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Unveiling the Potential and Challenges of Herbal Antibiotics: Nature's Medicine Chest

Dasgupta Ramesh Kumari* and Haque Shaikh Ershadul

Department of Pharmaceutical Technology, Brainware University, Barasat 700125, Kolkata, West Bengal, India

**Corresponding Author*

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Abstract: Antimicrobial resistance poses a serious threat to world health hence it calls for original approaches. This review looks at herbal antibiotics, the alternatives source for conventional antibiotics. Rich in history in traditional medicine, herbal medicines consist on a large spectrum of bioactive compounds having antibacterial action. These drugs either directly kill germs, inhibit their spread, or interfere with their communication mechanisms. Although herbal remedies have broad-spectrum antibacterial effect, their complex composition and lack of standardization limit their therapeutic application. Among its various advantages are environmental sustainability, low adverse effects, and maybe overcoming of antibiotic resistance by herbal antibiotics. Still, issues like unequal potency, inadequate absorption, and inadequate clinical data demand additional research. Herbal antibiotics coming forward will be defined by standardization, bioavailability enhancement, mechanistic research, combination therapies, regulatory approval, and sustainable manufacture. Considering these issues, herbal antibiotics can assist to produce a strong and environmentally friendly antibacterial tool. This review reveals their significant potential even while highlighting the need of further scientific investigation to release the full therapeutic efficacy of herbal antibiotics.

Keywords: Herbal, Antibiotic, Resistance, Medicine, Antibiotic, Phytochemicals

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Introduction

Antimicrobial resistance is a growing risk whereby microorganisms such as bacteria acquire the capacity to resist formerly successful drugs against them (Colson *et al.*, 2021; Parmanik *et al.*, 2022). Different elements contribute to the complicated problem of growing antibiotic resistance. Abuse and overuse of antibiotics in people, animals, and agriculture are among major causes. These elements create a selection pressure that aids to survive resistant microorganisms (Knight *et al.*, 2018). Poor sanitation and environmental degradation also drive these resistant pathogens to spread. Certain bacteria also have naturally occurring traits that

enable their better adaptation for the development of resistance (Iskandar *et al.*, 2020). Most of the antimicrobial drugs on the market are not totally successful in treating these resistant bacteria to get full patient recovery (Vaou *et al.*, 2021). Thus, the mounting spectre of antibiotic resistance calls for creative solutions. Other antimicrobial medications are much required to lessen dependency on antibiotics and stop the spread of resistance against them. This has caused scholars to return to the richness of nature-herbs (Penesyan *et al.*, 2010; Tortorella *et al.*, 2018; Khameneh *et al.*, 2021). Historically, minerals, plants, and other natural items have been sought for healing in the surroundings. Generation after generation of people have inherited these natural medicines and therapies to cure a variety of diseases and disorders (Dias *et al.*, 2010).

With a long history in both developed and developing countries, natural remedies or natural products like phytonutrients and nutraceuticals have been the mainstays of natural therapies for centuries. In developing nations, this reliance is especially strong, with an estimated four billion people, or 80% of the population, using herbal remedies as their primary source of healthcare (Ekor, 2014; Ahmad *et al*., *2014*). In ancient India, Ayurveda stood as a unique system -- both the oldest known form of medicine and a comprehensive set of spiritual teachings. (Jaiswal and Williams, 2017). The plants or herbs utilised in Ayurveda provide an abundance of therapeutic benefits, significantly contributing to strengthening healthcare. Even modern medicine recognises the potential of these natural ingredients (Tambekar and Dahikar, 2011). The growing interest in natural solutions, fuels the development of modern drugs, dietary supplements, and even ingredients for food, beverages, and cosmetics derived from these herbs. (Chaughule and Barve, 2024). Herbal products show a wide spectrum of biological activities and have been used for centuries to combat infections (Yuan *et al.*, 2016).

Herbal therapies are often seen as safe and efficient drugs by people. Growing numbers of people are looking for herbal therapy as they think plant-based remedies are safe and free from adverse effects (Ardalan and Rafieian-Kopaei, 2013). This review covers the numerous herbs or plants used against multidrug-resistant bacteria. Humans have looked to the potential of herbal remedies to address a variety of ailments for millennia. Exposing the incredible power of medicinal herbs and plants to fight against germs, modern science is catching up with this age-old knowledge (Zhang and Ma, 2018). The alarming rise of drug-resistant bacteria demands increasing focus on creating new weapons. Standardized modern techniques enable us to isolate and identify powerful bioactive compounds; medicinal plants provide several possibilities. These compounds generated from plants show significant promise to offer effective and novel ways to combat resistant bacteria (Nourbakhsh *et al*., 2018).

Methods for Fighting Bacteria that are Resistant to Drugs

Killing microbes directly: Many plant extracts virtually completely eliminate bacteria by weakening their cell walls or membranes. The membrane of bacteria represents their two-edged weapon. Dealing as a gatekeeper, it covers the internal machinery of the bacteria with a layer of low sugar content, proteins, and lipids. Aiming at this barrier, numerous antibiotics gently regulate chemical flow in both in- and out- directions. These medications either completely breach the membrane or damage the structure, therefore entering the bacteria and upsetting essential mechanisms triggering cell death. Still, this same wall helps bacteria to acquire antibiotic resistance (Gonelimali *et al.*, 2018). In the battle against diseases, scientists are finding amazing new weapons in herbal chemicals that resemble the action of conventional antibiotics. Presenting a fresh strategy to fight diseases, these plant-based substitutes show great promise to overcome the resistance mechanisms bacteria

have evolved (Page and Walker, 2021).

Inhibiting growth: Plant extracts can prevent microbes from reproducing, slowing down the spread of infection. Plant extracts have the potential to be natural infection-fighters. They can act on microbes in a way that disrupts their reproduce-tion, essentially throwing a wrench into their machinery and preventing them from multiplying. This slowdown in their growth builders. The defence mechanism recognises and eliminate the invaders, potentially preventing a full-blown infection. Previous studies revealed that the plant extracts were equally effective in inhibiting the growth of both ESBL/MRSA bacteria and antibiotic-susceptible strains. This suggests the presence of unique antibacterial mechanisms within the plant's phytochemicals, potentially offering new avenues for future research and drug development (Zai *et al.*, 2024).

Interfering with communication: Some plant chemicals can interfere with the communication among microorganisms, therefore impairing their capacity to be harmful. Plant chemicals have the capacity to disrupt microbial communication, a phenomena known as quorum sensing inhibition or QSI. Using signalling molecules, quorum sensing is the mechanism by which bacteria and other microbes interact. This correspondence helps them to coordinate their activities, including when to release poisons or build biofilms (Rasko and Sperandio, 2010; LaSarre and Federle, 2013; Sharma *et al.*, 2020). Plants' generated variety of secondary metabolites can interfere with quorum sensing abilities of bacteria. These molecules are components of the plant's defences against infections. These plant chemicals might therefore possibly interfere with the capacity of dangerous bacteria to coordinate their actions, including virulence factor synthesis or biofilm develop-ment, by blocking quorum sensing. The disturbance might make it more challenging for the bacteria to induce infections or other kind of damage (Krishnan *et al.*, 2012; Mutungwa *et al.*, 2015; Cosa *et al.*, 2019).

Benefits of Herbs for Antimicrobial Purposes

Medicinal herbs operate as antibiotics as naturally occurring compounds produced by plants drive their action (Table 1). Strong against a wide spectrum of bacteria, these compounds have emerged regularly as defence mechanisms against microbial illnesses (Namasivayam and Vivek, 2016; Vaou *et al.*, 2021; Abdalla *et al.*, 2023). Many medicinal herbs have broad-spectrum antibacterial effect, hence they may target numerous types of microorganisms, including protozoa, bacteria, fungi, and viruses. When treating several types of diseases, this flexibility is more beneficial than conventional medications to which germs may acquire resistance over time. Many times comprising many bioactive elements, medicinal plants exhibit synergistic activity (Hochma *et al.*, 2021; Bittner *et al.*, 2021). Their complexity increases difficulty for bacteria acquiring resistance (Uddin *et al.*, 2020).

Apart from their direct antibacterial effect, several medicinal herbs boost immunity. They may enhance immune system performance, therefore helping the body to fight off diseases (Cheesman *et al.*, 2017; Tamboli *et al.*, 2021; Farooqui *et al.*, 2022). Long employed in traditional medical systems worldwide, various therapeutic plants have long been known to be the basis of current scientific research as the safety and efficacy shown by decades of usage (Anand *et al.*, 2019). Researching medicinal plants with antibacterial qualities might motivate the synthesis of fresh compounds or formulations suitable for use as substitute therapeutic agents against drug-resistant diseases. Although some discovered antibiotics (Rao *et al.*, 2004) entail complicated chemical processes that might damage the environment, cultivating and harvesting medicinal plants can be more ecologically benign than their manufacturing. Commonly found and reasonably priced in many different regions, medicinal plants offer readily available treatments for healthcare in wealthy and poor countries (Warra *et al.*, 2022).

Limitations of Medicinal Plants

Herbal drugs are those with active components

Table 1: Herbs for Battling Multidrug-Resistant Microorganisms

Plant name	Family	Part used
Allium sativum (Garlic)(Gupta *et al.*, 2015)	*Amaryllidaceae*	Bulb
Cuminum cyminum (Cumin) (Moradi *et al*., 2023)	*Apiaceae*	Fruit
Ocimum sanctum (Tulsi) (Mallikarjun *et al.*, 2016)	*Labiatae*	leaves
Syzygium aromaticum (Clove) (Faujdar *et al.*, 2020)	*Myrtaceae*	Buds
Zingiber officinale (Ginger) (Lucky *et al*., 2017)	Zingiberaceae	Rhizome
Curcuma longa (Turmeric) (Adamczak *et al.*, 2020)	*Zingiberaceae*	Rhizome
Rosmarinus officinalis (Rosemary) (Manilal *et al.*, 2021)	*Lamiaceae*	Seeds
Nigella sativa (black cumen) (Salman *et al.*, 2016)	*Ranunculaceae*	seeds
Mangifera indica (Mango) (Hannan *et al*., 2013)	Anacardiaceae	Fruits, seeds
Piper betle (Pan) (Nayaka *et al*., 2021)	*Piperaceae*	leaf
Glycyrrhiza glabra (Liquorice) (Hazlett *et al*., 2019)	*Fabaceae*	rhizome
Portulaca oleracea (Little hogweed) (Sun *et al*., 2024)	*Portulacaceae*	Flowers
Tribulus terrestris (Gokshur) (Suresh *et al*.,2024)	*Zygophyllaceae*	Fruit
Eryngium alpinum (sea holly) (Hatami *et al.*, 2022)	*Apiaceae*	Fruit
Mentha piperita (Pudina) (Muntean *et al*.,2019)	*Lamiaceae*	leaves
Foeniculum vulgare (Fennel)(Abd El-Mongy *et al*., 2017)	*Apiaceae*	seeds

derived from plant parts such as leaves, roots, seeds or flowers. Like traditional medicines, herbal medications impact the body and can be harmful if used improperly. Plant species, cultivation conditions, and extraction methods all affect the potency of herbal medicine (Kunle *et al*., 2012; Bose *et al*., 2019). Although herbal remedies are often seen as natural and safe replacements, many lack clear understanding on appropriate dosages and probable interactions with other pharmaceuticals. More study is needed to ensure safe and effective usage of herbal remedies as certain plants might be fairly strong and contradict with prescription drugs; so, this knowledge gap can be harmful (Hussain, 2011; Babu and Shankar, 2016).

Plant-Based Antimicrobials: Future Prospects

Plant-based antimicrobial treatments have enormous promise and a bright future ahead of them if research is focused on conquering existing problems. One of the key challenges is keeping continuous potency and purity throughout multiple batches of isolated compounds or plant extracts. Standardizing processes helps to guarantee safety and efficacy in clinical environments (Heinrich *et al.,* 2020). Researchers are looking at several delivery methods and formulations in order to improve bioavailability and guarantee therapeutic doses to reach the site of infection (Manach *et al*., 2005; Kumari *et al*., 2010). Though many such plant-based antibiotics exist, their exact modes of action against diseases should be known. The breakdown of these systems and the likelihood of bacteria acquiring resistance will make more tailored therapies feasible and help to reduce their effects (Cushnie *et al.*, 2021). Combining plant-based antimicrobial compounds with present antibiotics or other natural agents holds considerable promise to boost efficacy and combat antimicrobial resistance.

Researchers are investigating at probable additive effects and synergistic interactions to maximize efficacy and stop resistance development (Nisar *et al*., 2021; Li *et al.*, 2022) Bringing plant-based antimicrobial medicines from research into usage calls for careful legal route negotiation and ensuring adherence to safety and efficacy standards. This is a challenging operation requiring significant cash expenditure

and extensive collaboration (Bone and Mills, 2012). As demand for plant-based antimicrobial agents increases, so does the need of ensuring sustainable sourcing strategies and industrial scalability. Researchers are looking at sustainable agricultural methods and extraction technologies in order to meet world healthcare needs without compromising environmental integrity (Amarjeet *et al.*, 2024.). To get the safety and effectiveness of plant-based antibiotics for broad acceptance in mainstream medicine, thorough clinical investigations are absolutely required (Ernst, 2006).

Conclusion

In conclusion, the urgent threat of resistance to antibiotics underscores the imperative for novel therapeutic strategies. Herbal antibiotics, rooted in traditional medicine, offer a promising avenue. Their potential to combat resistant pathogens, coupled with their minimal side effects and environmental benefits. However, challenges related to standardization, bioavailability, and clinical evidence must be addressed. Rigorous scientific research is essential to unlocking the full potential of herbal antibiotics. By investing in research, development, and standardization, herbal medicines can be transformed into effective and safe clinical therapies, contributing to a sustainable

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Conflict of Interest

The authors declare no conflicts of interest.

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