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REVIVING ANTIBIOTIC EFFICACY WITH INDIAN HERBAL REMEDIES: A JOURNEY TOWARDS REVERSING ANTIBIOTIC RESISTANCE

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ABSTRACT

Over the past years, antibiotics have proven less effective against bacterial infections due to the increased development of resistance in bacteria. This has emerged as a significant worldwide health threat, potentially causing severe infections in humans and prompting the need for developing a new drug that can inhibit bacterial resistance So, certain herbs have shown good antibiotic activity towards resistant bacteria through various scientific studies. This study reviewed various methods to inhibit antibiotic-resistant bacteria by using Indian-originated herbs. The plans and strategies for treating antibiotic-resistant bacteria have been discussed by collecting information from various preclinical and clinical studies. This study includes the experimentation of herbs on various antibiotic-resistant bacteria and provides the therapeutic effects of each drug as this review can play an essential role in treating individuals with infectious diseases.

Keywords: Antibiotics, antibacterial resistance, traditional Indian medicine, active chemical constituents, mechanism of action

INTRODUCTION

Bacterial infections occur when bacteria invade the body, through the eyes, nose, skin, and various other pathways **[1, 2]**. The symptoms may vary based on the type of bacteria. When bacteria enter the bloodstream, it starts to spread and this leads to a condition called septicaemia **[3]**. Antibiotic is an important discovery that revolutionized medicine. Nevertheless, as a result of excessive antibiotic usage, the

bacteria develop resistance to them. This occurs due to antibiotics killing the bacteria that cause illness in addition to the good bacteria that protect from infection. The antibiotic paradox is, of course, based on the dual role. While necessary to treat infectious agents and save lives in the short term, overuse or abuse can lead to the development of antibiotic resistance and spread, and impair long-term effectiveness The need for appropriate antimicrobial use and innovation is emphasized strategies for combating antimicrobial resistance **[4]**. Antibiotic resistance has become an important global health concern. Since the introduction of penicillin G in the 1940s, the issue of antibiotic resistance has continued to grow, posing a serious threat to public health **[5]**. So many measures and interventions have been implemented in an attempt to address this challenge, but unfortunately, these practices have ultimately led to antibiotic resistance

Antibiotic resistance in bacteria directly leads to delayed access to effective antibacterial treatment, which ultimately results in a reduced quality of life for affected patients and an elevated mortality rate **[6]**. It has been reported that the methicillin-resistant bacterium kills about 50,000 people a year in the United States and Europe, spreading its effects elsewhere Also, antibiotic-resistant diseases such as tuberculosis ravage developing countries development, and nearly 480,000 cases of multidrug-resistant TB were reported in 2013. Including developed and developing countries with non-bacterial infections in terms of impact in the world all in all, this is important to conduct a comprehensive analysis of the development of antibiotic resistance worldwide **[7]**. Therefore, there is an urgent need to prevent antibiotic-resistant bacteria. Research has shown that although individual compounds can provide a selective advantage over resistance, specific combinations of compounds applied appropriately can effectively disrupt bacterial growth and prevent the development of partial resistance **[4]**.

Consequently, research has been undertaken to elucidate the mechanisms of bacterial antibiotic resistance and prevent treatment delays or failures resulting from the use of ineffective drugs **[8]**. Research has shown that Indian herbs and their phytoconstituents exhibit tremendous therapeutic potential in antibiotic-resistant bacteria. Some of the herbs include liquorice, turmeric, cumin, ginger, garlic, etc. In this review, we have outlined the reversion mechanism of antibiotic-resistant bacteria using Indian herbs and their phytoconstituents to prevent the death and infections caused due to multidrug-resistant bacteria

The graph which is mentioned below **(Figure 1)** shows the evolution of bacterial species over the past 20 years.

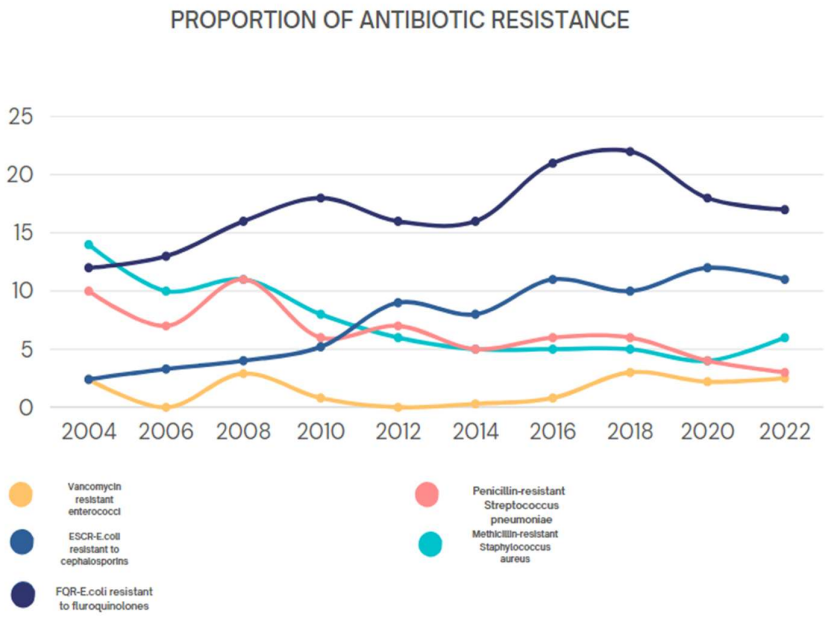


Figure 1

MECHANISM OF ACTION

Hence, to develop an antibiotic that is not resistant to bacteria, we need to understand the mechanism of antibiotic-resistant bacteria.

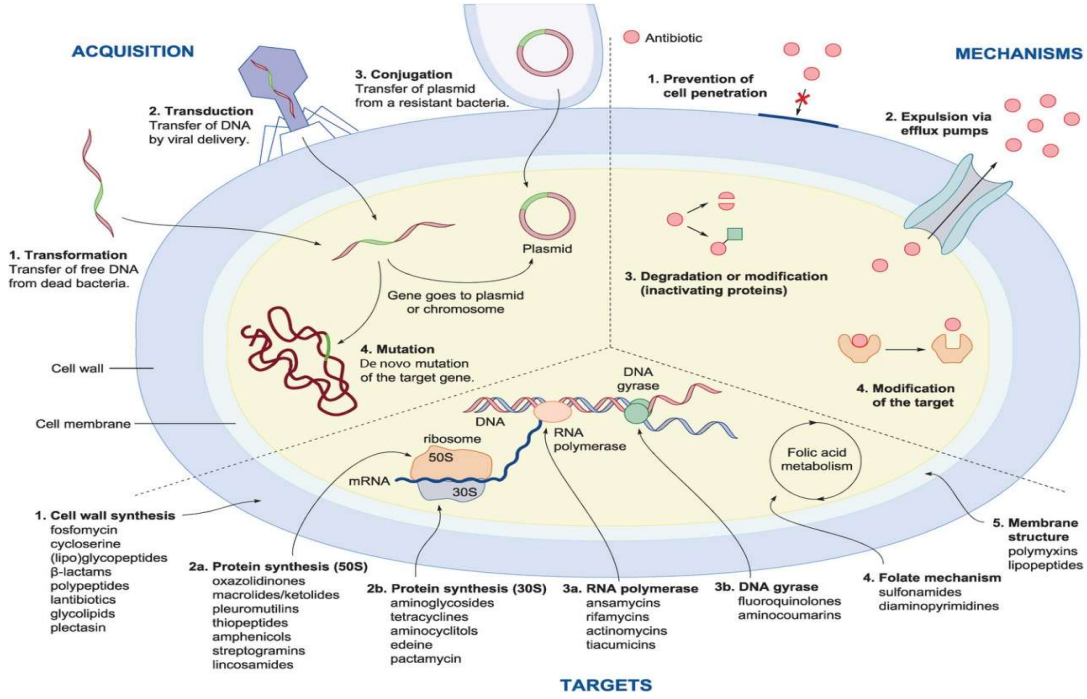


Figure 2

Antibiotic resistance arises when bacteria acquire mechanisms to withstand the effects of an antibiotic, thus resisting its action. Generally, resistance is due to intrinsic and acquired causes. The above **Figure 2** includes the mechanisms of antibiotic resistance **[9]**.

RESISTANCE DUE TO MUTATION

Bacteria reproduce rapidly and during this process, their DNA can undergo changes or mutation. Bacteria can develop resistance through spontaneous mutations in their DNA, particularly in the genes targeted by antibiotics **[10]**. These mutations cause structural or functional changes in the proteins targeted by antibiotics, resulting in bacterial resistance. The suspectable bacteria may undergo genetic mutation and influence the drug's efficacy, thus consequently leading to the survival of cells in the existence of an antibacterial drug. As the resistant mutant emerges, it outcompetes susceptible bacteria and establishes dominance **[11]**. Mutations lead to change in the antibiotic molecule through the following mechanisms I) Target Modification-Occurs due to point shift mutation of selected genes leading to rapid development of resistance **[12]**. II) Efflux mechanism activation III) Reduction in the drug uptake **[11]**. These resistances are based on the acquired causes

HORIZONTAL GENE TRANSFER (HGT)

Bacteria have the ability to share genes with each other, allowing the transfer of genes that carry resistance to antibiotics. HGT occurs through three main mechanisms: transformation, transduction, and conjugation **[13, 14]**.

I) TRANSFORMATION

Transformation is a process that involves the absorption, incorporation, and utilization of extracellular DNA by bacteria, which is freely available and frequently found in the surrounding environment, which may contain antibiotic-resistant genes **[15, 16]**. These mechanisms depend upon conserved proteins, which are encoded by the genes that are simultaneously expressed at the onset of competence. During transformation, double-stranded DNA acts as a substrate where one strand undergoes degradation while the other is inserted into host genome **[17 ,18]**. The transformation has significantly contributed to the emergence of antibiotic-resistant strains like streptococcus and Neisseria **[19]**. This mechanism significantly influences bacterial evolution, allowing them to develop new genetic material and capabilities such as antibiotic resistance.

II) TRANSDUCTION

Transduction is a process where the genetic material is transferred between the bacterial cells through the action of bacteriophage. Transduction has been seen to occur in many environments like potable water and

polluted water; however, 16S ribosomal RNA molecule sequences of bacteria have been detected in polluted water which confirms that the bacteriophage can carry the genes of bacteria **[20]**. Bacteriophages have the capacity to aid in the transfer of genetic materials within their genomes from the other bacterial classes **[21]**. Sometimes bacterial DNA is packed into bacteriophage capsid, this capsid is capable of binding to a recipient and will inject the foreign DNA **[22]**. Transduction can be classified as generalized and specialized. A generalized mechanism occurs when the gene from the host is packed with the viral DNA into a bacteriophage head (such as P22 of salmonella) and then it is transferred to the recipient **[23, 24]**. Transduction is the main mechanism causative for the emergence of antibiotic resistance in pathogens. Specialized was first discovered in coliphage λ, it is restricted to the transfer of particular genes. In this mechanism, a portion of viral DNA is joined to the adjoining part of DNA within the host bacteria chromosome. Recently there have been discoveries indicating that transduction occurs through a lateral mechanism and it was seen in *Staphylococcus aureus* , in the bacterial chromosomal DNA is transferred at a frequency of at least 1000-fold greater than previous mechanisms **[25]**.

III)CONJUGATION

Bacterial conjugation belongs to the group of the large type IV secretion system **[26]**. In this process the cells of bacteria connect through a structure called "sexual pilus "and it is a one-way transmission mechanism **[27]**. Conjugate transfer systems are predominantly linked to plasmids and bacteriophages which are known as conjugates **[28]**.

The sequence of conjugation is as follows

a) bacteria cell-to-cell interaction

b) pairing up by mating

c) plasmid DNA transfer via conjugative pilus **[29]**.

Conjugation is one of the active ways of gene transfer and is accountable for the propagation of genes resistant to antibiotics conjugate transfer mainly depends upon the host factors **[30, 31]**. Conjugation is mainly responsible for the proliferation of antibiotic resistance and conjugative elements are mostly present in the plasmids or integrated into chromosomes as conjugative elements **[32, 33]**.

EFFLUX OF PUMPS

Bacteria may consist of efflux pumps, which are specialized transporters that can efflux out the antibiotics from within the bacterial cell before the drugs can reach the targets which leads to a reduced concentration of antibiotics and makes it less effective **[34]**. Efflux pumps are extensively found in gram-negative bacteria, some pump effluxe out a selective type of antibiotic whereas others pump out multiple classes of antibiotics

leading to multiple drug resistance (MDR) in bacteria **[20]**. The efflux mechanism is a significant mechanism of resistance apart from various molecular and biochemical mechanisms efflux mechanism plays a vital role in intrinsic and acquired MDR **[35]**. Prokaryotes consist of five major classes of efflux transporters:

I) ATP binding cassette (ABC) superfamily
II) Multidrug and toxic efflux (MATE)
III) Major facilitator superfamily (MFS)
IV) Resistance-nodulation-division (RND)
V) Small multidrug resistance (SMR)

All of these systems utilize proton motive force as a source of energy except for the ABC superfamily which relies on ATP hydrolysis to expel the substrates **[36, 37]**. An increase in the resistance due to mutation and efflux of the pump results in bacteria with high resistance that is difficult to treat and hence these mechanisms have to be taken into consideration for developing an antibiotic in the future **[36]**.

REDUCED CELL MEMBRANE PERMEABILITY

Bacteria have the capacity to undergo alterations in their cell membrane or cell wall structures, making it harder for the antibiotic to penetrate hence the antibiotics cannot reach the target site. In gram-negative bacteria such as Pseudomonas aeruginosa, Vibrio cholera, and Salmonella enterica, the outer membrane creates a permeability barrier **[38]**. This acts as an effective barrier to permeability and makes them resistant to antibiotics like erythromycin, azithromycin, and rifamycin **[39]**. Decreased permeability of the outer membrane leads to reduced uptake of antibiotics. This is especially true for the anionic antibiotics, given that the cell membrane consists of anionic molecules which results in electrostatic repulsion that prevents antibiotic penetration **[40]**. This mechanism is effective in both gram-positive and gram-negative bacteria but is found to be more effective in gram-negative bacteria **[41]**.

ANTIBIOTIC MODIFICATION

Some bacteria can directly modify the antibiotic molecules and make them inactive so that they cannot exert antibiotic effect. The enzyme-catalyzed modification is the major mechanism of antibiotic modification **[42]**. Antibiotics are modified by I) enzyme modification II) alteration of the binding site III) change in permeability of the cell **[43]**. The bacteria can produce enzymes that can modify the antibiotic molecules and inhibit their action.

FORMATION OF BIOFILM

Bacteria form a protective matrix, which is less susceptible to antibiotics due to limited drug penetration and altered metabolism, this protective layer is known as biofilm **[44]**. biofilms can be formed on living and non-living surfaces, which are formed by the

microorganisms that enable the bacteria to protect themselves from antibiotics **[45]**.

The cells within the biofilm are encased in the matrix which is produced and it has been associated with the development of bacterial infections that are resistant to antibiotic treatment **[46]**. Biofilm formation significantly contributes to the development of antibiotic resistance and leads to increased doses of antibiotic drugs **[47]**. Pseudomonas aeruginosa and *E. coli* are the classes in which biofilm formation is a major mechanism of antibiotic resistance **[48]**. In nature, bacteria exist in two forms that are planktonic and biofilm and when planktonic adhere to surfaces either living or non-living they get converted to biofilm, which is the survival strategy of bacteria resulting in resistance to antibiotics **[49]**.

So, combating antibiotic resistance requires a multifaced approach, the creation of novel antibiotics, and strategies to prevent the spread of antibiotic-resistant bacteria.

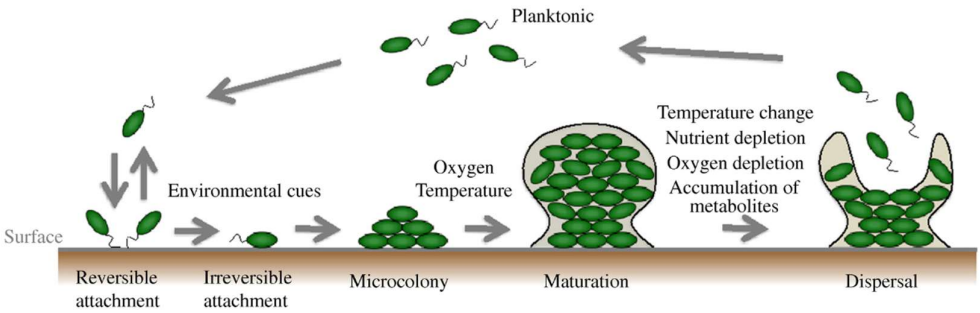


Figure 3: Biofilm formation

The above **Figure 3** shows the development of biofilm formation **[50]**.

ROLE OF INDIAN HERBS IN ANTIBIOTIC RESISTANCE

Several herbs from India have been investigated for their potential to meet the challenge of antibiotic resistance. The rise of resistance is a worldwide health concern and it calls for innovative approaches to tackle bacterial infections. In this regard, traditional Indian herbs have been recognized for their potential in combating resistance providing a complementary strategy to conventional antibiotics. This introduction explores the increasing interest in utilizing herbs as valuable resources for combating bacteria that are resistant to antibiotics.

For centuries India has nurtured a tradition of medicine called Ayurveda, which emphasizes using natural remedies derived from plants, spices, and herbs. Many of these herbs have shown properties and the ability to influence bacterial resistance mechanisms.

This investigation dives into Indian herbs such as Turmeric (Curcumin) Neem (*Azadirachta indica*) Tulsi (Holy Basil) Garlic, Cinnamon, Ginger, Amla (Indian Gooseberry), and Ashwagandha. Certain bioactive compounds obtained from traditional plants demonstrate the capability to counteract antibiotic resistance and enhance synergistic interactions with existing antibiotic agents **[51]**.

However, it is crucial to approach the use of herbs with a perspective. Although they hold promise in integrating these herbs into management strategies, resistance requires scientific validation through clinical trials and comprehensive research.

Moreover, it is crucial to adopt an approach that integrates wisdom alongside contemporary However it's important to maintain a viewpoint when considering the use of herbs. While they show promise it's necessary to subject them to validation, through clinical trials and extensive research in order to effectively manage antibiotic resistance. Moreover, a multidisciplinary approach that combines wisdom with medicine is crucial, for fully harnessing the capabilities of these herbs' medical practices to fully maximize the benefits offered by these medicinal herbs. Some of these medicinal herbs include:

TURMERIC

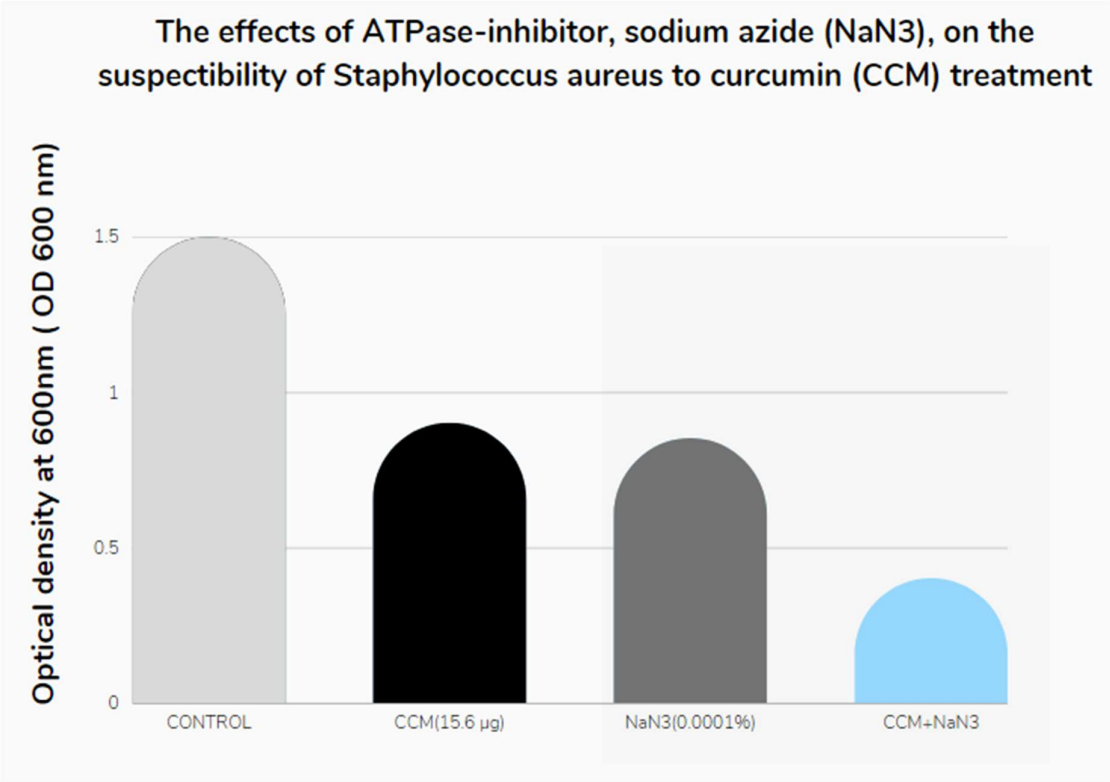
Turmeric also known as curcumin is derived from the rhizomes of Curcuma longa which belongs to the Zingiberaceae family, and is extensively used as a spice and colouring material in various parts of Asian countries **[52]**. Turmeric is rich in vitamins C, and E and other chemical components. The active components of turmeric are curcumin, tetrahydro curcuminoids, desmethoxycurcumin, and bisdemethoxycurcumin and these components are proven to be effective against bacteria **[53]**. Numerous studies have shown the effectiveness of turmeric and its phytoconstituents used in treating a wide range of disease conditions such as wound healing, cardiovascular disease, autoimmune disease, and metabolic disorders. It has various properties such as antiviral, Antifungal, anti-inflammatory, etc. It can act as an important source of alternative antibiotics due to its antibacterial properties **[54, 55]**. Studies have shown that curcumin along with quinolone and β-lactam antibiotics produces synergistic activity. Turmeric has an antibacterial property effective against various bacteria such as *Bacillus subtilis, Escherichia coli,* and *S. aureus* and was found to increase the vulnerability of *S. aureus*. Methicillin-resistant *Staphylococcus aureus* (MRSA), a Gram-positive bacterium, exhibits resistance to β-lactam antibiotics due to reduced affinity between β-lactams with

penicillin-binding proteins (PBPs) of the mecA gene.

MRSA has obtained the mecA gene enabling the bacteria to maintain cell wall synthesis, resulting in the evolution of multiple drug-resistant bacteria **[56]**.

ANTI-MRSA ACTION OF CURCUMIN

The mechanism by which curcumin acts MRSA was evaluated in combination with ATPase inhibitors, detergents, and peptidoglycan (PGN). The bactericidal effect of curcumin was enhanced by increasing the bacterial cell permeability and the highest effect was observed when Tx-100 (Triton X-100) and Tris were administered. The addition of curcumin along with detergent or an ATPase inhibitor has been found to be effective in treating MRSA infections **[56]**.



CUMIN

Cumin is obtained from the seeds of *Cuminum cyminum* which belongs to the Apiaceae family **[57]**. It can be used as a spice or flavoring agent. It is also used in veterinary and traditional Indian medicine as a carminative, astringent, and to treat conditions like indigestion, diarrhoea, etc. **[58]**. Cumin contains active compounds such as cuminaldehyde, terpenoids, and cymene, which have the potential to act as antimicrobials and antioxidants **[59]**. Cuminaldehyde is the major active constituent of cumin which is responsible for insect-resistant, anti-epileptic anticancer, and antidiabetic properties **[60]**. Bacterial

membranes contain antibacterial efflux pumps, which play a role in the development of multi-drug resistance.

The multi-drug efflux pumps TetA, NorA, QacA, Tet38, and LmrS, are present in *S. aureus* which accounts for the mechanism of resistance Cumin acts as an inhibitor for the LmrS multidrug efflux pump. It acts by inhibiting the growth of *S. aureus* which contains a multi-drug efflux pump. Cumin and cumin aldehyde also inhibit the growth of cells that lack LmrS. Cumin inhibit the LmrS efflux pump at low concentration and at high concentration, it disrupts the cell membrane of bacteria **[61]**.

CINNAMON

Cinnamon is obtained from the bark of Cinnamon zeylanicum belonging to the family Lauraceae **[62]**. The chemical constituents of cinnamon are cinnamaldehyde, cinnamate, cinnamic acid, and essential oils such as cinnamyl acetate, eugenol, and caryophyllene oxide **[63, 64]**. Cinnamon has antioxidant, antibacterial, antidiabetic, anti-cancer and anti-inflammatory properties

Cinnamaldehyde is the main chemical constituent which has antibacterial activity. Cinnamaldehyde acts by targeting the cell membrane of the bacteria and it alters the morphology and permeability, ultimately leading to increased electrical conductivity **[65, 66]**.

GINGER

Ginger is obtained from roots or rhizomes of *Zingiber officinale* which belongs to the family Zingiberaceae **[67]**. The major chemical constituents of ginger are camphene, α- terpineol, gingerol, shogaol, zingiberene, zingerone, gingerenone, β-myrcene, α – phellandrene **[68, 69]**.

Ginger has antioxidant, anti-cancer, antibacterial, and anti-inflammatory properties **[70]**. Ginger finds application in treating various disorders such as cardiovascular disease, obesity, neurodegenerative diseases, nausea, headache, and respiratory disorders **[68]**.

MECHANISM BY WHICH GINGER ACTS:

Ginger acts by inhibiting the growth of antibiotic-resistant strains of Pseudomonas aeruginosa by affecting the stability of cell membrane and it inhibits the biofilm formation by reducing the level of c-di-GMP (cyclic dimeric guanosine monophosphate). Ginger also acts by inhibiting ergosterol biosynthesis **[71]**.

CLOVE

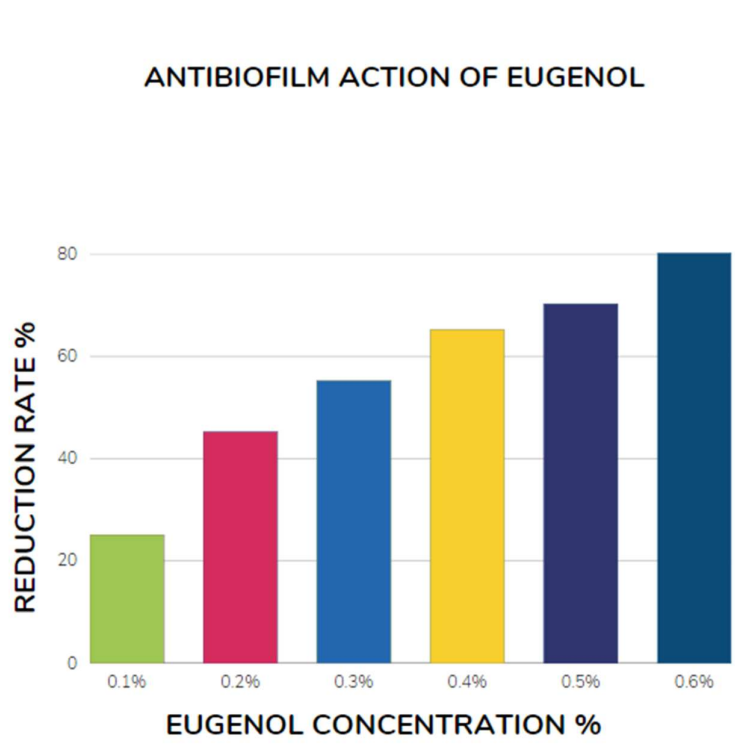
Clove which is also known as Syzygium aromaticum is derived from the flower bud of Eugenia caryophyllus which belongs to the family Myrtaceae **[72, 73]**. Clove consists of chemical constituents which include sesquiterpenes, monoterpenes, hydrocarbons, and phenolic compounds. The significant chemical constituents are

Eugenyl acetate, Eugenol, and β-caryophyllene **[74, 75]**.

Eugenol is the major chemical constituent in clove oil which is used as a flavouring agent **[76]**. Eugenol possesses analgesic, anticancer, antispasmodic, anti-inflammatory, antiviral, antiseptic, anti-depressant, antibacterial, and antifungal properties **[74, 77]**.

ANTIBIOFILM ACTION OF EUGENOL

Eugenol was found to show potent antimicrobial activity against V. parahaemolyticus isolates. Eugenol shows strong antibiofilm efficacy against both environmental and clinical isolates of *V. parahaemolyticus*. Treating biofilms with 0.1%-0.6% eugenol shows a significant decrease in biofilm formation. Eugenol decreases the viable bacterial count thereby decreasing the ability to form biofilms. With an increase in eugenol concentration, the ability of biofilm formation decreases **[76]**. Clove also acts by inhibiting DNA synthesis **[65]**.



AMLA

Amla is commonly referred to as Indian gooseberry. Amla is derived from the fruit of Emblica officinalis or Phyllanthus emblica belonging to the family Euphorbeaceae **[78]**.

Amla contains numerous chemical constituents such as emblicol, gallic acid, emblicanin A, emblicanin B, ellagic acid, tannins, ellagitannins, flavonoids, alkaloids, and cardiac glycosides. Amla is also rich in

vitamin C, iron, calcium, methionine, phosphorus, and riboflavin **[79, 80]**.

Amla has analgesic, antioxidant, memory enhancing, antidepressant, cardioprotective activity, anti-inflammatory, antipyretic, antibacterial, anticancer, antidiabetic, diuretic, hair tonic, and immune-boosting properties **[81, 82]**. Amla possesses potent antibacterial properties. Amla consists of alkaloids, cardiac glycosides, and tannins, which contribute to its antibacterial action **[83]**.

ANTIBACTERIAL ACTION OF AMLA

Amla has the capability to destroy both the bacterial cell wall and cytoplasmic membrane resulting in cytoplasmic leakage, damaging proteins, and affecting both RNA and DNA synthesis. Flavonoids inhibit RNA synthesis in the bacteria. Tannins inhibit the oxidative phosphorylation and inhibit extracellular microbial enzymes **[84]**.

GARLIC

Garlic also known as allium is obtained from the ripe bulb of the plant Allium sativum belonging to the family Liliaceae **[85]**. Garlic has many phytochemicals which include: compounds that contain sulphur such as allicin (a major chemical constituent), vinyldithiins, Ajoene (E-Ajoene, Z-Ajoene), and sulfides such as DADS (diallyl disulfide) and DATS (diallyl trisulfide) **[86, 87]**.

Allium sativum possesses significant pharmacological effects, including antibacterial, antiviral, antifungal, anti-parasitic, cardiovascular, anti-inflammatory, immunomodulation, hypolipidemic, hypoglycaemic, and antioxidant properties **[85, 88]**.

ANTIBIOFILM ACTION OF GARLIC

Biofilms result from the aggregation of bacterial cells within a matrix composed of extracellular polymeric substances (EPS) comprising lipids, proteins, nucleic acid, and polysaccharides all of which are secreted by these bacteria. This is a complicated process that is intricately linked to quorum sensing (QS) and is connected with the expression and subsequent release of virulence factors **[89]**.

SOURCE	MECHANISM
1. Allicin	**1) Inhibits biofilm formation of *S. aureus* 2) Decreases the thickness of *S. epidermidis* biofilms and modulates the gene expression downwards**
2. Ajoene	**Inhibits Pseudomonas quinolone signal**
3. Ajoene along with ciprofloxacin	**Decreases the biofilm formed by *Pseudomonas aeruginosa***
4. diallyl and allyl methyl sulfides	**Inhibits the toxins produced by *C. botulinum***
5. DADS	**Decrease the quorum sensing associated with biofilm formation and suppresses the expression of virulent gene.**

The above table shows the source and mechanism exhibited by garlic and its organosulfur compounds **[89]**.

NEEM

Neem is derived from the bark of the *Azadirachta indica* tree which belongs to the family Meliaceae **[90]**.

The main Phytoconstituents of neem are nimbinin, Nimbidin, nimbidinin, nimbolide, Nimbin, nimbidic acid, and mahmoodin and azadirachin **[91, 92]**.

Neem has many beneficial properties like antiviral, antibacterial, antiseptic, antifungal, anti-inflammatory, wound healing, and antimutagenic. It is also used to treat acne, skin disease, and ulcers **[92, 93]**.

BACTERIOCIDAL ACTION OF NEEM

Nimbolide has bactericidal activity. It acts by killing both free-living bacteria and cells within the biofilm. Even Mahmoodin also has antibacterial activity **[94]**.

TULSI

Tulsi is known as the "Queen of herbs". *Ocimum sanctum* (Tulsi) is of mainly two varieties that is Krishna Tulsi (black) and Rama Tulsi (green). Tulsi is a member of the Labiatae family **[95]**.

The chemical constituents present in Tulsi are eugenol, euginal, urosolic acid, caryophyllene, methyl eugenol, vallinin acid, and camphene **[96, 97]**.

Tulsi has antibacterial, antiviral, antifungal, and immunomodulatory activity. Tulsi also possesses antipyretic, anti-inflammatory, analgesic, anti-helminthic, antioxidant, anticoagulant, and wound healing properties **[98]**. Eugenol is mainly used as a flavouring agent in food and cosmetics **[99]**.

MECHANISM OF ACTION

Eugenol has potent antibacterial properties it is effective against a wide range of bacteria, and acts on both gram +ve and gram -ve bacteria. Eugenol acts by increasing the permeability of cell membrane, leading to disruption in the ion transport of bacteria, it also prevents ATP synthesis, causes DNA degradation, protein oxidation, and lipid peroxidation, and then finally leads to cell death **[100]**.

CONCLUSION

Recent studies have shown that antimicrobial resistance has emerged due to excessive and improper use of antibiotics, this led to Drug-resistant harmful bacteria and jeopardizing beneficial microbial communities. Due to this adequate disease management requires a therapeutic dosage beyond the current level. In conclusion, addressing reverse antibiotic resistance is imperative for sustaining the efficacy of existing antibiotics. Focusing on research, responsible antibiotic use, and innovative therapeutic approaches are essential in mitigating this growing global health threat. Furthermore, public awareness campaigns can play a pivotal role in educating the general population about the responsible use of antibiotics and the consequences of

reverse antibiotic resistance. Exploring the potential of Indian herb remedies represents a promising avenue in combating reverse antibiotic resistance. The rich diversity of Indian herbs holds significant promise in the fight against reverse antibiotic resistance Research into the antimicrobial properties of various herbs like garlic, neem, cinnamon, etc, and their phytoconstituents can yield natural alternatives to synthetic antibiotics. Integrating herbal medicines into mainstream healthcare practices, while ensuring their safety and efficacy through rigorous scientific evaluation, could offer sustainable solutions.

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