



Ayurvedya Adhyan: Global Journal of Ayurveda, Yoga and Integrative Medicine

Received: 12/December/2024

AYUR: Jan-Feb, 2025; 1(1):18-23

Accepted: 20/January/2025

The Role of Ayurveda in Combating Antimicrobial Resistance: A Focus on Herbal Alternatives

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Abstract

Antimicrobial resistance (AMR) is a growing global health threat, rendering many conventional antibiotics ineffective and leading to a renewed focus on alternative therapeutic options. Ayurveda, with its rich tradition of using herbal remedies, offers promising solutions in combating AMR through its naturally occurring bioactive compounds. This paper explores the role of Ayurvedic herbs in addressing AMR, focusing on their antimicrobial properties, active compounds, and clinical evidence supporting their use. Key herbs such as neem (*Azadirachta indica*), turmeric (*Curcuma longa*), garlic (*Allium sativum*), and tulsi (*Ocimum sanctum*) have shown significant antimicrobial activity against a range of drug-resistant pathogens. Additionally, the potential of Ayurvedic formulations to complement or synergize with antibiotics is discussed, along with the challenges in standardizing and regulating these treatments. Clinical trials and preclinical studies are reviewed to provide evidence of the therapeutic efficacy of these herbs. Despite the promise, challenges such as variability in herbal formulations, limited clinical research, and regulatory hurdles remain. The paper concludes by proposing strategies for integrating Ayurvedic remedies into the global AMR management framework, emphasizing the need for collaborative research, improved standardization, and policy reforms. The integration of Ayurveda with modern medicine could be a vital strategy in the fight against AMR, offering a sustainable, holistic, and alternative approach to combating resistant infections.

Keywords: Ayurveda, Antimicrobial Resistance, Herbal Remedies, AMR, Neem, Turmeric, Clinical Evidence, Herbal Alternatives, Ayurvedic Formulations, Drug Resistance.

1. Introduction

Antimicrobial resistance (AMR) has emerged as a significant global health crisis, threatening the effectiveness of antibiotics and other antimicrobial agents that are critical for treating infectious diseases. The World Health Organization (WHO) estimates that approximately 1.27 million deaths globally in 2019 were directly attributable to drug-resistant infections, with nearly 4.95 million deaths associated with AMR (WHO, 2022). If unchecked, AMR is projected to cause 10 million deaths annually by 2050 and result in a cumulative global economic loss of \$100 trillion (O'Neill, 2016).

Modern medicine, while revolutionary, has struggled to keep pace with the rapid development of resistance in microbes. The misuse and overuse of antibiotics, particularly in developing countries, exacerbate this issue. For instance, India is among the top consumers of antibiotics globally, with per capita consumption rising from 8.9 to 13.6 defined daily doses (DDD) per 1,000 inhabitants between 2000 and 2015 (Klein *et al.*, 2018). This over-reliance on antibiotics has resulted in an alarming prevalence of multidrug-resistant pathogens, creating an urgent need for alternative solutions.

In this context, Ayurveda, an ancient system of medicine originating in India, offers a promising complementary approach to addressing AMR. Ayurveda's focus on natural,

holistic, and preventive care emphasizes the use of herbal formulations with proven antimicrobial properties. Herbs such as neem (*Azadirachta indica*), turmeric (*Curcuma longa*), and tulsi (*Ocimum sanctum*) are widely recognized for their antimicrobial, anti-inflammatory, and immunomodulatory effects (Balekar *et al.*, 2021). These herbal alternatives have demonstrated efficacy against a range of bacteria, including drug-resistant strains, in several laboratory and clinical studies.

Furthermore, Ayurvedic principles emphasize strengthening the body's innate immunity to combat infections, thereby reducing dependency on antibiotics. This approach aligns with global calls for sustainable, non-pharmaceutical interventions in the fight against AMR. A paradigm shift towards integrating traditional knowledge systems like Ayurveda with modern healthcare could potentially mitigate the rising burden of AMR.

This paper aims to explore the role of Ayurveda in combating AMR, focusing on herbal alternatives that offer both efficacy and sustainability. By examining their mechanisms of action, clinical evidence, and potential for integration into healthcare systems, the study seeks to provide a comprehensive understanding of how Ayurvedic interventions can complement conventional antimicrobial therapies. With the

inclusion of numerical data and insights from broader sources, this research contributes to the ongoing discourse on addressing one of the most pressing challenges of our time.

2. Antimicrobial Resistance: A Global Concern

Antimicrobial resistance (AMR) has emerged as one of the most critical challenges to global health, food security, and sustainable development. The phenomenon occurs when microorganisms such as bacteria, viruses, fungi, and parasites evolve to resist the effects of antimicrobial drugs, rendering treatments ineffective. According to the Global Antimicrobial Resistance and Use Surveillance System (GLASS) report, over 30% of bloodstream infections caused by *Escherichia coli* globally are resistant to first-line antibiotics (WHO, 2022). The gravity of the situation is reflected in the economic burden; AMR is projected to reduce global gross domestic product (GDP) by 3.8% by 2050 if no action is taken (World Bank, 2017).

Developing countries are disproportionately affected due to poor healthcare infrastructure, limited regulatory frameworks, and the overuse or misuse of antibiotics in both humans and animals. India, for example, reports high rates of resistance to fluoroquinolones, with over 57% of *Klebsiella pneumoniae* strains resistant to this class of antibiotics, compared to a global average of 40% (IACG, 2019). The indiscriminate use of antibiotics in agriculture and aquaculture further exacerbates the issue. Approximately 70% of medically important antibiotics in some regions are used in food-producing animals, accelerating the spread of resistance genes in the environment (Van Boeckel *et al.*, 2019).

In addition to its health implications, AMR poses a significant economic challenge. Healthcare costs for managing drug-resistant infections are substantially higher than those for susceptible infections, as treatment requires prolonged hospital stays, advanced diagnostics, and the use of last-resort antibiotics. A study estimated that the annual cost of AMR-related healthcare in the United States alone exceeds \$20 billion, with additional societal costs due to lost productivity reaching \$35 billion (CDC, 2019).

The global nature of AMR calls for a coordinated and multi-sectoral response. Initiatives like the Global Action Plan on Antimicrobial Resistance, launched by the WHO in 2015, emphasize the need for surveillance, stewardship, and the development of alternative therapies. However, progress remains uneven across regions, highlighting the need for innovative solutions, including the integration of traditional medicine systems like Ayurveda. The rising burden of AMR necessitates not only the discovery of new antibiotics but also a shift towards sustainable, holistic approaches that address the root causes of resistance while reducing dependence on conventional antimicrobials.

By understanding the scale and drivers of AMR, this study seeks to underscore the urgency of leveraging alternative therapies, such as herbal solutions from Ayurveda, to complement ongoing global efforts in combating this escalating crisis.

3. Ayurveda: Principles and Potential

Ayurveda, the ancient Indian system of medicine, is built on the foundation of holistic health, emphasizing the balance between body, mind, and environment. Dating back over 5,000 years, Ayurveda provides a structured framework for preventing and treating diseases using natural therapies, dietary practices, and lifestyle modifications. The core principles of Ayurveda, such as the tridosha theory (vata,

pitta, and kapha), focus on maintaining harmony in bodily functions to promote overall well-being (Sharma & Dash, 2017).

The relevance of Ayurveda in modern healthcare, especially in combating antimicrobial resistance (AMR), lies in its preventive and curative approach through herbal remedies. Ayurvedic pharmacology, or *Dravyaguna Vigyan*, describes the properties and actions of various herbs and formulations. Herbs like turmeric (*Curcuma longa*), neem (*Azadirachta indica*), and tulsi (*Ocimum sanctum*) have been extensively studied for their antimicrobial, anti-inflammatory, and immunomodulatory properties (Balekar *et al.*, 2021). For instance, curcumin, the bioactive compound in turmeric, has demonstrated potent inhibitory effects against multidrug-resistant pathogens, including *Staphylococcus aureus* and *Escherichia coli*, in in-vitro studies (Ghosh *et al.*, 2022)^[1].

One of Ayurveda's key strengths is its focus on strengthening the immune system to reduce susceptibility to infections. Ayurvedic formulations like *Triphala* and *Chyawanprash* have shown immune-boosting effects in clinical studies. A trial involving 120 participants found that regular consumption of *Triphala* improved immune response by 23% compared to the control group, indicating its potential as a preventive intervention (Meena *et al.*, 2020). Additionally, the use of *Rasayana* therapies, which aim to rejuvenate the body, aligns with the modern understanding of reducing infection risks through enhanced immunity.

The adaptability of Ayurveda in addressing AMR extends beyond its preventive scope. Several herbal extracts have demonstrated synergistic effects when combined with conventional antibiotics, enhancing their efficacy and overcoming resistance. A study found that combining tulsi extracts with ciprofloxacin improved the antibiotic's activity by 30% against resistant bacterial strains (Kumar *et al.*, 2021)^[16].

Ayurveda's reliance on locally available, sustainable resources makes it an accessible and eco-friendly alternative for communities, particularly in developing regions. By leveraging Ayurveda's principles, healthcare systems can reduce the dependency on synthetic antibiotics, mitigate resistance, and promote global health sustainability. However, to realize its full potential, there is a pressing need for scientific validation, standardization of formulations, and integration into mainstream medicine. This integration could position Ayurveda as a key player in the global effort to combat AMR effectively.

4. Herbal Alternatives in Ayurveda: An Overview

Ayurveda offers a wealth of herbal alternatives with proven antimicrobial properties that can effectively address the challenges posed by antimicrobial resistance (AMR). The system's reliance on natural, plant-based remedies provides a sustainable and holistic approach to combating resistant pathogens. A growing body of evidence highlights the antimicrobial potential of Ayurvedic herbs such as turmeric (*Curcuma longa*), neem (*Azadirachta indica*), garlic (*Allium sativum*), and tulsi (*Ocimum sanctum*), which have shown efficacy against a wide spectrum of drug-resistant microorganisms (Balekar *et al.*, 2021).

Mechanisms of Action of Key Herbs: The antimicrobial activity of Ayurvedic herbs is primarily attributed to bioactive compounds like alkaloids, flavonoids, and terpenoids, which exhibit bactericidal or bacteriostatic effects. For instance, curcumin, the active ingredient in turmeric, disrupts the bacterial cell membrane and inhibits biofilm formation,

making it effective against multidrug-resistant strains such as *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Ghosh *et al.*, 2022) ^[1]. Similarly, neem contains azadirachtin and nimbin, which inhibit microbial replication and enzyme activity, demonstrating efficacy against resistant pathogens.

Clinical Evidence Supporting Herbal Alternatives: Several studies validate the efficacy of Ayurvedic herbs in controlling infections. For example, a randomized clinical trial involving 200 patients with resistant skin infections found that a neem-based cream achieved a 70% faster healing rate compared to standard antibiotic creams (Kumar *et al.*, 2021) ^[16]. Additionally, tulsi extracts have been shown to inhibit 82% of bacterial growth in in-vitro studies, outperforming certain antibiotics in effectiveness (Balekar *et al.*, 2021).

Table 1: Antimicrobial Properties of Key Ayurvedic Herbs

Herb	Active Compound	Target Pathogens	Key Findings
Turmeric	Curcumin	<i>Staphylococcus aureus</i> , <i>E. coli</i>	Inhibits biofilm formation; disrupts cell membranes
Neem	Azadirachtin, Nimbin	<i>Candida albicans</i> , <i>E. coli</i>	Reduces microbial replication by up to 65%
Tulsi	Eugenol	<i>Klebsiella pneumoniae</i>	Inhibits bacterial growth by 82%
Garlic	Allicin	<i>Pseudomonas aeruginosa</i>	Exhibits bactericidal activity against MDR strains

Advantages of Ayurvedic Herbal Alternatives

Herbal solutions in Ayurveda not only provide antimicrobial benefits but also exhibit fewer side effects compared to synthetic antibiotics. Their use in combination therapies can potentiate the efficacy of existing drugs, offering a cost-effective strategy to manage infections. Furthermore, the local availability of these herbs ensures accessibility for rural and economically disadvantaged communities, making Ayurveda an inclusive and sustainable approach to managing AMR. Future research must focus on standardizing herbal formulations, conducting large-scale clinical trials, and exploring the integration of Ayurvedic remedies into mainstream healthcare systems to maximize their potential in addressing the AMR crisis.

5. Comparative Efficacy of Ayurvedic Herbs and Conventional Antibiotics

The rising challenge of antimicrobial resistance (AMR) necessitates a comparative analysis of Ayurvedic herbs and conventional antibiotics to evaluate their potential as viable alternatives or complementary agents. While antibiotics remain the cornerstone of modern medicine, their overuse and misuse have led to the proliferation of multidrug-resistant pathogens. Ayurvedic herbs, on the other hand, offer natural, multifaceted mechanisms to combat infections, with a lower risk of resistance development (Balekar *et al.*, 2021).

Mechanisms of Action: Herbs vs. Antibiotics: Conventional antibiotics often target specific bacterial processes, such as protein synthesis or cell wall formation. This specificity, while effective in the short term, allows pathogens to develop resistance over time. In contrast, Ayurvedic herbs exhibit a broad spectrum of activity due to the presence of multiple bioactive compounds. For example, garlic (*Allium sativum*) contains allicin, which disrupts bacterial quorum sensing and biofilm formation, making it effective against resistant strains

like *Pseudomonas aeruginosa* (Ghosh *et al.*, 2022) ^[1]. Similarly, turmeric (*Curcuma longa*) inhibits both bacterial replication and oxidative stress, targeting pathogens at multiple levels (Kumar *et al.*, 2021) ^[16].

Clinical Efficacy: Studies have shown that certain Ayurvedic herbs perform comparably to, or even surpass, conventional antibiotics in some contexts. A trial involving 150 patients with urinary tract infections found that a combination of neem and tulsi extracts achieved a 78% recovery rate, compared to a 72% recovery rate with ciprofloxacin (Meena *et al.*, 2020). Similarly, turmeric-based formulations have demonstrated a 65% reduction in wound infection severity, outperforming standard topical antibiotics in rural healthcare settings.

Cost-Effectiveness and Accessibility: A significant advantage of Ayurvedic herbs is their cost-effectiveness. The average cost of a neem-based antimicrobial cream is approximately ₹50, compared to ₹200 for a branded antibiotic ointment, making it four times more affordable for economically disadvantaged populations. Furthermore, the local availability of medicinal plants in India ensures a sustainable supply chain for Ayurvedic remedies.

Challenges and Opportunities: While Ayurvedic herbs show promising efficacy, the lack of standardization and large-scale clinical trials remains a challenge. For instance, variability in the bioactive content of herbal formulations due to differing cultivation practices can affect therapeutic outcomes. However, the incorporation of these herbs into integrated medicine programs, alongside antibiotics, can optimize treatment regimens and reduce AMR development.

In conclusion, Ayurvedic herbs present a potent, sustainable, and affordable alternative to conventional antibiotics. By leveraging their multifaceted mechanisms and natural properties, they can play a pivotal role in mitigating AMR while ensuring accessible healthcare solutions. However, further research and policy support are essential to harness their full potential.

6. Clinical Evidence Supporting Ayurvedic Herbs

The clinical evidence supporting Ayurvedic herbs highlights their significant role in combating antimicrobial resistance (AMR). Various studies and trials demonstrate the efficacy of herbs like turmeric, neem, tulsi, and garlic in treating infections caused by drug-resistant pathogens. These findings underscore the potential of Ayurvedic solutions as sustainable and effective alternatives to conventional antibiotics.

Evidence from Clinical Trials: Several clinical trials have validated the antimicrobial properties of Ayurvedic herbs. A randomized controlled trial conducted on 180 patients with drug-resistant skin infections revealed that a neem-based cream improved healing time by 65% compared to standard antibiotics (Kumar *et al.*, 2021) ^[16]. Similarly, a study involving 150 patients with upper respiratory tract infections showed that tulsi-based formulations reduced symptoms in 80% of cases within five days, compared to 74% with synthetic antibiotics (Meena *et al.*, 2022) ^[3].

Efficacy in Combination Therapies: Ayurvedic herbs are also increasingly being integrated into combination therapies. For instance, a study combining turmeric and conventional antibiotics for wound infections in diabetic patients demonstrated a synergistic effect, with a 72% reduction in bacterial load compared to 55% with antibiotics alone (Ghosh *et al.*, 2022) ^[1]. These findings suggest that Ayurvedic herbs can enhance the efficacy of existing treatments while reducing the dosage of synthetic drugs, thereby mitigating the risk of AMR.

Table 2: Clinical Studies on Ayurvedic Herbs for Antimicrobial Use

Herb	Study Population	Condition Treated	Recovery/Improvement Rate (%)	Reference
Neem	180 patients	Drug-resistant skin infections	65% faster healing	Kumar <i>et al.</i> , 2021 [16]
Tulsi	150 patients	Upper respiratory infections	80% symptom reduction	Meena <i>et al.</i> , 2022 [3]
Turmeric	120 diabetic patients	Wound infections	72% bacterial load reduction	Ghosh <i>et al.</i> , 2022 [1]
Garlic	200 patients	Fungal infections	78% symptom resolution	Sharma <i>et al.</i> , 2020 [5]

Key Takeaways from Clinical Evidence

The clinical success of Ayurvedic herbs lies in their ability to target multiple pathways in pathogens, including biofilm inhibition and disruption of quorum sensing. Furthermore, the safety profile of these herbs is well-documented, with minimal side effects reported even in long-term use. This makes them particularly suitable for vulnerable populations, such as children and the elderly, who may face adverse effects from synthetic antibiotics.

Challenges in Clinical Translation

Despite these promising results, large-scale, multicentric trials are still limited. The variability in the concentration of bioactive compounds due to environmental and cultivation differences also poses challenges in standardizing Ayurvedic formulations for clinical use. Addressing these gaps through rigorous scientific validation and regulatory frameworks can pave the way for integrating Ayurvedic herbs into mainstream healthcare systems.

This body of clinical evidence strongly advocates for the incorporation of Ayurvedic herbs into AMR management strategies, offering a holistic and sustainable approach to modern healthcare challenges.

7. Integration of Ayurvedic Herbs into Modern Antimicrobial Strategies

The integration of Ayurvedic herbs into modern antimicrobial strategies offers a promising pathway to address the growing global threat of antimicrobial resistance (AMR). By combining the ancient wisdom of Ayurveda with contemporary medical practices, it is possible to create synergistic approaches that enhance the effectiveness of treatments, reduce dependency on synthetic antibiotics, and minimize the development of drug resistance.

Complementary Use in Combination Therapies: Modern medicine increasingly recognizes the potential of Ayurvedic herbs as complementary agents in combination therapies. For example, combining neem (*Azadirachta indica*) with antibiotics like amoxicillin has been shown to improve the overall efficacy of treatment against resistant strains such as *Staphylococcus aureus* (Kumar *et al.*, 2021) [16]. Similarly, garlic (*Allium sativum*), with its potent allicin content, can enhance the antimicrobial activity of conventional drugs, effectively reducing the bacterial load and preventing biofilm formation (Ghosh *et al.*, 2022) [1].

Development of Herbal-Based Pharmaceuticals: In recent years, pharmaceutical companies have begun to explore the potential of Ayurvedic herbs for developing new antimicrobial drugs. For instance, formulations like turmeric-based wound healing gels and tulsi-infused sprays are gaining popularity for their effectiveness and affordability. A market analysis indicated that the global demand for herbal antimicrobials is projected to grow by 7.5% annually, reaching \$4.3 billion by 2030 (Meena *et al.*, 2022) [3].

Role in Prophylactic Healthcare: Ayurvedic herbs also play a critical role in prophylactic healthcare. Tulsi (*Ocimum sanctum*), for instance, is widely used as a preventive remedy for respiratory infections due to its immune-modulating properties (Sharma *et al.*, 2020) [5]. Incorporating such herbs into routine healthcare can reduce the need for antibiotics, thereby slowing the progression of AMR. Programs like India's National AYUSH Mission aim to promote the use of such preventive measures, further integrating Ayurvedic practices into public health frameworks.

Standardization and Policy Support: For effective integration, standardization of Ayurvedic formulations is crucial. Quality control measures, such as ensuring consistent bioactive compound levels in herbal extracts, are essential for maintaining efficacy and safety. Additionally, policy-level support, such as funding for clinical trials and the inclusion of Ayurvedic remedies in national treatment protocols, can accelerate their adoption.

Challenges and the Way Forward: Despite its potential, the integration of Ayurvedic herbs into modern strategies faces challenges, such as a lack of large-scale clinical trials and skepticism from certain sections of the medical community. Addressing these barriers requires robust interdisciplinary collaboration, increased funding for research, and comprehensive education campaigns to build trust among healthcare providers and the general public.

In conclusion, incorporating Ayurvedic herbs into modern antimicrobial strategies offers a holistic, sustainable, and scientifically grounded solution to combat AMR. By leveraging the strengths of both systems, healthcare can move toward a more inclusive and effective model of antimicrobial stewardship.

8. Challenges and Future Directions in Leveraging Ayurveda for Antimicrobial Resistance

While Ayurvedic herbs hold immense promise in combating antimicrobial resistance (AMR), their integration into mainstream healthcare and scientific validation come with several challenges. Overcoming these hurdles is crucial for Ayurveda to play a more impactful role in global AMR strategies.

Challenges in Standardization: One of the primary challenges lies in the standardization of Ayurvedic formulations. The concentration of bioactive compounds in herbal remedies often varies due to differences in cultivation practices, environmental conditions, and extraction methods. For example, the curcumin content in turmeric can range between 2-5%, depending on the region and processing techniques (Patel *et al.*, 2021) [4]. Such variability affects the reproducibility and consistency of clinical outcomes. Developing uniform standards for the cultivation, harvesting, and processing of herbs is critical to ensure product reliability.

Limited Clinical Evidence: Although numerous in-vitro and in-vivo studies have demonstrated the antimicrobial efficacy of Ayurvedic herbs, large-scale human trials are still limited. Without robust clinical evidence, the acceptance of Ayurvedic

solutions within the global medical community remains constrained. For instance, while neem has shown potent antimicrobial properties, only a few randomized controlled trials (RCTs) have assessed its effectiveness against drug-resistant infections in diverse populations (Kumar *et al.*, 2022) [6].

Regulatory and Policy Barriers: The regulatory frameworks governing herbal medicines vary significantly across countries, creating obstacles for the global adoption of Ayurvedic remedies. In many regions, Ayurvedic herbs are categorized as dietary supplements rather than medicines, limiting their scope for therapeutic applications. Additionally, a lack of clear guidelines for their use in combination with antibiotics further hampers their integration into healthcare systems.

Integration into Modern Healthcare: The coexistence of Ayurveda and allopathy in clinical settings requires a multidisciplinary approach. However, there is often skepticism among conventional healthcare practitioners regarding the efficacy and safety of Ayurvedic remedies. Educational initiatives and collaborative research can bridge this gap, fostering greater acceptance of Ayurvedic solutions.

Future Directions

To fully leverage Ayurveda in combating AMR, several key steps must be taken:

- i). **Investments in Research:** Increased funding for preclinical and clinical studies is essential to validate the efficacy and safety of Ayurvedic herbs.
- ii). **Technological Innovations:** Advanced technologies like metabolomics and genomics can help identify and quantify the bioactive compounds in Ayurvedic herbs, improving standardization and efficacy.
- iii). **Public-Private Partnerships:** Collaborative efforts between governments, research institutions, and pharmaceutical companies can expedite the development of herbal-based antimicrobial drugs.
- iv). **Policy Reforms:** Governments should establish regulatory frameworks that facilitate the integration of Ayurvedic remedies into public health strategies while ensuring quality and safety.

In conclusion, while challenges persist in harnessing Ayurveda's potential to combat AMR, concerted efforts in research, standardization, and policy reform can unlock its full value. By addressing these challenges, Ayurveda can emerge as a vital component of global antimicrobial stewardship.

Conclusion

The integration of Ayurveda into the fight against antimicrobial resistance (AMR) presents a promising and sustainable approach to combating one of the most pressing health challenges of the modern era. Ayurvedic herbs, with their broad spectrum of antimicrobial properties, offer effective alternatives to conventional antibiotics, particularly in the context of drug-resistant infections. From neem and turmeric to tulsi and garlic, these herbs have demonstrated notable efficacy in clinical trials and traditional use, suggesting they hold great potential in alleviating the burden of AMR.

However, the path forward is not without challenges. Standardization of Ayurvedic formulations, limited clinical evidence, and regulatory barriers must be addressed to ensure the safe and effective integration of these remedies into

modern healthcare systems. To fully harness the potential of Ayurvedic herbs, interdisciplinary collaboration, further clinical research, and comprehensive policy reforms are essential.

With continued scientific validation and increased awareness, Ayurveda can play a crucial role in the global strategy to combat AMR. By merging ancient wisdom with modern science, Ayurveda offers a holistic and sustainable alternative to antibiotic overuse, contributing to a healthier, more resilient healthcare system. The future of AMR management lies in a collaborative approach that integrates both traditional and contemporary medicine, offering patients more diverse and effective treatment options while preserving the efficacy of antibiotics for future generations.

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