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Popular Article

Garlic: Nature's Powerful Antibacterial

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ABSTRACT

Garlic (*Allium sativum* L.) is globally recognized for its culinary and medicinal uses, and historical evidence supports its role in disease prevention and treatment. It is rich in sulfur-containing bioactive compounds such as ajoene, S-allyl-cysteine, allicin, alliin, and diallyl sulfide. Garlic extracts and oil display a wide range of biological activities, including anti-inflammatory, antibacterial, antifungal, antiviral, antiparasitic, antioxidant, and immunomodulatory effects, as well as protective actions on the cardiovascular system, liver, digestive tract, kidneys, and nervous system, plus anticancer, anti-diabetic, and anti-obesity properties. In this review, we briefly discuss the principal bioactive compounds of garlic and the antibacterial effects of garlic extracts against diverse pathogenic bacteria, highlighting the potential of garlic as a functional food or nutraceutical for disease prevention and management.

Key words: *Allium sativum* L, antibacterial, disease prevention

1. INTRODUCTION

Allium sativum L., a species of Allium in the Amaryllidaceae family, originates from Central Asia and northeastern Iran. Garlic has been cultivated and used worldwide for millennia as a culinary seasoning and traditional medicinal agent. The bulb, typically composed of 10–20 cloves, is the primary portion consumed and employed therapeutically. Garlic has been used to treat infections, wounds, leprosy, cardiovascular disorders, and hypertension in ancient medical systems, including those in China and Greece. Modern epidemiological investigations and clinical trials have further corroborated the health benefits of garlic, linking its consumption to antimicrobial activity. These historical uses, together with contemporary evidence, underpin the ongoing interest in garlic as a functional food and therapeutic supplement.

2. Phytochemical Composition

Garlic contains a variety of phytochemicals with significant bioactivity (Table 1):

- Organosulfur compounds: Allicin, ajoene, diallyl sulfide, diallyl disulfide, diallyl trisulfide, and S-allyl-cysteine are the major bioactive sulfur-containing compounds in garlic and exhibit antimicrobial activity against a wide range of microorganisms.
- Flavonoids: Flavanols, flavanones, and flavones are antioxidants with anticancer and antidiabetic properties.
- Saponins: Various saponosides exhibit antitumor, antioxidant, and cholesterol-lowering effects.
- Phenols: β-resorcylic acid, pyrogallol, and quercetin have broad protective effects, including anti-inflammatory and cardiovascular benefits.
- Terpenoids: Citral, geraniol, and linalool possess antimicrobial and immunomodulatory activities.

Allicin, one of the most extensively studied bioactive compounds in garlic, is not naturally present in the intact cloves. It is formed when alliin is converted by the enzyme alliinase following the crushing or chopping of garlic cloves. Because allicin is chemically unstable and quickly breaks down into other sulfur-containing compounds, garlic's biological effects can vary widely depending on the processing methods, storage conditions, and the form in which it is prepared.

Table 1: Phytochemical properties of garlic and major bioactive compounds present in them.

S. No	Phytochemical	Principle Bioactive Compound	Properties
1	Organosulfur compounds	Allicin (diallyl-dithiosulfinate), Z-ajoene, DAS, DADS, DATS, SAC, and S-allyl-cysteine sulfoxide	Potential to treat various multidrug-resistant bacterial infections in addition to viral and fungal diseases.
2	Flavonoid	Flavanols, Flavanones and Flavones	It protects cells from oxidative damage, exhibits potent anticancer activity, and mitigates diabetes.
3	Saponin	Desgalactotigonin-rhamnose, proto-desgalactotigonin, proto-desgalactotigonin-rhamnose, voghieroside D1, sativoside B1-rhamnose, and sativoside R1	It exerts anti hypercholesterolemic and antibacterial effects. Additionally, saponins exhibit antitumor, antioxidant, and antimutagenic activities and may reduce cancer risk by inhibiting tumor cell growth.
4	Phenols	β-resorcylic acid, pyrogallol, gallic acid, rutin, protocatechuic acid, quercetin	It has antioxidant, antiobesity, neuroprotective, hepatoprotective, and renoprotective properties.
5	Terpenoids	Citral, geraniol, linalool	Antimicrobial, antifungal, antiparasitic, antiviral, anti-allergenic, antispasmodic, antihyperglycaemic, anti-inflammatory, and immunomodulatory properties.

diallyl sulfide (DAS), diallyl disulfide (DADS), diallyl trisulfide (DATS), S-allyl-cysteine (SAC), and S-allyl- cysteine sulfoxide, respectively.

3.Antibacterial Activity

Garlic has traditionally been used in the management of infectious diseases and has demonstrated antibacterial activity in numerous laboratory investigations. The antibacterial potency of garlic is mainly attributed to allicin, which inhibits sulfhydryl enzymes that are critical for bacterial survival. Garlic extracts also show synergistic effects with antibiotics such as streptomycin, vancomycin, and ciprofloxacin, enhancing their efficacy against resistant strains. It has exhibited antibacterial activity against multiple Gram--

3.1 Against Staphylococcus *aureus* and Escherichia *coli:* Garlic extracts have a stronger bactericidal effect on gram-positive bacteria, such as *Staphylococcus aureus,* than on gram-negative bacteria, such as *Escherichia coli.* For example, aqueous and ethanolic garlic extracts showed inhibition zones for *S. aureus* ranging from approximately 9.5 mm at low concentrations (10 mg/mL) to 18.2 mm at higher concentrations (100 mg/mL). For *E. coli,* the inhibition zones were smaller, ranging from approximately 7.8 mm to 15.6 mm at identical concentrations (Nisa et al., 2025). The MIC values 8 mg/mL were reported for *S. aureus* and 16 mg/mL for *E. coli,* with minimum bactericidal concentrations (MBC) of 16 mg/mL for *S. aureus* and 32 mg/mL for E. coli. This indicates that higher concentrations are required to inhibit and kill *E. coli* than *S. aureus* (Nisa et al., 2025). Similarly, other studies confirmed MICs of approximately 125 mg/mL for both *S. aureus* and *E. coli* from garlic extracts, with slightly higher bactericidal concentrations (250 mg/mL and 500 mg/mL, respectively). The inhibition zones at 500 mg/mL were approximately 30 mm for *S. aureus* and 24.5 mm for *E. coli,* suggesting a dose-dependent effect (Sonme & Ogbu, 2026).

3.2 Against Propionibacterium acnes (associated with acne): Ethanol garlic extracts showed significant antibacterial activity against *P. acnes.* At 10 %, 40 %, 70 %, and 100% concentrations, the inhibition zones were approximately 15.3, 26.6, 28.9, and 32.8 mm, respectively, compared to 38.8 mm for doxycycline. Among these, the 70% concentration showed particularly favorable activity, balancing efficacy, and concentration (Seran et al., 2025).

3.3 Against Multidrug-Resistant (MDR) Salmonella*:* Garlic extract has demonstrated potential in reducing biofilm formation by up to 70% and lowering MIC values for resistant *Salmonella* strains, supporting its capacity as a natural antimicrobial against challenging pathogens (Ebrahim 2022).

3.4 Against Uropathogenic E. *coli:* When combined with ciprofloxacin, garlic extract acted synergistically, enhancing bacterial inhibition zones up to 34 mm compared to 25 mm for garlic alone, and matching the MIC and MBC values of ciprofloxacin at 10 µg/mL and 15 µg/mL, respectively. This suggests an adjuvant role for garlic in the treatment of resistant urinary tract infections (Ali et al., 2025).

3.5 Against Salmonella *typhi:* Water and other solvent extracts of garlic showed antimicrobial effects, with the highest inhibition zone (14 mm) at 800 mg/mL for *Salmonella typhi* clinical isolates. This was effective even against multidrug-resistant isolates, indicating the potential of garlic in drug formulations for typhoid (Olukunle & Adenola, 2019).

3.6 Against Bacillus *anthracis:* Aqueous garlic extract (AGE) exhibits strong anti-Bacillus anthracis activity. When applied at concentrations ranging from 0– 3.6% (w/v), AGE inhibited the growth of exponentially growing *B. anthracis* in a dose-dependent manner. Concentrations ≥1.9% (w/v) completely suppressed *B. anthracis* growth, whereas lower concentrations progressively retarded growth depending on the dose (Kaur et al., 2021). The minimum inhibitory concentration (MIC) for *B. anthracis* was ≤20 mg/mL, which is lower than the previously reported MIC range for gram-positive bacteria (142.7–35.7 mg/mL) but falls within the MIC range observed for gram-negative strains (35.7–1.1 mg/mL) (Duke et al., 2008).

4. Mechanisms of Action

The antimicrobial effects of garlic are primarily due to allicin and ajoene, which react with thiol groups in enzymes that are critical for microbial metabolism. Allicin inhibits cysteine proteinases, alcohol dehydrogenases, and thioredoxin reductases, thereby disrupting the redox balance and enzyme function in microorganisms. It also partially inhibits DNA, RNA, and protein synthesis. Ajoene inhibits phosphatidylcholine biosynthesis in pathogens. The broad-spectrum antimicrobial activity results from multiple enzyme targets with varying sensitivities to different microbes.

5. Other Biological Functions

Garlic exerts diverse health benefits in addition to antimicrobial activity. It has hypocholesterolemic, hypolipidemic, and antihypertensive effects, reducing LDL cholesterol and triglyceride levels, thus preventing atherosclerosis and cardiovascular diseases (CVDs). Garlic compounds inhibit platelet aggregation and promote fibrinolysis, contributing to their antithrombotic effect. It also exhibits anticancer potential by inhibiting mitosis in tumor cells and demonstrating antileukemic activity. Garlic possesses antioxidant and neuroprotective properties that have shown potential benefits in experimental models of dementia and Alzheimer's disease; however, further clinical validation is required.

6. Safety Profile and Adverse Effects of Garlic

Garlic is generally considered safe when consumed in culinary amounts, but higher doses used medicinally can cause certain side effects. The most frequently reported adverse effects include: (i) body odor and garlic breath due to sulfur-containing compounds such as allicin and ajoene; (ii) gastrointestinal discomfort, including nausea, heartburn, flatulence, and diarrhea, especially when consumed in large quantities or as concentrated extracts; and (iii) bleeding due to garlic’s antithrombotic and fibrinolytic activities, which can increase the risk of bleeding, especially in patients taking anticoagulants or antiplatelet drugs. Garlic can potentiate the effects of blood thinners, such as warfarin, increasing bleeding risk. It can also interact with cardiovascular drugs: A study on rats showed garlic altered the pharmacokinetics of amlodipine, losartan, enalapril, and carvedilol, changing their plasma concentrations and half-lives, which could necessitate dose adjustments and careful monitoring to avoid toxicity or reduced efficacy (Pawar & Dhaminigi, 2019), (iv) Reproductive and Toxicological Considerations: Garlic has shown protective antioxidant effects in animal studies—for instance, ameliorating busulfan-induced testicular toxicity by improving sperm quality and reducing oxidative stress, suggesting some safety in reproductive contexts (Soleimanzadeh et al., 2018), (v) Allergic and Sensitivity Reactions: Although uncommon, garlic can cause allergic contact dermatitis or other allergic reactions in sensitive individuals. Topical exposure to raw garlic can induce skin irritation and burns; therefore, care should be taken when applying garlic topically. (vi) Garlic may reduce the efficacy of certain antiviral drugs, such as saquinavir, which is used for HIV treatment. Some individuals may experience mild headaches or flushing.

7. Future Prospects

With the rise in antibiotic resistance, the bioactive compounds of garlic offer promising leads for developing new antimicrobial agents. Further research is needed to isolate and characterize these compounds, elucidate their molecular mechanisms of action, determine optimal dosage regimens, and evaluate their efficacy and safety in well-designed clinical studies. Investigations into the effects of processing (fermentation, heat) on garlic bioactivity and more clinical trials are needed to support its therapeutic applications. Garlic's multifunctional properties make it a promising source of bioactive compounds for future drug discovery and functional food development.

8. CONCLUSION

Garlic is a widely used spice with significant medicinal properties attributed to its rich content of sulfur-containing bioactive compounds. It exhibits broad antimicrobial, antioxidant, anti-inflammatory, cardioprotective, anticancer, and immunomodulatory properties. Garlic and its derivatives are generally considered safe when consumed as part of a normal diet; however, high-dose supplementation may cause adverse effects or interact with certain medications. Nevertheless, garlic holds considerable potential as a functional food and nutraceutical for disease prevention and health promotion purposes. Continued research and clinical validation will enhance our understanding and utilization of the health benefits of garlic.

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