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Review article

Phytoconstituents with antimicrobial activity against food poisoning microbes: mechanism and screening approaches

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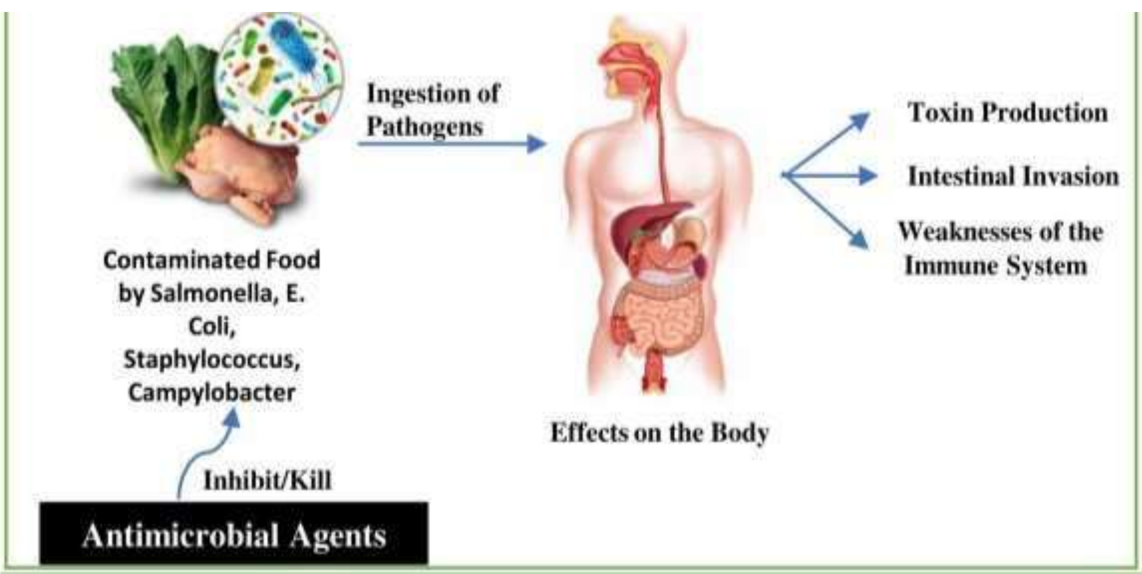
ABSTRACT

Food poisoning driven on by pathogenic microorganisms continues to be a major global public health concern, resulting in high rates of morbidity and financial costs. The hunt for substitute antimicrobial agents has accelerated due to the growing incidence of antimicrobial resistance and safety issues with synthetic preservatives. Because of their multi-target modes of action, natural origin, and broad-spectrum activity, plant-derived antimicrobials have drawn a lot of research. Antimicrobial screening methods against bacteria that cause food poisoning are summarized in this study, with a focus on plant sources and their incorporation into the drug discovery process. Salmonella species, Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, Bacillus cereus, and other common foodborne pathogens are discussed as the main targets for antimicrobial screening. The relevance of several in vitro antimicrobial screening techniques in early-stage evaluation is emphasized, including agar diffusion, broth dilution, time-kill kinetics, and anti-biofilm assays. The review also examines the bioactive phytochemicals found in medical plants and culinary herbs that have antimicrobial properties, as well as the underlying mechanisms of action, such as membrane rupture, enzyme inhibition, interference with nucleic acid production, and suppression of virulence factors.



Keywords: Food poisoning, Phytoconstituents, Plant-derived antimicrobial activity, Drug discovery, Antimicrobial resistance.

INTRODUCTION

Foodborne infections remain a significant global public health concern, contributing substantially to morbidity, mortality, and financial losses. Escherichia coli, Salmonella enterica, Listeria monocytogenes, Staphylococcus aureus, and Bacillus cereus are some of the pathogens most commonly linked to outbreaks involving tainted meat, dairy, fresh fruit, and ready-to-eat foods. The hunt for natural, efficient, and sustainable antimicrobial agents has accelerated due to rising rates of antimicrobial resistance, consumer demand for minimally processed foods, and growing worries about the safety of synthetic preservatives. In this regard, phytoconstituents derived from plants have garnered considerable interest as potential substitutes or supplements to traditional antibacterial substances.

Phytochemicals, which have a variety of structural characteristics and biological functions, are essential parts of edible and therapeutic plants. These include phenolics, flavonoids, tannins, alkaloids, terpenoids, saponins, and plant peptides. By focusing on vital cellular functions, several of these metabolites have broad-spectrum antibacterial actions against foodborne pathogens [1]. Cytoplasmic membrane disruption, energy metabolism inhibition, nucleic acid and protein synthesis disruption, quorum sensing and biofilm formation regulation, efflux pump inhibition, and oxidative stress induction are some of their modes of action. In contrast to manufactured antimicrobials with a single target, phytoconstituents frequently have many effects, which lessens the possibility of resistance developing. Furthermore, a number of phytochemicals work in concert with current antibiotics or food preservatives to increase their usefulness. Strong screening techniques that can detect antimicrobial activity in both crude plant extracts and purified compounds are essential for the identification and confirmation of bioactive phytoconstituents. Agar diffusion, broth microdilution, minimum inhibitory concentration (MIC) measurement, time-kill kinetics, and biofilm inhibition tests are examples of traditional microbiological assays that continue to be fundamental instruments. By enabling bioassay-guided fractionation, chromatographic separation, dereplication, and structural characterisation using GC–MS, LC–MS, and NMR approaches, analytical chemistry advancements have significantly improved this sector. The identification of lead compounds and the clarification of their mechanisms of action have been expedited more recently by high-throughput screening systems, metabolomics-assisted bioprospecting, and in silico modelling.

A thorough analysis of phytoconstituents, their processes, and screening methods is essential, given the growing interest in natural antimicrobial preservatives and the requirement for safe and efficient methods to fight foodborne infections [2].

This study summarises what is now known about plant-derived antimicrobials that are effective against microbes that cause food poisoning, talks about the molecular mechanisms that underlie their action, and describes both traditional and sophisticated screening methods for identifying and characterising these substances. The goal is to offer a comprehensive viewpoint that encourages the creation of phytochemical-based interventions for better public health and food safety.

Medicinal plants with antimicrobial activity

Pathogenic microorganism-induced food poisoning is still a major worldwide public health concern. Food contamination and severe gastrointestinal infections are caused by common foodborne pathogens include Bacillus cereus, Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, and Salmonella spp. Interest in plant-derived antimicrobial compounds has increased due to rising resistance to traditional antibiotics and consumer demand for natural food preservatives. A wealth of bioactive phytochemicals that can prevent bacteria that cause food poisoning can be found in medicinal plants and culinary herbs [3].

Allium sativum (Garlic) has potent antibacterial action against a variety of foodborne infections. Allicin and other sulfur-containing substances have bactericidal effects on Salmonella, E. coli, and Staphylococcus aureus by upsetting microbial enzyme systems and compromising the integrity of cell membranes.

Curcuma longa (Turmeric) contains curcumin, which has antibacterial and anti-biofilm properties. Bacterial cell division is disrupted by curcumin, which also suppresses the expression of virulence factors in pathogens, including Bacillus cereus and Listeria monocytogenes.

Azadirachta indica (Neem) has long been utilised for its antibacterial qualities. Neem extracts are efficient against Salmonella and E. coli because they include limonoids, flavonoids, and tannins that prevent bacterial development by disrupting membranes and inhibiting enzymes.

Ocimum sanctum (Tulsi) possesses essential oils that are high in phenolics, including eugenol. By enhancing membrane permeability and interfering with the metabolic activities of both Gram-positive and Gram-negative foodborne bacteria, these chemicals have antimicrobial action [4].

Cinnamomum verum (Cinnamon) contains cinnamaldehyde, exhibits strong antibacterial activity against Listeria monocytogenes, Salmonella spp., and E. coli by interfering with membrane function and preventing energy metabolism.

Syzygium aromaticum (Clove) is rich in eugenol, has a potent bactericidal effect on microorganisms that produce toxins, including Bacillus cereus and Staphylococcus aureus.

Thymus vulgaris (Thyme) and *Origanum vulgare* (Oregano) contain thymol and carvacrol, which successfully prevent microbial growth and biofilm formation in foodborne pathogens.

Major phytochemical classes with reported anti-foodborne activity

Plant-derived antimicrobial drugs are effective against a variety of bacteria that cause food poisoning because they work through several, frequently complementary pathways. Phytochemicals work on several microbial targets at once, in contrast to traditional antibiotics that usually target a single biological route. This multi-target mechanism of action improves antibacterial activity while lowering the risk of resistance development. Plants produce a wide range of secondary metabolites called phytochemicals in response to biotic and abiotic stress. Among these, a number of classes have shown notable antibacterial potential against important foodborne pathogens, such as Bacillus cereus, Escherichia coli, Salmonella enterica, Staphylococcus aureus, and Listeria monocytogenes. Because of their structural diversity, they can interact with a variety of microbial targets, promoting broad-spectrum activity and lowering the risk of resistance formation. Below is a summary of the main phytochemical groups that have been shown to be important for food safety [5].

Phenolics and polyphenols

One of the most prevalent and well-researched types of antimicrobial phytochemicals are phenolic compounds. Simple phenols, phenolic acids (such as gallic, caffeic, and chlorogenic acids), stilbenes, coumarins, and complex polyphenols like tannins and ellagitannins are among them. Phenolics and polyphenols interact with membrane proteins and phospholipids to disrupt the integrity of cell membranes, precipitate proteins and inhibit enzymes, impair cellular metabolism, chelate metal ions, limit essential cofactors for microbial growth, and exhibit strong antioxidant/pro-oxidant behaviour that can cause oxidative stress in bacteria. Although some phenolics, such as gallic and chlorogenic acids, also prevent Gram-negative foodborne pathogens, they typically have a greater impact against Gram-positive bacteria [6].

Flavonoids

Flavones (apigenin, luteolin), flavanones (hesperidin, naringenin), isoflavones, and flavonols (quercetin, kaempferol) make up the vast family of flavonoids. At higher concentrations, they work by disrupting the integrity of the cytoplasmic membrane, inhibiting nucleic acid synthesis and energy metabolism, impairing bacterial virulence systems, including quorum sensing, modulating efflux pumps, and enhancing intracellular accumulation of antimicrobials. Staphylococcus aureus, Listeria monocytogenes, and E. coli have all been shown to be inhibited by flavonoids, frequently in concert with antibiotics [7].

Terpenoids and essential oil constituents

Terpenoids (mono-, sesqui-, and diterpenes) and chemicals found in essential oils (EO) are known to have strong antibacterial properties. Thymol, carvacrol, eugenol, citral, linalool, menthol, and borneol are important substances. Strong membrane-active characteristics, such as enhanced permeability, depolarization, and cellular content leakage, disruption of proton motive force and ATP synthesis, effective anti-biofilm activity even at sub-lethal concentrations, and quick bactericidal effects in comparison to many other phytochemical classes, are some of the ways they work. Although EO ingredients are especially effective against Listeria, Salmonella, and S. aureus, formulation changes are necessary for food applications because to their volatility and sensory impact [8].

Alkaloids

Alkaloids are nitrogen-containing substances with a variety of antibacterial qualities, including piperine, solanine, berberine, and sanguinarine. DNA intercalation, inhibition of nucleic acid synthesis, alteration of membrane potential, interference with cell division and cytoskeletal functions, and inhibition of ATP-dependent transport are the main mechanisms. alteration of efflux pump activity, which increases antibiotic susceptibility. When paired with membrane-permeabilizing drugs, berberine exhibits strong action against Staphylococcus aureus and Gram-negative bacteria [9].

Saponins and glycosides

Amphipathic glycosides containing triterpenoid or steroidal aglycones are known as saponins. They have the capacity to decrease biofilm biomass in foodborne pathogens, promote the uptake of other antimicrobial drugs by membrane destabilization, and increase membrane permeability and pore creation through surfactant-like activity. Their pH sensitivity and foaming properties frequently affect how well they work in food systems [10].

Organosulfur compounds

Bioactive sulfur compounds including allicin, diallyl sulfide, and ajoene, are found in plants belonging to the Allium genus, which includes onions and garlic. They work by disrupting vital bacterial metabolic processes, reacting with thiol-containing enzymes, exhibiting potent activity against both Gram-positive and Gram-negative food pathogens, and successfully suppressing strains that produce toxins like S. aureus. Although these substances show promise as natural preservatives, they become unstable at high temperatures [11].

Anti-microbial screening for food poisoning causing microorganisms, herbals and drug discovery pipeline

Foodborne illnesses, which are mostly brought on by pathogenic microbes contaminating food and water, continue to be a significant global public health concern. Food poisoning outbreaks are mostly caused by bacterial infections, including Salmonella spp., Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, and

Bacillus cereus. The need for new, safe, and efficient antimicrobial agents has increased due to the rising prevalence of antimicrobial resistance as well as the negative consequences of synthetic preservatives and antibiotics. In this regard, natural substances and herbal items have drawn a lot of interest as potential sources of antibacterial leads. Finding bioactive chemicals and incorporating them into the drug discovery process depends heavily on systematic antimicrobial screening. Food poisoning is often associated with eating food contaminated by pathogenic bacteria, fungi, or their toxins. Gram-negative bacteria like Campylobacter jejuni, Salmonella spp., and E. coli O157:H7 can cause gastrointestinal infections that manifest as fever, diarrhoea, and stomach pain [12].

Serious foodborne infections can be brought on by toxins generated by gram-positive bacteria such as Bacillus cereus, Listeria monocytogenes, and Staphylococcus aureus. Additionally, some fungi, such as Aspergillus flavus, indirectly contribute by creating mycotoxins that are dangerous to long-term health. These microorganisms are the main target of antimicrobial screening programs [13].

In vitro antimicrobial screening methods

Antimicrobial potential is first assessed using in vitro screening techniques. Zones of inhibition in the disk diffusion experiment, which is frequently used for initial screening, show microbial susceptibility. The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC), which provide quantitative indicators of antibiotic activity, are found using broth micro dilution and agar dilution procedures. While anti-biofilm assays evaluate test chemicals' capacity to stop or interfere with biofilm development, a crucial component of persistent food contamination, time-kill kinetic assays aid in differentiating between bacteriostatic and bactericidal effects [14].

Agar diffusion methods

The initial assessment of antibacterial activity is frequently conducted using agar diffusion techniques. In the disk diffusion method (Kirby-Bauer assay), sterile filter paper disks are impregnated with test substances and then placed on agar plates that have been infected with the target microorganism. The antibacterial potency is evaluated by measuring the zones of inhibition surrounding the disks after incubation. In a similar vein, liquid extracts or chemicals are introduced using wells punched into agar plates in the agar well diffusion method. These techniques are straightforward and efficient for qualitative screening, although the test substance's solubility and diffusion characteristics may have an impact on the outcomes [15].

Broth dilution methods

By calculating the minimum inhibitory concentration (MIC), broth dilution tests offer a quantitative assessment of antimicrobial activity. In microtiter plates with standardised microbiological inocula, serial dilutions of test substances are made using the broth microdilution method. Following incubation, microbial growth is evaluated visually or via spectrophotometry. Subculturing non-turbid wells into agar plates to assess microbial viability can yield the minimum bactericidal concentration (MBC). These techniques are popular for comparative antibacterial research because they are very reproducible [16].

Agar dilution method

In the agar dilution method, different doses of the test substance are directly added to molten agar medium, and then microbial strains are inoculated. Microbial growth is evaluated to ascertain inhibitory concentrations following incubation. Although this approach is more labour-intensive than broth-based assays, it is especially helpful for assessing substances with limited diffusion ability and yields accurate quantitative findings [17].

Time-kill kinetic assays

Time-kill experiments assess the rate and degree of microbiological death at particular test drug concentrations over a predetermined amount of time. To differentiate between bacteriostatic and bactericidal effects, microbial counts are monitored at predefined intervals. Time-kill assays help dose optimization and mechanism-based evaluation by offering insightful information about the dynamic interaction between antimicrobial drugs and bacteria [18].

Anti-biofilm assays

In food processing environments, biofilm development plays a major role in the persistence of foodborne pathogens. Anti-biofilm tests evaluate a compound's capacity to prevent the production of new biofilms or break up existing ones. While metabolic tests like resazurin or XTT assess biofilm vitality, the crystal violet staining method is frequently employed to measure biofilm biomass. When screening antimicrobials that target resistant microbial communities, these tests are essential [19].

Molecular and rapid screening methods

Molecular techniques like quantitative polymerase chain reaction (qPCR) are used in advanced in vitro screening methods to measure changes in microbial load and gene expression after treatment. Antimicrobial effects can be quickly and accurately detected using reporter gene assays and fluorescence-based viability assays. These techniques improve throughput and provide a mechanistic understanding of antibacterial activity [20].

CONCLUSION

Food safety and global public health continue to be seriously threatened by food poisoning brought on by pathogenic microbes. The critical need for alternative antimicrobial methods is highlighted by the rising incidence of antimicrobial resistance and the drawbacks of traditional antibiotics. Early detection of effective drugs against foodborne pathogens such Salmonella spp., Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, and Bacillus cereus depends heavily on antimicrobial screening. Antimicrobials derived from plants are a promising and sustainable source of bioactive substances with multi-target modes of action and broad-spectrum activity. Numerous phytochemicals found in medicinal plants and culinary herbs can prevent microbial growth, interfere with the creation of biofilms, and reduce the production of toxins. Their potential use in food preservation and the creation of antimicrobial drugs is further supported by their natural origin, relative safety, and compatibility with food systems. The smooth transition of plant-based antimicrobials from laboratory research to practical application is hampered by a number of methodological and translational issues, despite promising in vitro results. Reproducibility and therapeutic relevance are hampered by phytochemical composition variability, lack of standardisation, low bioavailability, and insufficient prediction models. It is crucial to address these issues using improved translational models, mechanism-based evaluation, and standardised screening procedures.

In conclusion, incorporating plant-based antimicrobial screening into the drug discovery process provides a workable strategy to fight microbes that cause food poisoning. Transforming potential plant-derived antimicrobials into safe and effective interventions for food safety and public health will require ongoing interdisciplinary research that focuses on standardization, formulation, safety assessment, and regulatory alignment.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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