Review

A Literature-Based Comparative Analysis of the Antibacterial Effects of Garlic (*Allium sativum*), Ginger (*Zingiber officinale*), and Clove (*Syzygium aromaticum*) on *E. coli* ,*S.* aureus ,and *P. aeruginosa*

NourEldin Ayman *

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Article

A Literature-Based Comparative Analysis of the Antibacterial Effects of Garlic (*Allium sativum*), Ginger (*Zingiber officinale*), and Clove (*Syzygium aromaticum*) on *E. coli*, *S. aureus*, and *P. aeruginosa*

NourEldin Ayman

Independent Researcher; noureldin1805@gmail.com

Abstract: Background: The rising threat of antibiotic resistance has intensified the search for natural antimicrobial agents. Among these, plant-based compounds have shown promising potential in controlling pathogenic bacteria. Garlic (*Allium sativum*), Ginger (*Zingiber officinale*), and Clove (*Syzygium aromaticum*) are widely studied for their antimicrobial activities. Objective: This study aims to compare the reported antibacterial activities of the extracts of Garlic, Ginger, and Clove against three clinically relevant bacterial strains: *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, based solely on existing scientific literature. Methods: This is a literature-based analytical review. No experimental or laboratory procedures were performed. All data and interpretations are derived from previously published peer-reviewed articles and academic sources. The antibacterial activity, including inhibition zones, MIC values, and effects on biofilm formation, were collected and compared across selected studies. Results: According to the literature, Garlic exhibits significant antibacterial activity, particularly against *S. aureus* and *E. coli*, and demonstrates the ability to disrupt biofilms. Ginger shows moderate to strong effects on *E. coli* and *S. aureus*, with variable results against *P. aeruginosa*. Clove extract is noted for its potent inhibitory effects on both Gram-positive and Gram-negative strains, especially *E. coli*. The strength of activity varied depending on extraction methods and bacterial strain. Conclusion: The comparative literature analysis suggests that all three plant extracts possess notable antibacterial properties, with Garlic and Clove showing relatively higher efficacy across the selected strains. These findings support further exploration of plant-based antimicrobials, although direct experimental validation remains essential. (Note: This literature review was conducted using AI-assisted tools to synthesize and analyze existing published data.)

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1. Introduction

The emergence and rapid spread of antimicrobial resistance among pathogenic bacteria has become a global public health challenge, necessitating the exploration of alternative treatment options beyond conventional antibiotics. One promising area of research lies in the use of medicinal plants, which are known to possess diverse bioactive compounds with antimicrobial properties. Several plant species, such as *Allium sativum* (garlic), *Zingiber officinale* (ginger), and *Syzygium aromaticum* (clove), have been traditionally used for their therapeutic effects and are now being scientifically investigated for their potential role in combating bacterial infections and biofilm-associated resistance mechanisms.

Biofilms, which are structured communities of bacterial cells encased in a self-produced extracellular polymeric matrix, contribute significantly to chronic and recurrent infections. Their presence greatly increases bacterial tolerance to antibiotics and host immune defenses, rendering conventional therapies ineffective in many cases. Targeting biofilm formation and viability has thus become a critical objective in antimicrobial research.

Previous studies have demonstrated that extracts of *A. sativum*, *Z. officinale*, and *S. aromaticum* exhibit varying degrees of antibacterial and anti-biofilm activity against a range of Gram-positive

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and Gram-negative pathogens, including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa—organisms frequently associated with multidrug resistance and biofilm formation. These plant-derived compounds interfere with bacterial growth, quorum sensing, and adhesion mechanisms, suggesting their potential as effective antimicrobial agents.

In this study, we aim to comparatively assess the antimicrobial and anti-biofilm activities of garlic, ginger, and clove extracts against *S. aureus*, *E. coli*, and *P. aeruginosa*, using data extracted from previously published literature. The objective is to evaluate the relative efficacy of each plant extract and explore their potential application in developing plant-based antimicrobial strategies, especially in the context of biofilm-related infections.

2. Materials and Methods

In this comparative literature-based study, we investigated the antibacterial and antibiofilm effects of three medicinal plant extracts — *Allium sativum* (garlic), *Zingiber officinale* (ginger), and *Curcuma longa* (turmeric) — on three bacterial strains: Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa. The methodology followed a systematic selection of published experimental studies that evaluated the antibacterial and antibiofilm activity of the chosen plant extracts using standard microbiological assays, including disc diffusion methods, minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), and biofilm inhibition assays (e.g., microtiter plate method). All included studies were published in peer-reviewed journals and involved either ethanolic, methanolic, or aqueous plant extracts prepared under laboratory conditions. Only studies that used clinically relevant bacterial strains and quantified their antimicrobial outcomes using standard procedures were considered. The current work aimed to compare the antimicrobial efficacy of these three plant extracts against the selected bacteria, as reported in prior studies, to determine their relative strengths and potential applications in antibacterial treatments. No new experimental data were generated. All interpretations and comparisons were based solely on information extracted from the following peer-reviewed publications: [1–7].

3. Results and Comparative Analysis

3.1. Garlic (Allium sativum)

- **Planktonic Activity:**
  Garlic extracts showed no inhibition zones in disc diffusion assays, yet demonstrated strong antibacterial properties with MIC values ranging from 0.078 to 2.5 mg/mL, effectively inhibiting planktonic *E. coli*, *S. aureus*, and *P. aeruginosa*.
- **Anti-Biofilm Activity:**
  A dose-dependent inhibition of biofilm formation for all three species was observed—higher concentrations yielded greater biofilm suppression.

3.2. Ginger (Zingiber officinale)

- **Planktonic Activity:**
  Against *E. coli* and *S. aureus:*
  Fresh and dried ginger extracts produced inhibition zones ranging from 6–15 mm at high concentrations (up to 40 mg/mL) against both bacteria.
  MIC Values:
  MIC for both S. aureus and *E. coli* was approximately 2.5 mg/mL. The oil extract was inactive against *E. coli* in broth dilution tests.
  Against *P. aeruginosa*:
  A study on a multidrug-resistant clinical isolate showed:
  - $\sim$3 $\log_{10}$ CFU/mL reduction after 12 h treatment.
  - 68–85 % biofilm inhibition rate.

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- **Anti-Biofilm Activity:**
  Substantial 68–84.9 % inhibition of *P. aeruginosa* biofilm was documented

3.3. Clove (*Syzygium aromaticum*)

- **Antibacterial Activity:**
  The sources specify strong activity of clove oil (rich in eugenol) against multiple bacteria including *E. coli*, *S. aureus*, and *P. aeruginosa*.
- **MIC/Disc Data:**
  Some studies noted inhibition zones up to 25 mm against clinical isolates of S. aureus, with comparable effects on *E. coli* and *P. aeruginosa*.
- **Anti-Biofilm Activity:**
  Eugenol-rich clove extracts exhibited significant inhibition of biofilm formation by *P. aeruginosa* and other pathogens.

Table 1. Biofilm inhibition assessed via microtiter plate methods in cited studies..

Plant	*E. coli* Activity	*S. aureus* Activity	*P. aeruginosa* Activity
Garlic	MIC 0.078–2.5 mg/mL; strong inhibition in planktonic form; dose-dependent biofilm ‡	same as *E. coli*	same; dose-dependent biofilm ‡
Ginger	Inhibition zones 6–15 mm; MIC ≈ 2.5 mg/mL	Similar inhibition; MIC ≈ 2.5 mg/mL	3 $\log_{10}$ CFU reduction; 68–84.9 % biofilm inhibition
Clove	Inhibition zones up to 25 mm	Similar to *E. coli*	Significant biofilm inhibition documented

4. Discussion

The comparative evaluation of garlic, ginger, and clove extracts against *E. coli*, *S. aureus*, and *P. aeruginosa* reveals notable differences in their antibacterial and anti-biofilm activities.

4.1. Garlic (*Allium sativum*)

Despite the absence of visible inhibition zones in disc diffusion assays, garlic extracts showed potent bacteriostatic effects reflected in low MIC values between 0.078 and 2.5 mg/mL across all three bacteria. Additionally, the extracts exhibited a dose-dependent inhibition of biofilm formation, indicating that garlic's antimicrobial activity is concentration-dependent and effective in disrupting sessile bacterial communities.

4.2. Ginger (*Zingiber officinale*)

Ginger extracts displayed moderate to strong antibacterial activity against *E. coli* and *S. aureus*, with inhibition zones of 6–15 mm and MIC values around 2.5 mg/mL . However, its efficacy against *P. aeruginosa* was comparatively lower. Still, significant reductions in viable *P. aeruginosa* cells (∼3 $\log_{10}$ CFU) and 68–84.9% biofilm inhibition suggest that ginger has a meaningful role in attenuating both planktonic growth and biofilm formation, albeit to a lesser extent than garlic.

4.3. Clove (*Syzygium aromaticum*)

Clove extracts exhibited strong antibacterial activity, with inhibition zones reaching up to 25 mm against *E. coli* and *S. aureus*, and comparable efficacy against *P. aeruginosa* . The high eugenol content likely underlies clove's capacity to disrupt bacterial cell membranes and biofilm integrity.

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4.4. Comparative Insights

- Biofilm inhibition was most pronounced with garlic, which exhibited clear concentration-dependent effects against all three bacteria. Ginger and clove also reduced biofilm formation, especially in *P. aeruginosa*, but garlic's effect was comparatively stronger.
- Variable susceptibility: *P. aeruginosa* demonstrated more resistance overall, yet all three extracts could reduce planktonic growth and biofilm—clove through membrane disruption and ginger via moderate bactericidal effects.
- Extract concentration matters: Both garlic and ginger's antimicrobial effects were largely concentration dependent. In contrast, clove's effectiveness may be attributed more to the potency of its active compounds than to high concentration alone.

4.5. Limitations and Recommendations

The study is limited by its reliance on literature-based data without in-house experimentation or laboratory-controlled comparisons. Variations in extract preparation, bacterial strains, and assay protocols between studies may influence comparative conclusions. Future work is recommended to standardize extraction methods, conduct side-by-side lab experiments, and investigate combination therapies using these plant extracts.

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