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Mini Review

Herbal Approaches to Combat Antimicrobial Resistance (AMR)

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ABSTRACT

Antimicrobial resistance (AMR) has emerged as one of the greatest global health challenges of the 21st century. The excessive and irrational use of antibiotics in humans, animals, and agriculture has accelerated the development of drug-resistant microorganisms [1–3]. As a result, several common infections are becoming harder to treat, leading to higher medical costs and increased mortality rates. In recent years, herbal medicines have gained significant attention as potential alternatives or adjuncts to conventional antibiotics [7,9,11]. Medicinal plants contain a variety of phytochemicals such as alkaloids, flavonoids, tannins, terpenoids, and essential oils that exhibit strong antimicrobial and anti-inflammatory activities. This review highlights the mechanisms of AMR, explores the potential of selected herbal plants in combating resistant microorganisms, and discusses their possible integration into modern therapeutic strategies.

INTRODUCTION

The discovery of antibiotics revolutionized modern medicine and saved millions of lives. However, the widespread and often inappropriate use of these drugs has resulted in the emergence of antimicrobial resistance (AMR), a serious public health concern worldwide [1–4]. According to the World Health Organization (WHO), AMR occurs when microorganisms such as bacteria, fungi, viruses, and parasites evolve mechanisms that render antimicrobial drugs ineffective. This resistance limits treatment options and increases the risk of disease spread, severe illness, and death [2,5]. In developing countries like India, misuse of antibiotics—such as self-medication, over-the-counter availability, and incomplete therapy—is a

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major contributor to AMR [6–8]. The rise of resistant pathogens such as Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Mycobacterium tuberculosis has made infection management more complicated. Hence, there is an urgent need to explore new and safer therapeutic approaches.

Herbal medicines, derived from plant sources, have been used for centuries in traditional systems like Ayurveda, Siddha, and Unani [9–12]. They are rich in bioactive constituents that can either directly kill pathogens or enhance the body's immune response. Research on medicinal plants offers an opportunity to discover novel antimicrobial agents that are safe, effective, and less prone to resistance [11,13].

Mechanisms of Antimicrobial Resistance

Microorganisms develop resistance through several biochemical and genetic mechanisms. Understanding these mechanisms is essential for developing new strategies to overcome AMR.

Enzymatic degradation of drugs

Some bacteria produce enzymes such as β-lactamases that destroy antibiotic molecules before they can act [5–7].

Alteration of target sites

Mutations in microbial DNA can modify drug-binding sites, preventing antibiotics from attaching effectively [5,6].

Efflux pump mechanisms

Bacteria can actively pump out antibiotic molecules using efflux proteins, reducing drug concentration inside the cell [8,25].

Reduced permeability of cell wall

Changes in membrane structure can decrease drug entry, making antibiotics less effective [8,25].

Biofilm formation

Bacteria form a protective biofilm layer that acts as a physical and chemical barrier, reducing the penetration of antibiotics [9,25].

Horizontal gene transfer

Bacteria can share resistance genes through transformation, conjugation, or transduction, leading to rapid spread of resistance traits [4,8].

Herbal Approaches to Combat AMR

Medicinal plants are rich sources of secondary metabolites that possess antimicrobial, anti-inflammatory, and antioxidant activities. These compounds either kill the pathogens or inhibit their growth by affecting cellular metabolism, disrupting membranes, or interfering with genetic material [9–11].

Neem (Azadirachta indica)

Neem is widely recognized for its antibacterial, antiviral, and antifungal properties. The active constituents include nimbidin, azadirachtin, and quercetin [13,14]. Neem extracts inhibit bacterial cell wall synthesis and reduce microbial adhesion, making them effective against Staphylococcus aureus, E. coli, and Pseudomonas aeruginosa [12,13].

Turmeric (Curcuma longa)

Curcumin, the major active compound in turmeric, exhibits strong antibacterial and antioxidant properties [15,16]. It disrupts microbial membranes and interferes with quorum sensing, thereby reducing virulence. Combination therapy of curcumin with antibiotics enhances drug efficacy and minimizes resistance [15,27].

Tulsi (Ocimum sanctum)

Tulsi contains eugenol and ursolic acid that show potent antimicrobial and anti-inflammatory activity [18,19]. Its extracts are effective against both Gram-positive and Gram-negative bacteria. Tulsi also supports immune modulation, helping the body fight infections naturally [19].

Aloe vera (Aloe barbadensis miller)

Aloe vera gel is rich in anthraquinones and polysaccharides that have antibacterial and wound-healing properties [20,21]. Its application helps in the management of skin infections, acne, and wound healing by inhibiting microbial growth and inflammation.

Garlic (Allium sativum)

Garlic contains allicin, a sulphur-containing compound with strong antimicrobial activity [9,11,27]. It interferes with bacterial enzymes and suppresses toxin production. Studies show that garlic extracts are effective even against multidrug-resistant strains.

Spirulina (Arthrospira platensis)

Spirulina is a blue-green microalga known for its antioxidant, anti-inflammatory, and immunomodulatory effects [22,23]. The compounds such as phycocyanin and phenolic acids help in reducing oxidative stress and bacterial growth. Spirulina-based formulations are being explored for topical antimicrobial therapy.

Combination therapy using herbal extracts

Combining different herbal extracts often provides synergistic effects, reducing the required dose and minimizing resistance development [27,28]. For example, Neem and Turmeric together show enhanced activity against Gram-positive bacteria, while Aloe vera and Spirulina promote faster wound healing [29].

Future Perspectives

Herbal remedies have significant potential in combating antimicrobial resistance, but several challenges remain. The major concerns include standardization of extracts, identification of active components, and ensuring batch-to-batch consistency [24–26]. Further, pre-clinical and clinical trials are essential to validate safety and efficacy. Integration of herbal medicine with modern drug discovery techniques, such as nanotechnology and bioinformatics, can help in designing novel formulations with improved stability and bioavailability [27,28].

CONCLUSION

Antimicrobial resistance poses a severe threat to global health, and the discovery of new antibiotics has not kept pace with the rate of resistance development [1,2]. Herbal medicines, owing to their rich phytochemical diversity, represent a promising solution to this problem [9,11,28,30]. Plants like Neem, Tulsi, Turmeric, Aloe vera, and Spirulina possess powerful antimicrobial properties that can help reduce the burden of drug-resistant infections. However, more research is needed to isolate active compounds, understand their mechanisms, and establish standardized formulations [26,27]. The integration of traditional herbal knowledge with modern pharmaceutical science can play a crucial role in developing effective alternatives to combat AMR..

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