].

Therefore, strict quality control, standardization, and safety evaluation are essential before clinical application.

7. Conclusion

Medicinal plant extracts represent a promising source of antimicrobial compounds with diverse mechanisms of action. However, the current body of evidence is largely dominated by in vitro studies, with limited validation in animal models and a significant lack of clinical trials.

Major challenges include variability in phytochemical composition, lack of standardization, potential toxicity, and contamination risks. These limitations hinder the translation of plant-derived compounds into clinically applicable therapies.

Future research should focus on well-designed in vivo and clinical studies, standardization of extraction methods, and comprehensive toxicity assessments to ensure safety and efficacy. Only through such approaches can medicinal plants be effectively integrated into modern antimicrobial strategies.

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النشاط المضاد للميكروبات للمستخلصات النباتية الطبية: مقالة مراجعة

الملخص

أدى الاستخدام غير المناسب للمضادات الحيوية إلى تسريع ظهور مقاومة الميكروبات، مما قلل من فعالية العديد من العلاجات التقليدية وخلق حاجة ملحة إلى بدائل مضادة للميكروبات. تهدف هذه المراجعة إلى التقييم النقدي للنشاط المضاد للميكروبات لمستخلصات النباتات الطبية، مع التركيز على تركيبها الكيميائي النباتي، وآليات عملها، والأدلة المستسقاة من الدراسات المخبرية والحيوانية والسريرية.

أُجري بحث منهجي في الأدبيات العلمية باستخدام قواعد البيانات العلمية الرئيسية، وصُنفت الدراسات وفقًا للنموذج التجريبي وجودة المنهجية. تحتوي النباتات الطبية على مركبات حيوية متنوعة، بما في ذلك القلويدات، والفلافونويدات، والتربينويدات، والتانينات، والبوليفينولات، والتي تُظهر تأثيرات مضادة للميكروبات من خلال آليات متعددة مثل تعطيل الأغشية، وتثبيط تخليق الأحماض النووية والبروتينات، والتداخل مع عوامل ضراوة الميكروبات.

في حين تُشير العديد من الدراسات المخبرية إلى نشاط قوي مضاد للميكروبات - غالبًا بتركيزات تثبيط دنيا منخفضة - إلا أن الأدلة المستسقاة من النماذج الحيوانية والتجارب السريرية لا تزال محدودة. علاوة على ذلك، يُمثل تباين تركيب المستخلصات، وعدم وجود معايير موحدة، ونقص بيانات السمية، تحدياتٍ كبيرة أمام تطبيقها سريريًا.

وختامًا، تُعدّ مستخلصات النباتات الطبية مصادر واعدة لعوامل مضادة للميكروبات جديدة؛ إلا أن هناك حاجة إلى مزيد من الدراسات السريرية والتجارب على الحيوانات، المصممة جيدًا، إلى جانب بروتوكولات موحدة للاستخلاص وتقييم السلامة، لدعم استخدامها العلاجي.

الكلمات المفتاحية: النباتات الطبية، الاستخلاص؛ المركبات النشطة بيولوجيًا؛ مضادات الميكروبات