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Allium spp. as a Source of Bioactive Antibacterials: A Review of Compounds, Mechanisms, and Effectiveness

Febry Rahmadhani Hasibuan[1]*, Aloysia Sri Pujiyanti[1], Annisa Nurul Ilmi[1], Nova Hariani[1]

[1]***Program Studi Biologi. Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Mulawarman***
Jl. Barong Tongkok, Gn. Kelua, Kota Samarinda, Kalimantan Timur 75242, Indonesia
Email: febryrahmadhani@fmipa.unmul.ac.id **Corresponding Author*

Abstract

***Allium spp.* has long been recognized for its diverse therapeutic benefits, particularly as a natural source of antibacterial agents. Various bioactive compounds found in *Allium spp.*, such as allicin, diallyl disulfide, ajoene, and quercetin, have demonstrated significant antimicrobial activity against both gram-positive and gram-negative bacterial pathogens. Research on the mechanisms of antibacterial action of these compounds reveals that they work by disrupting bacterial cell membranes, inhibiting protein synthesis, and interfering with bacterial metabolism. This literature review aims to examine existing studies on the antibacterial potential of *Allium spp.*, reviewing the bioactive compounds involved, their mechanisms of action, and their effectiveness in inhibiting bacterial growth, including antibiotic-resistant pathogens such as methicillin- resistant *Staphylococcus aureus* (MRSA) and *Escherichia coli*. The findings of this review indicate that while their effectiveness may vary depending on the specific compound and form of application, *Allium spp.* shows considerable promise as a natural alternative for combating bacterial infections and addressing the growing issue of antibiotic resistance. This article provides deeper insights into the relevance and potential of *Allium spp.* in the development of antimicrobial therapies based on natural sources through a literature-based approach.**

Keywords: *Allium spp*, antibacteria, gram-negative bacteria, gram-positive bacteria, active compounds

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Introduction

Bacterial infections are one of the main challenges in the world of health and the food industry. Increasing bacterial resistance to synthetic antibiotics encourages the search for alternative antibacterial materials that are safer, more effective, and environmentally friendly. One potential source that has been widely studied is the Allium genus, which includes various plants such as garlic (*Allium sativum*), shallots (*Allium cepa*), hobo onions (*Allium chinenese G.Don*), lanang onions and onions (*Allium fistulosum*). These plants are known to have various bioactive compounds that play a role in antibacterial activity. Various studies have shown that *Allium spp.* contain active compounds such as allicin, saponins, flavonoids, and organosulfur that have the ability to inhibit the growth of pathogenic bacteria (Octiara *et al.*, 2024). The mechanism of action of these compounds varies, ranging from damaging bacterial cell membranes, inhibiting essential enzymes, to increasing the production of reactive oxygen species (ROS) that can cause bacterial cell death (Yunus *et al.*, 2021). The antibacterial effectiveness of *Allium spp.* also depends on the concentration of active compounds, extraction method, as well as the type of target bacteria. In addition to their potential as natural antibacterial agents, *Allium spp.* plants also offer advantages in terms of safety and availability. Its use in traditional medicine has been going on for centuries, thus supporting its use in various clinical applications as well as the food industry. However, challenges such as stability of active compounds and optimal formulation still need to be further researched to improve their effectiveness (Enejiyon *et al.*, 2020).

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Compounds in Allium spp. also exhibit anti-inflammatory, antioxidant, and antimicrobial activities. These properties highlight the potential of these plants in modern medical applications. *Allium Spp* also has potential as an antifungal, especially in garlic which has been tested in (Ananda *et al.*, 2020). This article presents a literature review that collects and analyzes relevant scientific publications related to the antimicrobial properties of Allium species.

This research collects and analyzes various relevant scientific literature in the last 10 years to evaluate the role of *Allium spp.* as a source of antibacterial bioactives. The main focus of this review is on the active compounds contained in *Allium spp.*, their mechanism of action in inhibiting bacterial growth, and their effectiveness against various types of pathogenic bacteria. A better understanding of the antibacterial potential of Allium spp. may support the development of novel strategies to combat bacterial infections and improve food safety.

Research Method

The literature in this study was obtained from research results published in reputable national and international journals. Relevant journals were identified through searches on Google Scholar and Research Gate. Literature analysis was carried out with reference to the established inclusion and exclusion criteria. This study utilised literature published between 2015 and 2025, with full-text access available. No studies were found that examined all the variables considered in this review simultaneously. Therefore, the researchers screened and selected journals that contained some or had a strong connection to the variables reviewed in this study using search keywords such as *Allium cepa*, *Allium chinense G.don*, and *Allium spp*, bioactive compounds, antibacterial activity, quercetin, organosulfur, and the names of Gram-negative and Gram-positive test bacteria.

Then, articles were selected based on inclusion and exclusion criteria. Inclusion criteria included articles with full-text access, published in peer-reviewed journals, and directly discussing the relationship between Allium spp. active compounds and antibacterial activity. Exclusion criteria included non-scientific articles, articles irrelevant to the main variables, or articles not available in English or Indonesian. After screening through title review, abstract review, and article content analysis, 20 articles were selected as eligible for further analysis. The selected articles were then analysed narratively by grouping information based on the type of active compound, the spectrum of antibacterial activity, and the reported potential mechanisms of action.

Active compound content of allium spp

Based on the results of the literature review, *Allium spp* has bioactive compounds such as allicin, saponins and flavonoids. Allicin compounds contained in garlic have antibacterial abilities that are effective against gram-negative and gram-positive bacteria by damaging cell membranes and inhibiting metabolic enzymes in bacteria. In this study, the antibacterial activity of garlic was tested using the diffusion method with paper disks to measure the diameter of the inhibition zone of bacterial growth. The results showed that garlic powder, namely allium, has an antibacterial effect, with an inhibition zone diameter of 13.78 mm against *S. aureus* (Prihandani, 2015). Saponins found in shallots and onions also contribute to antibacterial activity by disrupting the permeability of bacterial cell membranes, causing leakage of cell contents and ultimately bacterial cell death (Anggraini & Retnaningsih, 2022). Flavonoids contained in various types of onions act as antioxidants that can increase the production of reactive oxygen species (ROS), which negatively affect pathogenic bacteria. In hobo onions (*Allium chinenese G.Don*) active compounds such as flavonoids, saponins, and allicin contribute to antibacterial mechanisms by damaging cell membranes, inhibiting metabolic enzymes, and increasing oxidative stress in bacterial cells. The antibacterial effectiveness of these compounds shows variability that is influenced by factors such as the type of onion, the extraction method applied, the concentration of active compounds used in the study, as well as environmental conditions.

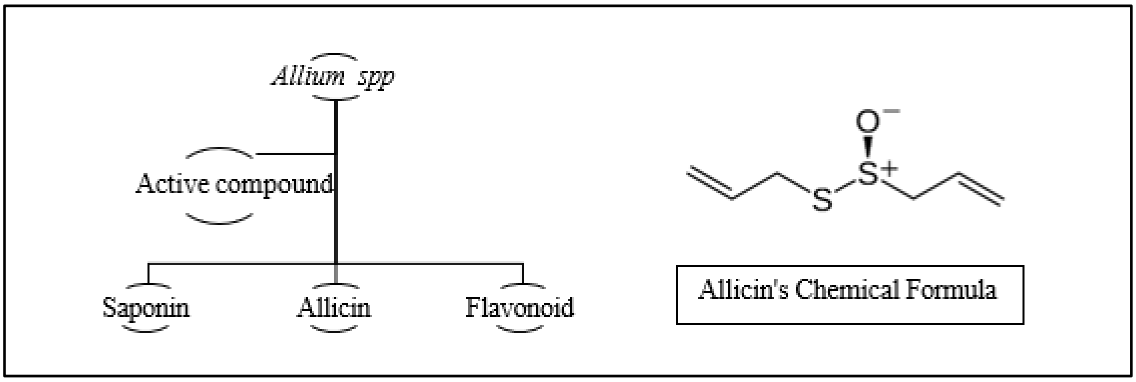

Figure 1. Active compound content in *Allium spp.*

The main advantage of *Allium spp.* lies in the content of bioactive compounds, such as allicin, diallyl disulfide, and ajoene, which have tremendous potential in fighting various types of bacteria. One of the reasons why *Allium spp.* so attractive for research is their ability to inhibit the growth of various bacteria, both gram-negative and gram-positive, which are common pathogens that cause human infections. Gram-positive bacteria such as *Staphylococcus aureus* and *Streptococcus pyogenes* and gram-negative bacteria such as *Escherichia coli* and *Pseudomonas aeruginosa* are often the cause of intractable infections, especially with increasing resistance to antibiotics. However, various studies have shown that the active compounds in *Allium spp.*, particularly allicin, have significant antimicrobial effects against these two groups of bacteria (Bhatwalkar *et al.*, 2021; Sornsenee *et al.*, 2023).

Allicin which is formed when garlic is crushed or cut, has a complex mechanism of action, including damaging bacterial cell membranes and disrupting bacterial cell metabolism, thereby inhibiting their growth. Laboratory studies have shown that *Allium spp.* can inhibit the growth of gram- positive bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA), which is one of the main pathogens that often cause nosocomial infections in hospitals (Sornsenee *et al.*, 2023). On the other hand, *Allium spp.* also effective against gram-negative bacteria, which are known to have more complex cell walls and are more resistant to many antibiotics. Bacteria such as *Escherichia coli* and *Pseudomonas aeruginosa* show considerable sensitivity to garlic extract and the compound allicin (Rahmi *et al.*, 2019).

Allium spp. has shown the ability to inhibit both Gram-positive and Gram-negative bacteria. This highlights its strong potential as an alternative or adjunct to antibiotics, especially amid the rise of resistant bacterial strains. Moreover, the presence of other bioactive compounds in *Allium spp.* such as diallyl disulfide, ajoene, and quercetin enriches the antibacterial profile of these plants, making them ideal candidates in the development of nature-based antimicrobial therapies. With the growing problem of antibiotic resistance worldwide, the potential of *Allium spp.* to inhibit gram- negative and positive bacteria offers a promising solution. Further development of the therapeutic applications of *Allium spp.* may pave the way for the discovery of new, safer and more effective antibiotics, which are urgently needed in today's medical world (Rahmi *et al.*, 2019).

Table 1. Effectiveness of Natural Compounds

Mechanism	Gram-Positive Bacteria	Gram-Negative Bacteria
Membrane Disruption	Easier penetration due to lack of outer membrane; compounds like allicin are highly effective.	Outer membrane acts as a barrier; higher concentrations or longer exposure required.
Protein Synthesis Inhibition	Ribosomes are more accessible; flavonoids and polyphenols show strong activity.	LPS layer hinders access; effectiveness depends on compound's ability to penetrate.
Enzyme Inhibition	Enzymes in the cytoplasm are easily targeted by sulfur compounds (e.g., allicin).	Enzymes in the periplasmic space are harder to target due to the outer membrane.
Biofilm Formation Inhibition	Biofilm disruption is more effective due to simpler cell wall structure.	Biofilm disruption is challenging due to the complexity of the outer membrane.

Mechanism of Antibacterial Activity against Gram-Positive and Gram-Negative Bacteria

Antibacterial resistance has become a significant global health challenge, driving the search for new antimicrobial agents that can effectively fight both Gram-positive and Gram-negative bacteria. Gram-positive bacteria, which have a thick peptidoglycan layer, as well as Gram-negative bacteria, with complex outer membrane structures, create challenges in the development of antimicrobial therapies (Arrigoni *et al.*, 2024). Understanding the mechanisms by which antibacterial agents target these pathogens is critical to developing effective treatments (Zhao *et al.*, 2021). Recent research has highlighted the role of natural compounds, synthetic peptides, and nanoparticles in disrupting the bacterial cell wall, inhibiting protein synthesis, and interfering with DNA replication. This review explores the diverse mechanisms of antibacterial activity against Gram-positive and Gram-negative bacteria, emphasizing the potential for innovative strategies to overcome resistance and improve therapeutic outcomes.

Compound Content and Antibacterial Activity of Onion Types against Gram Negative and Gram-Positive Bacteria

The following are the results of research on the potential of *Allium spp* as antibacterial against gram-positive bacteria and gram-negative bacteria that have been carried out by several researchers and published from 2015-2025, as shown in Table 2.

Table 2 in this study presents data on the content of active compounds in various species of *Allium spp.* and their effectiveness as antibacterials against gram-negative and gram-positive bacteria. Some of the main species analyzed include *Allium cepa L.* , *Allium sativum L.* , *Allium chinense G. Don*, *Eleutherine bulbosa*, *Allium cepa L.* , and *Allium sativum "solo garlic"*. Various bioactive compounds are found in each species, including flavonoids, saponins, tannins, alkaloids, polyphenols, and organosulfur compounds such as allicin and ajoene.

In this study, *Allium cepa* L. was found to contain various bioactive compounds such as quercetin (flavonoid), diosgenin (saponin), tannic acid (tannin), allyl propyl disulfide glycoside (glycoside), ferulic acid and gallic acid (polyphenols), and isoalliin (alkaloid) which exhibit antibacterial activity (Maroto-Tello *et al.*, 2024). These compounds are effective against Gram-negative bacteria such as *Salmonella typhi*, *Escherichia coli*, *Shigella dysenteriae*, and *Pseudomonas aeruginosa*. Meanwhile, in Gram-positive bacteria, red onion extract has been proven to inhibit the growth of Propionibacterium acnes, Staphylococcus aureus, Staphylococcus epidermidis, and Streptococcus mutans. The quercetin content in Allium cepa L. acts as an antioxidant that increases the production of Reactive Oxygen Species (ROS), thereby inducing oxidative stress in bacterial cells and inhibiting the growth of pathogenic microorganisms (Nguyen & Bhattacharya, 2022; Susanto & Khanifah, 2023).

Allium sativum L. contains alkaloids, tannins, saponins, flavonoids, and allicin that have a broad spectrum of activity against gram-negative bacteria such as *Campylobacter jejuni*, *Helicobacter pylori*, *Porphyromonas gingivalis*, *Escherichia coli*, *Salmonella typhimurium*, *Klebsiella pneumoniae*, Pseudomonas aeruginosa, and Acinetobacter baumannii. Meanwhile, in gram-positive bacteria, garlic showed effectiveness against *Mycobacterium tuberculosis*, *Staphylococcus aureus*, *Enterococcus faecium*, and *Bifidobacterium lactis*. The allicin contained in garlic has a mechanism of action by damaging the bacterial cell membrane, disrupting enzymatic metabolism, and increasing membrane permeability, which ultimately leads to bacterial cell death (Siregar *et al.*, 2020).

Allium chinense G. Don contains flavonoids, steroids/terpenoids, and saponins that are proven effective in inhibiting the growth of gram-negative bacteria such as *Salmonella typhi* and *Escherichia coli*. On gram-positive bacteria, hobo onions can inhibit *Staphylococcus aureus*, *Streptococcus mutans*, *Bacillus cereus*, *Staphylococcus epidermidis*, *Enterococcus faecalis*, and *Propionibacterium acnes*. The saponin content in hobo onions works by increasing the permeability of the bacterial membrane and causing leakage of the cell contents, thereby disrupting the biological functions of the bacteria and causing their death. *Allium chinense G. Don* has also been studied as an anti-quorum sensing against *Aeromonas hydrophila* and *Enterobacter cloacae* bacteria. *Allium chinense G. Don* was extracted with methanol (MeOH) and ethyl acetate (EtOAc) which was then tested first on *Serratia marcescens* in inhibiting prodigiosin synthesis through quorum sensing. Inhibition of prodigiosin synthesis was observed visually and measured based on absorbance value (A534) compared to the control. The results showed that both extracts did not inhibit the growth of the test strain, as indicated by the optical density (OD600) at the various concentrations tested. However, increasing concentrations of MeOH and EtOAc extracts led to a decrease in prodigiosin synthesis by S. marcescens, with the most significant effect at a concentration of 0.3% (b/v) after 30 hours of incubation (Hasibuan *et al.*, 2019).

Eleutherine bulbosa contains alkaloids, glycosides, flavonoids, phenolics, steroids, and tannins. These bioactives compound show antibacterial activity against various gram-negative bacteria such as *Escherichia coli*, *Salmonella paratyphi*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Shigella dysenteriae*. Meanwhile, in gram-positive bacteria, dayak onions are effective against *Staphylococcus aureus*, *Streptococcus mutans*, *Propionibacterium acnes*, *Staphylococcus epidermidis*, *Bacillus pumilus*, and *Methicillin-resistant Staphylococcus aureus* (MRSA). The phenolic content in *Eleutherine bulbosa* functions as an antibacterial agent by inhibiting the action of bacterial enzymes and preventing biofilm formation, which is often a major factor in bacterial resistance to conventional antibiotics (Rusli *et al.*, 2023).

Allium cepa L. also has a wide range of antibacterial activity. The flavonoids, saponins, steroids, and alkaloids in onions provide inhibitory activity against gram-negative bacteria such as *Escherichia coli, Pseudomonas aeruginosa*, and *Salmonella typhi*. For gram-positive bacteria, onions are effective in inhibiting *Staphylococcus aureus* and *Staphylococcus epidermidis*.Research also shows that lanang onions, known for their high allicin content, have antibacterial effectiveness against *Escherichia coli* and *Pseudomonas aeruginosa* (gram-negative), as well as against *Staphylococcus aureus* and *Bacillus subtilis* (gram-positive) (Murnah, 2009).

Table 2. Compound Content and Antibacterial Activity of Onion Types against Gram Negative and Gram Positive Bacteria

No	Allium spp	Compound	Gram Negatif	Gram Positif	Referensi
1	*Allium Cepa L* (Bawang Merah)	Flavonoids, saponins, tannins, glycosides, polyphenols, alkaloids	*Salmonella thypi, Eschericia coli. Shigella Dysenteriae, Pseudomonas aeruginosa*	*Propionibacterium acne, Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus mutans*	- (Bagas, 2020; Edy, 2022; Prabowo & Noer, 2020; Sa`adah *et al.*, 2020; Susanto & Khanifah, 2023; Tri Rumanti & Saragih, 2023)
2	*Allium sativum L* (Bawang Putih)	Alkaloids, tannins, saponins, flavonoids, and allicin	*Campylobacter jejuni, Helicobacter pylori, Porphyromonas gingivalis, Eschericia coli, Salmonella typhimurium, Klebsiella pneumoniae, Pseudomonas aeruginosa, Acinetobacter baumannii*	*Mycobacterium tuberculosis, Staphylococcus aureus, Enterococcus faecium, Bifidobacterium lactis*	- (Anatasya Pajan *et al.*, 2016; Kristiananda *et al.*, 2022; Prihandani, 2015)
3	*Allium Chinense G.Don* (Bawang Batak)	Flavonoids, Steroids/Terpenoids, Saponins	*Salmonella typhi Eschercia coli*	*Staphylococcus aureus, Streptococcus mutans, Bacillus cereus, Staphylococus epidermedis, Enterococcus faecalis, Propionibacterium Acnes*	- (Fahmi, 2020; Irmayanti Harahap *et al.*, 2022; Siregar *et al.*, 2020)
4	*Eleutherine bulbosa* (Bawang dayak)	Alkaloids, glycosides, flavonoids, phenolics, steroids, and tannins	*Eschercia coli, Salmonella paratyphi, Klebsiella pneumoniae ATCC 10031, Pseudomonas aeruginosa, Shigella dysenteriae.*	*Staphylococcus aureus, Streptococcus mutans, Propionibacterium acnes, Staphylococcus epidermidis, Bacillus pumilus ATCC 7061, Bacillus subtilis ATCC 6633,Methicillin-resistant*	- (Fitriyanti *et al.*, 2023; Hamid & Yauri, 2021; Mierza *et al.*, 2021; Sagala *et al.*, 2021)
5	*Allium Cepa L* (Bawang Bombay)	Flavonoids, saponins, steroids, and alkaloids, glycosides, flavonoids, phenolics, steroids, and tannins.	*Eschercia coli Pseudomonas aeruginosa Salmonella typhi*	*Staphylococcus aureus Staphylococcus epidermidis*	- (Anggraini & Retnaningsih, 2022; Diarsih, I., T. Yuniarty., 2022; Oktaviani, 2021)
6	*Bawang Lanang*	Allicin, saponin, disulphide	*Eschercia coli Pseudomonas aeruginosa*	*Staphylococcus aureus Bacillus Subtilis*	- (Kulla & Herrani, 2022; Pudiarifanti & Farizal, 2022)

Overall, the findings in Table 2 indicate that various *Allium spp.* species have diverse bioactive contents and are effective in inhibiting the growth of various pathogenic bacteria, both gram-positive and gram-negative. Compounds such as allicin, flavonoids and saponins contribute to this antibacterial effectiveness by various mechanisms, including damaging bacterial cell membranes, inhibiting protein synthesis and increasing oxidative stress. This strengthens the potential of *Allium spp.* as a natural antibacterial agent that can be further developed in the health and food industry.

Gram-positive bacteria, with cell walls consisting of a thick peptidoglycan layer, tend to be more susceptible to bioactive compounds such as allicin from *Allium spp*. as these compounds can easily penetrate and disrupt the integrity of the cell membrane. On the other hand, Gram-negative bacteria have an outer membrane containing lipopolysaccharide (LPS), which provides additional protection. Nonetheless, sulfur compounds in *Allium spp*. remain capable of penetrating this layer, although it may require higher concentrations or longer contact times compared to Gram-positive bacteria. The differential effectiveness of garlic-derived compounds, such as allicin, against Gram-positive and Gram-negative bacteria suggests that Gram-positive bacteria are more susceptible as they lack an outer membrane, while Gram-negative bacteria require higher concentrations of bioactive compounds to achieve effective inhibition. The study also explored the potential of combining natural bioactives compound with conventional antibiotics to enhance their effectiveness against multidrug-resistant bacterial strains (Rahmi *et al.*, 2019).

Conclusions

Allium spp. and similar plants have been shown to be promising sources of bioactive compounds to combating bacterial infections. The active compounds contained in them, such as allicin, ajoene, organic sulfides, flavonoids, and polyphenols, exhibit significant antibacterial activity through various mechanisms, including disruption of the bacterial cell membrane, inhibition of protein synthesis, and inhibition of biofilm formation. The effectiveness of these compounds has been tested against a variety of pathogenic bacteria, both Gram positive and Gram negative, including strains resistant to conventional antibiotics. The potential of *Allium spp.* as natural antibacterial agents offers renewed hope in the face of the growing challenge of antibiotic resistance. The ability of *Allium spp.* has also been tested, as anti-oxidant, anti- fungal, quorum sensing inhibitor, anti-cancer and others. However, further research is needed to optimize the extraction, formulation, and application of these bioactive compounds in clinical medicine. *Allium spp.* not only play a role as a food ingredient, but also as a valuable natural source in the development of safer and more effective antibacterial therapies in the future.

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