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Article Review: Potential of Alkaloid Compounds from East Kalimantan Mangrove Plants as Antibacterial Agents

Kharis Matul Aini, Indah Astuti, Alya Syahirah, Muhfidah Lutfia Ulfa, Usman*, Wila
Chemistry Education, Faculty of Teacher Training and Education, Universitas Mulawarman, Jl. Kuaro, Gunung Kelua, Samarinda, Indonesia 75123
* Corresponding Author e-mail: usman@fkip.unmul.ac.id

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Abstract
Alkaloids are organic compounds characterized by a ring structure containing one or more nitrogen atoms and produced through secondary metabolism in plants and animals. Mangroves are woody plants that grow in wet, muddy, and brackish environments and are widespread in East Kalimantan. Some mangrove species found in this region include *Avicennia sp., Rhizophora apiculata, Rhizophora mucronata, Sonneratia alba, Rhizophora stylosa Griff., Avicennia marina,* and *Bruguiera gymnorrhiza*. This study uses a secondary research approach with a narrative review method to provide an overview and scientific information regarding mangrove leaf extract fractions from East Kalimantan that exhibit antibacterial activity. Data were collected from 60 scientific journals published between 2015 and 2025, sourced from electronic databases such as Google Scholar and Semantic Scholar. The review results indicate that mangroves in East Kalimantan possess high biodiversity and significant chemical potential, primarily due to their rich content of secondary metabolites, including alkaloids, flavonoids, tannins, terpenoids, and saponins, which contribute to various biological activities, including antibacterial, antioxidant, anti-inflammatory, and anticancer effects. The findings indicate that mangroves in East Kalimantan contain various secondary metabolites, particularly alkaloids, which contribute significantly to antibacterial activity. Among the species reviewed, *Avicennia sp*. and *Avicennia marina* exhibited the most consistent and potent antibacterial effects against several pathogenic bacteria. Overall, this review confirms that mangroves from East Kalimantan are a promising natural source for alkaloid-based antibacterial agents and have potential for further development in pharmaceutical applications.

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INTRODUCTION

Mangrove plants have long been used in traditional medicine because extracts from mangrove species have the ability to fight pathogens that attack humans, animals, and plants (Manopo et al., 2023). Several chemical compounds, such as alkaloids, phenolics, steroids, and terpenoids obtained from mangroves, are important in the fields of toxicology, pharmacology, and ecology (Latief et al., 2021).

Indonesia is one of the Asian countries with the largest mangrove forests in the world, stretching from Sabang to Merauke. The area of mangrove forests in Indonesia is approximately 42,550 km2, spread across 257 cities/regencies (Pambudi & Haryoto, 2022).

In East Kalimantan, the outermost mangrove area is in Berau, which covers an area of 89,000 hectares. Several types of mangrove plants in East Kalimantan include *Rhizophora* (mangrove), *Avicennia* (api-api), *Sonneratia* (pedada), *Bruguiera* (lacang), and *Xylocarpus* (nyirih). The secondary metabolite compounds contained in the mangrove samples were determined qualitatively

using several phytochemical test reagents (Usman, 2017). There are two main reasons underlying pharmaco-logical research into the chemical compounds in mangrove plants.

First, mangroves are a relatively easy tropical forest species to cultivate. Mangroves are able to survive in difficult conditions, such as extreme environments, very high and low water salinity levels, and the presence of various micro-organisms and insects. Second, many mangrove species are used in traditional medicine, and various types of mangroves have been shown to inhibit human pathogens (Manopo et al., 2023; Ligina & Sudarmin, 2022).

The researchers were interested in reviewing this mangrove topic because of its abundance, especially in East Kalimantan, due to its numerous coastal areas. Alkaloids are a type of organic chemical compound with a ring-shaped structure and containing one or more nitrogen atoms, making them basic. These compounds are widely found in nature, primarily as secondary metabolites produced by plants and animals. However, in the process of screening, identifying, and discovering alkaloids with pharmacological benefits, researchers have focused more on compounds derived from plants (Ligina & Sudarmin, 2022).

Alkaloids are a group of secondary metabolites that contain a significant number of hydrogen atoms and are commonly found in various plant tissues. Alkaloid compounds can be found in various parts of plants, such as flowers, seeds, leaves, twigs, and bark. Pharmacologically, alkaloids are known to possess numerous biological activities, such as antibacterial, anti-inflammatory, and antioxidant properties (Pambudi & Haryoto, 2022).

Antibacterials are compounds used to control the growth of harmful bacteria (Wibowo et al., 2023). The mechanisms by which antibacterial compounds inhibit bacterial growth include cell wall destruction by inhibiting its formation or altering it after it has formed, changes in the cytoplasmic membrane, resulting in the release of nuclear material from the cell, changes in protein and nucleic acid molecules, enzyme inhibition, and inhibition of nucleic acid and protein synthesis (Prasetya et al., 2024). Antibacterial substances can act bacteriostatically, bacteriocidally, and bacteriolytically based on their selective toxicity (Sari et al., 2019).

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This study emphasizes the innovation that mangrove-derived alkaloids may offer in pharmaceutical development, while simultaneously supporting sustainable management of mangrove resources. By synthesizing existing research findings, this review aims to contribute scientific insight into the utilization of mangrove

alkaloids as a promising solution to current antibacterial treatment challenges.

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METHOD

This study used a narrative literature review method to analyze the antibacterial activity of alkaloid compounds derived from mangrove plants. Article searches were conducted using Google Scholar and Semantic Scholar databases with the keywords "alkaloids as antibacterials" and "alkaloids from mangroves." The search was limited to articles published between 2015 and 2025. From the initial search results of 60 articles with cited 28, relevant articles were selected based on title, abstract, and full-text screening. The selected articles were then analyzed descriptively to identify the type of alkaloid, mangrove species, and reported antibacterial activity.

RESULTS AND DISCUSSION

Result

Mangroves in East Kalimantan are one of the coastal areas with high biodiversity and play a crucial role in maintaining environmental stability (Nia et al., 2017). In addition to their ecological functions, various mangrove species in this region are known to harbor significant chemical potential, particularly in their secondary metabolites (Rosa et al., 2024). One of the most prominent metabolites is alkaloids, which are basic organic compounds that generally contain nitrogen and are known to possess various biological activities. The presence of alkaloids in mangroves is often associated with mangrove adaptation mechanisms to extreme environmental stresses, such as high salinity, tidal fluctuations, and varying light intensity (Rozirwan et al., 2023).

The scientific findings of this narrative review indicate that mangrove plants in East Kalimantan possess significant antibacterial potential primarily associated with the presence of alkaloid compounds. Alkaloids were consistently identified as dominant secondary metabolites in various mangrove species, particularly in leaves and roots, suggesting their key role as bioactive agents. Their production is closely linked to mangrove adaptation to extreme environmental conditions, such as high salinity, tidal fluctuations, and microbial exposure, which stimulate the synthesis of secondary metabolites as chemical defense mechanisms.

Alkaloids exert antibacterial effects by disrupting bacterial cell walls, altering membrane permeability, and inhibiting protein synthesis. A clear trend observed across the reviewed studies is that polar and semi-polar solvents (methanol, ethanol, and ethyl acetate) yield extracts with stronger antibacterial activity compared to non-polar solvents such as n-hexane. This occurs because alkaloids are predominantly polar or semi-polar compounds, making them more efficiently extracted using polar solvents. As a result, extracts obtained with methanol or ethyl acetate showed greater inhibitory effects against pathogenic bacteria such as Escherichia coli and Staphylococcus aureus, while n-hexane fractions generally exhibited weak or no antibacterial activity.

Comparative analysis among mangrove species reveals that the genus Avicennia demonstrates the most consistent and potent

antibacterial activity, followed by Rhizophora species. Avicennia sp. and Avicennia marina showed strong inhibition against several pathogenic bacteria, likely due to the synergistic action of alkaloids with other secondary metabolites such as flavonoids and tannins. These findings collectively support the research objective stated in the introduction, confirming that mangrove plants from East Kalimantan represent a promising natural source of alkaloid-based antibacterial agents. However, further studies focusing on the isolation of pure compounds and their mechanisms of action are required to strengthen their pharmaceutical potential

Discussion

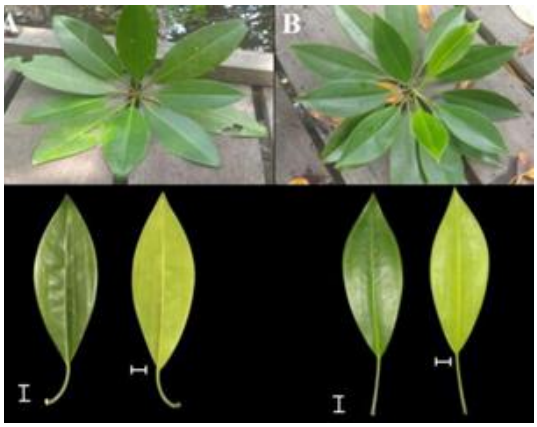
Table 1. phytochemicals and antibacterial activities from various parts of the mangrove that have been researched in several studies.

Types of Mangrove	Phytochemicals	Bioactivity	Reference
Leaves (*Rhizophora apiculata*)	Alkaloids glycosin	Antibacterial	Wibowo, M.A., et al., 2023 & Lubis., et al., 2024
Roots (*Rhizophora mucronata)*	Isoquinoline alkaloids	Antibacterial	Ligina, A.S & Sudarmin., 2022
Leaves *(Rhizospora stylosa Griff)*	Indole alkaloids	Antibacterial	Rahayuningsih, S.R., et al., 2023
Mangrove Leaves *(Avicennia sp.)*	Alkaloids Heterocyclic	Antibacterial	Alhaddad, Z.A., et al., 2019
Stem *(Avicennia marina)*	Heterocyclic alkaloids	Anticancer, antimicrobial, antioxidant, antibacterial	Rosa, K., et al., 2024
Roots *(Avicennia marina)*	Alkaloids Quaternary, phenolic, carotenoids, tannins, sugars, amino acids, and glycosides	Antibacterial	Prasetya, F., et al., 2024
Mangrove Leaves *(Bruguiera gymnorrhiza)*	Vinca alkaloids	Anticancer	Manopo, F. C., et al., 2023
Roots *(S. alba)*	Indole alkaloids	Antibacterial, anti-inflammatory, antioxidant	Latief, M., et al., 2021

*Volt

Mangrove plants have parts consisting of seeds, roots, stems, and leaf roots. These parts contain various compounds. The leaves and stems contain alkaloids, steroids, terpenoids, saponins, tannins, phenols, cyclolignan glycosides, aliphatic alcohol glycoside-ilicifolioside C, two Z-4-coumaric acid glycosides, phenylethanoid glycosides *(ilicifolioside A)*, and aliphatic alcohol glycoside *(ilicifolioside)* (Deandra et al., 2024).

The most dominant phytochemical compounds in mangrove plants are alkaloids and flavonoids, which are most abundant in the leaves and stems. The presence of these compounds makes this plant a potential antioxidant, anti-inflammatory, and antimicrobial agent. Other types of mangrove plants, such as Red Mangrove *(Rhizopora stylosa Griff)*, *Avicennia sp.*, *Rizophora apiculata*, *Rhizophora mucronata*, etc., contain many phytochemical compounds such as alkaloids, flavonoids, phenolic acids, tannins, terpenoids, saponins, and steroids (Kalasuba et al., 2023).



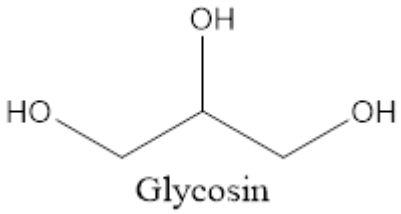


Figure 1. ***Rizhophora apiculata***

Phytochemical analysis of *R. apiculata* leaves using methanol extract showed the presence of phenolic compounds, tannins, alkaloids, flavonoids, and steroids. Analysis of secondary metabolite content using phytochemical methods was also carried out on *R. apiculata* leaf samples grown in Teluk Awur, Jepara Regency, which showed that alkaloids were present in all extracts. Flavonoids were found in the methanol extract, phenolics were found in the methanol and ethyl acetate extracts. Saponins were found in the methanol extract, while steroids were found in the n-hexane and ethyl acetate extracts. *R. apiculata* leaves contain glycosin-type alkaloid compounds. *R. apiculata* leaves are antibacterial against E. coli with a minimum inhibitory concentration for the methanol extract of 250 mg/mL. The methanol and dichloromethane fractions had MICs of 125 mg/mL and 250 mg/mL, respectively, while the n-hexane fraction did not inhibit E. coli at all test concentrations (Wibowo et al., 2023).

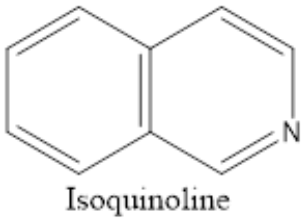


Figure 2. ***Rizhophora mucronata***

Rhizophora mucronata contains compounds from the phenol, tannin, flavonoid, saponin, glucoside, terpenoid, and alkaloid groups. The type of alkaloid compound in the mangrove plant *R. mucronata* is Isoquinoline.

Mangrove plants *(Rhizophora mucronata)* contain alkaloid compounds derived from isoquinoline derivatives, as indicated by a wavelength of 230 obtained from a UV-Vis instrument, reinforced by FT-IR absorption at 3317 cm-1, which is the characteristic N-H functional group region of alkaloid compounds. Isoquinoline alkaloid compounds show weak antibacterial activity in inhibiting the growth of Escherichia coli bacteria by 0 mm and Staphylococcus aureus by 2 mm (Ligina & Sudarmin, 2022).

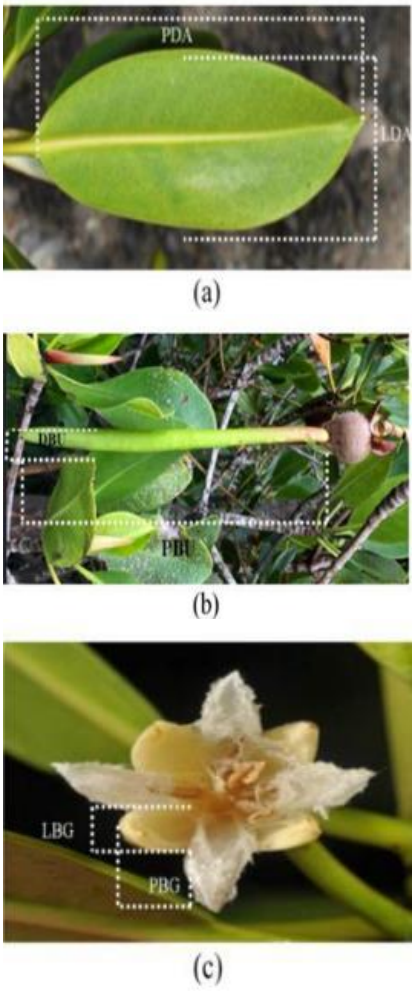
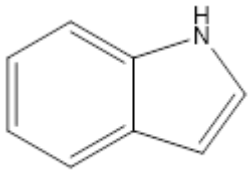


Figure 3. Morphometric measurements of *R. stylosa* organs: (a) leaf, (b) fruit, and (c) flower; LDA = leaf width; PDA = leaf length; DBU = fruit diameter; PBU = fruit length; LBG = flower calyx width; PBG = flower calyx length

R. stylosa mangrove is one of the most abundant mangrove species. In addition, mangroves contain bioactive secondary metabolites such as alkaloids, steroids, terpenoids, saponins, tannins, flavonoids, and quinones. R. stylosa mangrove plants contain indole alkaloids.

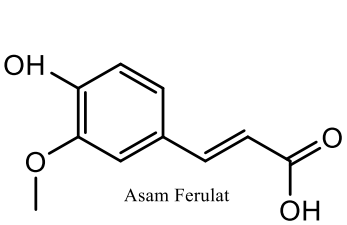


Indole

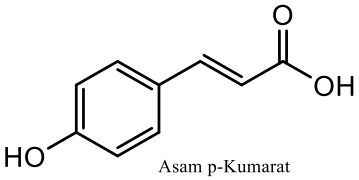
It was found that n-hexane extract from *R. stylosa* mangrove leaves was able to inhibit the growth of A. hydrophila bacteria. The extract used at a concentration of 1000 ppm-10,000 ppm produced an inhibition diameter of 6.15-8.45 mm. The antibacterial activity of *R. stylosa* leaves was extracted using the non-polar solvent n-hexane because this solvent can attract non-polar antibacterial substances. Mangrove *Rhizospora stylosa Griff* showed antibacterial activity against Vibrio spp and A. hydrophila bacteria, making it a natural antibiotic that does not cause side effects. The use of amoxicillin antibiotics (Rahayuningsih et al., 2023).

Figure 4. *Avicennia*

Mangrove leaves (Avicennia sp.) contain alkaloid compounds that were detected through phytochemical testing. The testing was conducted on three extract fractions using n-hexane, ethyl acetate, and ethanol solvents. The results showed that the ethyl acetate fraction contained alkaloids, flavonoids, triterpenoids, and polyphenols. This proves that Avicennia sp. mangrove leaves contain alkaloids that play an important role as bioactive compounds with antibacterial activity.



Asam Ferulat



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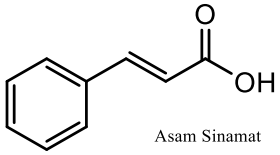

Asam Sinamat

Alkaloids contained in *Avicennia sp.* mangrove plants include ferulic acid, p-coumaric acid, and cinnamic acid. These alkaloids are thought to be able to inhibit the growth of pathogenic bacteria such as *Staphylococcus aureus* and *Escherichia coli*, thus supporting the use of mangrove leaves as a natural ingredient with high antibacterial properties (Alhaddad et al., 2019). *Avicennia marina* leaves are a natural ingredient with nutraceutical and economic potential.

Nutraceuticals are foods or food parts that provide medical benefits. *Avicennia marina* leaves have the potential as antioxidants, antibacterials, and can also be used for wound healing. Extraction methods can be used to obtain the phytochemical content of nutraceuticals. *Avicennia marina* leaves are known to contain alkaloids, terpenoids, and flavonoids that have antibacterial activity (Rosa et al., 2024). The roots and stems of the *Avicennia marina* mangrove plant are able to inhibit the growth of *Staphylococcus aureus* and *Escherichia coli* bacteria (Saputra, E et al., 2021 & Susanti, S et al., 2024).

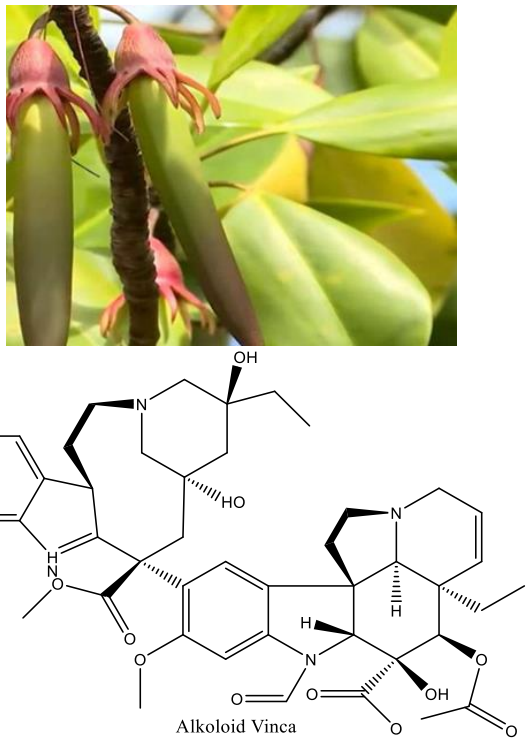

Figure 5. ***Bruguiera gymnorhiza***

The *Bruguiera gymnorhiza* mangrove plant contains several compound such as alkaloids, flavonoids, saponins, steroids, tannins, and triterpenoids. The presence of these compounds indicates that mangrove leaves have pharmacological effects and can be used as a raw material for medicines. The type of alkaloid contained in the *Bruguiera gymnorhiza* mangrove is vinca alkaloids. Alkaloids are very important because they have cytotoxic and anticancer activities, namely the ability to inhibit cell division and trigger natural cell death. In addition, saponins and tannins also have antibacterial activity, while flavonoids act as antioxidants and anticancer agents. Based on these test results, it can be concluded that mangrove leaf extract contains alkaloids and has potential antibacterial activity. However, this study focused on toxicity testing (BSLT) and anticancer potential, not on direct antibacterial testing (Manopo et al., 2021).

Figure 6. ***Sonneratia alba***

Sonneratia alba is a mangrove plant commonly found along the coasts of Asian countries, including Indonesia, Malaysia, the Philippines, India, China, and tropical Australia. It is a type of mangrove that grows in sheltered coastal swamp habitats, as well as in saltier areas along tidal rivers and coastlines. S. alba leaf extracts show the presence of bioactive compounds such as alkaloids, flavonoids, phenolics, and terpenoids, which play an important role in antibacterial activity. The type of alkaloid contained in *Sonneratia alba* is indole alkaloids.

People use mangroves as a traditional medicine with very high bioactive potential. *Sonneratia alba* has a variety of bioactivities including antibacterial, anti-inflammatory, and antioxidant properties. *S. alba* leaf extracts, whether using n-hexane, ethyl acetate, or methanol as solvents, have been shown to inhibit the growth of Gram-positive bacteria such as *Staphylococcus aureus* and *Bacillus cereus*, as well as Gram-negative bacteria such as *Escherichia coli*, and even certain pathogenic fungi. This antibacterial activity is linked to the mechanism of action of alkaloid and phenolic compounds, which can damage bacterial cell walls, disrupt membrane permeability, and inhibit microbial enzyme systems. Furthermore, one of the compounds in this plant can also be used as an antioxidant. Antioxidants are substances that can delay, slow, or prevent oxidation processes. Antioxidant compounds can inhibit the chain reaction of free radical formation in the body, often referred to as miracle compounds because they can fight premature aging and various other diseases (Latief et al., 2021).

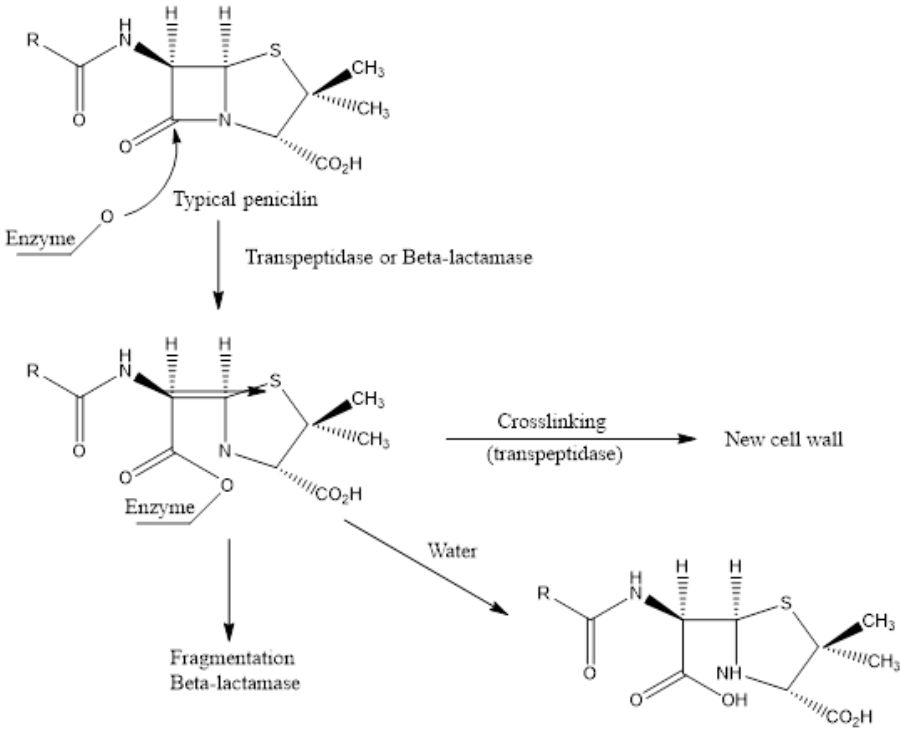

Figure 7. Mechanisms of Bacterial Resistance to Beta-Lactams

All bacteria have cell walls. Beta-lactams are used to fight both gram-positive and gram-negative bacteria. Because the cell wall structures of gram-positive and gram-negative bacteria differ, their resistance patterns also differ. Bacterial resistance to beta-lactams occurs through three pathways: destruction of the beta-lactam enzyme in the antibiotic, alteration of the antibiotic's target, and decreased antibiotic uptake within the bacterial cell. These three pathways all play a crucial role in increasing antibiotic resistance. However, bacteria capable of producing and destroying beta-lactams are the primary cause of resistance (Biutifasari, V 2018).

ESBL enzymes act specifically against certain antibiotic structures and also possess other resistance mechanisms such as alteration of their target, decreased membrane recognition, and increased bacterial excretion. Unlike beta-lactam antibiotics, alkaloid compounds typically act in diverse and nonspecific ways, such as damaging bacterial cell membranes, binding to DNA, inhibiting protein synthesis, and disrupting the function of enzymes essential for metabolism. Alkaloids act on multiple biochemical pathways, enzyme-based resistance mechanisms like ESBLs are less effective against alkaloids. Therefore, the presence of β-lactam resistance in bacteria indicates that alkaloids have potential as an antibacterial alternative, because they are able to bypass or overcome the resistance mechanisms commonly used by bacteria against synthetic antibiotics.

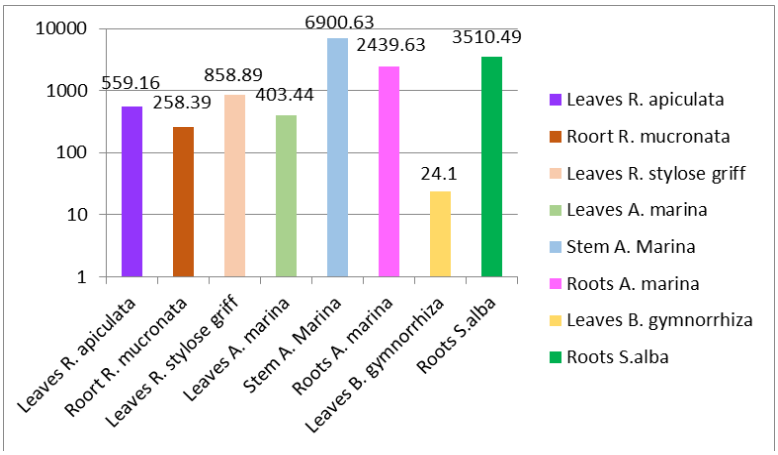

Figure 8. LC50 (antibacterial) Value of Mangrove Leaves *R. apiculata*, Roort *R. mucronata*, Leaves *R. stylose griff*, Leaves. *A. Marina*, *Stem A. Marina*, Roots *A. Marina*, Leaves *B. gymnorrhiza*, Roots *S. alba*

Toxicity testing is a crucial parameter in the study of the bioactivity of natural products, particularly for assessing the initial potential of secondary metabolite compounds contained within them. One parameter commonly used in various phytochemical toxicology studies is the LC_{50} (Lethal Concentration 50) value, which is the concentration of an extract capable of causing the death of 50% of test organisms. The LC_{50} value is often used as an early indicator of the toxicity and bioactivity of plant extracts; the lower the LC_{50} value, the higher the extract's toxicity.

Based on various reported studies, the LC_{50} values of mangrove plant extracts show quite wide variation, depending on the plant species and the plant part used. The following graph presents a comparison of the LC_{50} values of several mangrove plant parts, such as leaves, stems, and roots, reported in various studies. This data presentation aims to provide a comparative overview of the relative toxicity levels of each extract.

Based on the graph, it can be seen that the LC_{50} values of mangrove extracts range from very low to relatively high. The extract with the lowest LC_{50} value was *Bruguiera gymnorrhiza* leaves, with a value of approximately 24.1 ppm, indicating the highest level of toxicity compared to the other samples. Conversely, several other extracts, such as Avicennia marina stems and Sonneratia alba roots, showed much higher LC_{50} values, approximately 6900.63 ppm and 3510.49 ppm, respectively, indicating lower toxicity.

In terms of antibacterial potential, *Bruguiera gymnorrhiza* leaf extract was considered the best because its low LC_{50} value indicates strong biological activity, which generally aligns with the ability to inhibit bacterial growth. Meanwhile, *Avicennia marina* stem and *Sonneratia alba* root extracts with high LC_{50} values indicated low toxicity but tended to have weaker antibacterial potential.

Therefore, *Bruguiera gymnorrhiza* leaves are the most potential candidate as a source of natural antibacterials, while extracts with high LC_{50} are more suitable for applications that prioritize safety aspects. The mangrove species with the best antibacterial activity is *Bruguiera gymnorrhiza*. *Bruguiera gymnorrhiza* leaves exhibit strong antibacterial potential, containing alkaloids that have been shown to inhibit bacterial growth (Manopo, F. C., et al., 2023).

CONCLUSION

A review of several scientific articles indicates that mangroves in East Kalimantan have high pharmacological potential, particularly as a source of alkaloid compounds with antibacterial activity. Various species, such as Avicennia sp., Avicennia marina, Rhizophora apiculata, Rhizophora mucronata, Rhizophora stylosa, Sonneratia alba, and Bruguiera gymnorhiza, have been shown to contain important secondary metabolites such as alkaloids, flavonoids, tannins, terpenoids, and saponins. These compounds are distributed in the leaves, roots, stems, and seeds and contribute to inhibiting pathogenic bacteria such as Staphylococcus aureus, Escherichia coli, Vibrio spp., and Aeromonas hydrophila. This antibacterial activity is influenced by the type of solvent, extract fraction, and concentration used, with the Avicennia genus showing the most consistent effectiveness.

Overall, these results confirm that mangrove ecosystems are not only ecologically important but also hold strategic value in the health and pharmaceutical sectors. Mangroves have great potential to be developed as a source of natural ingredients for antibacterial agents, particularly through the utilization of alkaloid compounds that have been shown to be active against various pathogenic bacteria. Therefore, further research on the isolation of pure compounds, their mechanisms of action, and their potential applications in antibacterial drug development is urgently needed to optimize the use of mangroves as future phytopharmaceutical candidates. This review highlights the potential of mangroves as alternative natural resources for antibacterial agents, supports the sustainable utilization of mangrove ecosystems, and provides a scientific reference for future studies on the isolation of active compounds and the development of mangrove-based antibacterial drugs.

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