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Garlic (*Allium sativum*): Pharmacological Insights and Therapeutic Potential

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Abstract
Garlic (*Allium sativum*) has long been used in traditional medicine for its health-promoting properties, and contemporary research supports its diverse pharmacological effects, including antimicrobial, antioxidant, anticancer, antiviral, and cardiometabolic benefits. This review evaluates the therapeutic potential of garlic, focusing on its bioactive compounds and their effects on human health, including antimicrobial activity, cardiovascular protection, glycemic control, antioxidant capacity, and anticancer effects. Garlic's pharmacological effects are largely attributed to sulfur-containing compounds such as allicin, ajoene, and diallyl sulfides, which act on microbial cells, oxidative pathways, and immune mechanisms to produce antimicrobial, antifungal, antiviral, cardioprotective, hypoglycemic, and anticancer effects. Evidence from *in vitro, in vivo,* and epidemiological studies indicates that garlic inhibits a broad spectrum of bacteria, fungi, and viruses, including antibiotic-resistant strains. Garlic reduces cholesterol, modulates platelet aggregation, enhances fibrinolysis, and improves glycemic control, while its bioactive compounds suppress carcinogenesis, inhibit tumor growth, and stimulate immune responses. Additionally, garlic protects against oxidative stress and supports detoxification pathways, and in agricultural and food systems, it effectively prevents microbial contamination. Overall, garlic demonstrates significant therapeutic potential as a natural and complementary agent, with its bioactive compounds conferring antimicrobial, cardiometabolic, antioxidant, anticancer, and antiviral benefits. Standardized formulations and dosage optimization are recommended to expand its clinical and preventive applications.

Keywords: Antimicrobial activity; Antioxidant; Garlic (*Allium sativum*); Natural medicine; Therapeutic potential

Abstrak

Bawang putih (Allium sativum) telah lama digunakan dalam pengobatan tradisional karena sifatnya yang mendukung kesehatan, dan penelitian kontemporer mendukung berbagai efek farmakologisnya, termasuk aktivitas antimikroba, antioksidan, antikanker, antivirus, serta manfaat kardiometabolik. Tinjauan ini mengevaluasi potensi terapeutik bawang putih, dengan fokus pada senyawa bioaktifnya dan efeknya terhadap kesehatan manusia, termasuk aktivitas antimikroba, perlindungan kardiovaskular, pengendalian glikemik, kapasitas antioksidan, dan efek antikanker. Efek farmakologis bawang putih sebagian besar disebabkan oleh senyawa mengandung sulfur seperti allicin, ajoene, dan diallyl sulfide, yang bekerja pada sel mikroba, jalur oksidatif, dan mekanisme imun untuk menghasilkan efek antimikroba, antijamur, antivirus, kardio protektif, hipoglikemik, dan antikanker. Bukti dari penelitian in vitro, in vivo, dan epidemiologis menunjukkan bahwa bawang putih menghambat spektrum luas bakteri, jamur, dan virus, termasuk strain yang resisten terhadap antibiotik. Bawang putih menurunkan kolesterol, memodulasi agregasi trombosit, meningkatkan fibrinolisis, dan memperbaiki pengendalian glikemik, sementara senyawa bioaktifnya

menekan karsinogenesis, menghambat pertumbuhan tumor, dan merangsang respons imun. Selain itu, bawang putih melindungi terhadap stres oksidatif dan mendukung jalur detoksifikasi, serta dalam sistem pertanian dan pangan, efektif mencegah kontaminasi mikroba. Secara keseluruhan, bawang putih menunjukkan potensi terapeutik yang signifikan sebagai agen alami dan pelengkap, dengan senyawa bioaktifnya memberikan manfaat antimikroba, cardiometabolic, antioksidan, antikanker, dan antivirus. Formulasi standar dan optimasi dosis direkomendasikan untuk memperluas aplikasi klinis dan preventifnya.

***Kata Kunci**: Aktivitas antimikroba; Antioksidan; Bawang putih (Allium sativum); Obat alami; Potensi terapeutik*

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Introduction

Natural medicines have been used for centuries as primary remedies in traditional healthcare systems worldwide. Among these, garlic (Allium sativum) has gained considerable attention due to its wide-ranging therapeutic properties. Traditionally employed for its antimicrobial, cardiovascular, and digestive benefits, garlic has now been extensively studied for its pharmacological potential, supported by both laboratory and clinical evidence (do C. Cupertino et al., 2025; Abd El-Khalek et al., 2025; Barbole et al., 2024). Modern pharmacology recognizes garlic as a source of bioactive compounds capable of modulating physiological and pathological processes, bridging traditional knowledge and contemporary science (Lestari et al., 2025; Park et al., 2025; Saad et al., 2025).

Garlic (*Allium sativum*) continues to attract scientific interest due to its diverse therapeutic effects. Recent studies demonstrate that garlic is not only a common dietary component but also a biologically active natural product capable of inhibiting bacterial, fungal, and viral growth, including antibiotic-resistant strains (Sul et al., 2025; Barbole et al., 2024). Beyond antimicrobial activity, garlic has been shown to possess antihypertensive, anti-glycemic, antioxidant, detoxifying, anticancer, antiviral, and antifungal properties, as well as anti-thrombotic effects, highlighting its broad systemic impact (Al-Snafi, 2025; Abd El-Khalek et al., 2025). These diverse biological activities position garlic as a versatile natural therapeutic agent with both preventive and treatment potential.

This study examines garlic's therapeutic potential by analyzing its antimicrobial effects, cardiovascular and metabolic benefits, antioxidant and detoxifying roles, and cancer-preventive properties. Each section focuses on specific mechanisms of action supported by *in vitro, in vivo*, and epidemiological evidence (do C. Cupertino et al., 2025; Lestari et al., 2025). The central argument is that garlic represents a valuable natural medicine capable of complementing conventional therapies, contributing to disease prevention, and supporting overall health.

This study offers several novel contributions by bridging laboratory research and clinical application. It expands understanding of garlic's antimicrobial spectrum, showing efficacy against resistant strains, and highlights mechanistic insights into its bioactive compounds (Abd El-Khalek et al., 2025; Park et al., 2025). The findings elucidate how garlic modulates key physiological and pathological processes, positioning it as an innovative complementary strategy for preventing and managing cardiovascular, metabolic, and oxidative stress–related disorders while integrating traditional remedies into modern healthcare (Saad et al., 2025; Sul et al., 2025).

Literature Review

Garlic (*Allium sativum*) contains a rich array of sulfur-containing compounds, including allicin, diallyl sulfide, diallyl disulfide, and S-allyl cysteine, which are largely responsible for its broad pharmacological activities (Abd El-Khalek et al., 2025; Lestari et al., 2025). Allicin, generated when garlic is crushed or chopped, exhibits strong antimicrobial and antioxidant effects, while other organosulfur compounds contribute to cardiovascular protection, anti-inflammatory action, and anticancer properties. Flavonoids, saponins, and trace minerals further enhance garlic's therapeutic potential (Park et al., 2025; Saad et al., 2025).

Numerous studies have demonstrated garlic's antimicrobial activity against bacteria, fungi, and viruses, including antibiotic-resistant strains (Barbole et al., 2024; Sul et al., 2025). However, most evidence is derived from *in vitro* experiments or epidemiological observations, leaving gaps regarding optimal dosage, bioavailability, and long-term clinical efficacy in humans, particularly in populations at risk of resistant infections. Similarly, garlic's cardiovascular and metabolic benefits, such as blood pressure reduction, cholesterol modulation, and glycemic control, are well-documented (Al-Snafi, 2025), yet large-scale, controlled clinical trials are still needed to clarify mechanisms and standardize dosing.

While antioxidant, detoxifying, anticancer, and antiviral effects have been reported, most research focuses on isolated bioactive compounds, limiting understanding of the synergistic effects of whole garlic consumption *in vivo.* Mechanistic studies have explored garlic's modulation of enzymatic pathways, signal transduction, and gene expression related to inflammation, oxidative stress, and immune responses (Abd El-Khalek et al., 2025; Lestari et al., 2025), but translation into practical therapeutic applications remains incomplete. Integrative approaches combining garlic with conventional therapies show promise, yet systematic evaluations of safety, efficacy, and potential interactions are lacking (Saad et al., 2025). Addressing these knowledge gaps is essential to establish garlic as a reliable and standardized complementary therapy in modern pharmacology.

Method

This study employed a literature review as the primary method, systematically collecting and analyzing peer-reviewed articles, clinical trials, and epidemiological studies on garlic (*Allium sativum*) and its pharmacological properties (Abd El-Khalek et al., 2025; Lestari et al., 2025; Barbole et al., 2024). Databases including PubMed, Scopus, and Google Scholar were searched using keywords such as "garlic," "antimicrobial," "antioxidant," "anticancer," and "therapeutic potential" (Al-Snafi, 2025; Park et al., 2025). Selected studies were critically evaluated for relevance, methodological quality, study design, and outcomes, ensuring inclusion of the most recent and robust evidence (Saad et al., 2025; Barbole et al., 2024). Data synthesis integrated findings from *in vitro, in vivo*, and clinical research to identify consistent patterns, mechanistic insights, and knowledge gaps. This approach enabled a comprehensive and up-to-date understanding of garlic's bioactive compounds, their mechanisms of action, and their potential applications in modern therapeutic contexts, particularly for cardiovascular, metabolic, antimicrobial, and oxidative stress–related disorders (Abd El-Khalek et al., 2025; Lestari et al., 2025; Park et al., 2025).

Result and Discussion

Garlic's Role in Controlling Pathogenic and Drug-Resistant Microorganisms

Garlic (*Allium sativum*) exhibits broad-spectrum antimicrobial properties, which form the basis for both traditional and modern therapeutic applications (Barbole et al., 2024; Park et al., 2025). Recent studies have demonstrated that garlic extracts effectively inhibit pathogenic bacteria, including Escherichia coli, Salmonella typhi, and multidrug-resistant strains, highlighting its potential as a complementary or alternative antimicrobial agent (Mauro et al., 2022; Barbole et al., 2024). Encapsulated and nano-formulated garlic preparations have further enhanced stability and bioavailability, resulting in improved antibacterial efficacy against resistant pathogens (Abd El-Khalek et al., 2025; Lestari et al., 2025). In food safety applications, garlic has shown significant potential to control foodborne pathogens. Encapsulated garlic extracts and oils inhibit Salmonella, E. coli, and Bacillus species, preventing spore germination and toxin production under storage and processing conditions (Ramirez et al., 2021; Park et al., 2025). These findings underscore garlic's dual role as both a culinary ingredient and a natural preservative, offering practical strategies to reduce foodborne illnesses.

Garlic also demonstrates promise against chronic infectious diseases such as tuberculosis. *In vitro* studies reveal that garlic extracts inhibit Mycobacterium tuberculosis, including multi-drug resistant strains, while dietary garlic reduces coliform and anaerobic bacterial populations *in vivo,* indicating potential adjunctive effects on gut microbiota and host immunity (Barbole et al., 2024; Abd El-Khalek et al., 2025).

Furthermore, garlic's activity extends to oral health. Contemporary studies report that garlic extracts, particularly those rich in allicin, effectively suppress oral pathogens and reduce bacterial load in human trials, supporting its integration into oral hygiene products (Saad et al., 2025; Park et al., 2025). These findings highlight the multifaceted antimicrobial potential of garlic, emphasizing its relevance as a natural, safe, and effective agent for both systemic and localized infections.

Antifungal Properties of Garlic (Allium sativum)

Garlic (*Allium sativum*) exhibits broad-spectrum antifungal activity, effective against both human and plant pathogens, highlighting its potential in medical and agricultural applications (Barbole et al., 2024; Lestari et al., 2025). Recent research demonstrates that garlic's bioactive compounds, particularly allicin and ajoene, inhibit the growth of dermatophytes, Candida species, and Aspergillus strains, including pathogens resistant to conventional antifungals (Saad et al., 2025; Abd El-Khalek et al., 2025). Nano-formulated and encapsulated garlic preparations have further enhanced stability, bioavailability, and antifungal efficacy, providing innovative delivery methods for both clinical and agricultural use (Lestari et al., 2025).

In agricultural applications, garlic extracts suppress fungal colonization and spore germination in plant pathogens such as Fusarium, Colletotrichum, and Alternaria, without damaging crops (Park et al., 2025). These findings underscore garlic's potential as a natural fungicide, offering sustainable alternatives for crop protection while minimizing chemical pesticide use.

For human health, garlic has demonstrated efficacy against Candida albicans, the causative agent of thrush and other mucosal infections. Recent *in vitro and in vivo* studies indicate that aqueous and oil-based garlic extracts can eliminate fungal growth, reduce

virulence, and outperform some conventional antifungal medications in terms of efficacy and safety (Saad et al., 2025; Lestari et al., 2025). Additionally, topical and systemic formulations have shown promise in treating dermatologic and ocular fungal infections, providing non-toxic, natural alternatives to standard pharmacologic treatments (Abd El-Khalek et al., 2025; Barbole et al., 2024).

Collectively, these findings highlight garlic as a versatile antifungal agent with applications in both clinical therapy and sustainable agriculture. The recent advances in nano-encapsulation and bioactive stabilization not only improve its therapeutic potential but also provide innovative pathways for integrating garlic into modern healthcare and crop management strategies.

Bioactive Compounds of Garlic: Antifungal and Antiviral Applications

Garlic (*Allium sativum*) contains multiple bioactive compounds, including allicin and ajoene, which contribute to its potent antifungal and antiviral activities (Abd El-Khalek et al., 2025; Lestari et al., 2025). Recent *in vivo* studies confirm garlic's efficacy against Candida albicans and other pathogenic fungi. For instance, nano-encapsulated garlic formulations accelerated recovery in experimental models of candidiasis, achieving full clearance of infections within days, while untreated controls exhibited persistent lesions (Lestari et al., 2025). Topical applications similarly demonstrated rapid healing in dermatologic fungal infections, supporting garlic's practical therapeutic potential (Barbole et al., 2024).

Garlic also shows promise against systemic fungal infections, including central nervous system infections caused by encapsulated yeasts such as Cryptococcus species. Nano- and parenteral garlic formulations exhibited measurable antifungal activity in serum and cerebrospinal fluid, with minimal side effects, highlighting potential clinical applications for severe fungal infections (Abd El-Khalek et al., 2025; Saad et al., 2025). The effectiveness of garlic is largely attributed to allicin, ajoene, allyl methyl, and methylene thiosulfate, whose antifungal efficacy can vary depending on strain susceptibility and synergistic interactions among compounds (Barbole et al., 2024; Lestari et al., 2025).

Beyond antifungal activity, garlic demonstrates broad-spectrum antiviral properties. Recent studies show that raw, aged, and fermented garlic extracts inhibit viral replication and exhibit virucidal effects *in vitro and in vivo*, including against influenza and rotavirus, without significant cytotoxicity (Park, 2025; Saad et al., 2025). Encapsulation technologies further improve stability and bioavailability, enhancing antiviral potency while maintaining safety profiles (Lestari et al., 2025).

Overall, these findings highlight garlic as a versatile natural agent with both antifungal and antiviral efficacy. Advances in nano-formulation and encapsulation have expanded its therapeutic applications, offering innovative strategies for treating fungal and viral infections while bridging traditional knowledge with modern pharmacological approaches.

Cardioprotective and Cancer-Preventive Effects of Garlic

Garlic (*Allium sativum*) has demonstrated significant cardiovascular benefits, including modulation of platelet aggregation, fibrinolytic activity, and serum lipid and cholesterol levels. Recent studies highlight that garlic supplementation reduces cholesterol, triglycerides, and LDL in both humans and animal models, with effects sustained over extended periods (Abd El-Khalek et al., 2025; Lestari et al., 2025). Nano-

encapsulated garlic formulations have shown enhanced bioavailability, leading to improved lipid profile regulation and reduced aortic atherosclerosis in experimental models, underscoring its potential as a natural therapeutic strategy for cardiovascular health (Barbole et al., 2024).

Garlic also positively influences coagulation and fibrinolysis. Evidence indicates that ajoene and other organosulfur compounds inhibit platelet aggregation and thrombus formation by interacting with key platelet components and modulating arachidonic acid pathways, with effects observable within hours of administration (Abd El-Khalek et al., 2025; Lestari et al., 2025). Notably, garlic retains fibrinolytic activity even after cooking, emphasizing its practical dietary benefits.

Beyond cardiovascular protection, garlic exhibits cancer-preventive properties. *In vitro and in vivo* studies demonstrate that compounds such as diallyl sulfide and allyl sulfide suppress carcinogen-induced lesions and tumor growth while enhancing immune responses through stimulation of T cells and natural killer cells (Saad et al., 2025). Epidemiological evidence supports reduced incidence of stomach cancer in populations consuming garlic regularly, suggesting its potential as a chemopreventive agent (Park, 2025).

Garlic's antioxidant and detoxifying effects further support its therapeutic versatility. Bioactive compounds including allicin and alliin mitigate oxidative stress, protect against lipid peroxidation, and counteract cellular damage caused by free radicals and toxic compounds, providing protective effects in cardiovascular and oncological contexts (Abd El-Khalek et al., 2025; Lestari et al., 2025).

Finally, garlic demonstrates notable anti-glycemic activity, improving glucose tolerance, increasing serum insulin levels, and enhancing hepatic glycogen storage in diabetic models (Lestari et al., 2025). These findings highlight garlic's multifaceted role as a natural agent supporting cardiovascular, metabolic, and overall systemic health, with modern delivery strategies enhancing its therapeutic potential.

Conclusion

Garlic (*Allium sativum*) is a multifunctional natural medicine with wide-ranging pharmacological benefits, including antimicrobial, antifungal, antiviral, cardiovascular, anticancer, antioxidant, detoxifying, and anti-glycemic effects. Evidence from *in vitro, in vivo*, and clinical studies consistently demonstrates that garlic's bioactive compounds, particularly allicin, ajoene, and organosulfur derivatives, contribute to these therapeutic effects. Beyond its traditional use, modern research highlights garlic's potential as a complementary agent in disease prevention, management of metabolic and cardiovascular disorders, and support for immune function. Given its safety, accessibility, and broad-spectrum efficacy, health policymakers should consider integrating garlic into public health strategies, such as dietary guidelines and preventive nutrition programs, to reduce the burden of chronic and infectious diseases. Additionally, further research should be promoted to optimize dosing, improve bioavailability, and explore synergistic effects with conventional therapies, ensuring garlic's full potential is harnessed in modern healthcare.

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