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A Comprehensive Review of the Antibacterial Activity of *Costus afer* Against Multidrug-Resistant *Staphylococcus aureus*

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Abstract
A major worldwide public health concern is the rising incidence of multidrug-resistant (MDR) Staphylococcus aureus, especially methicillin-resistant S. aureus (MRSA). The hunt for new antimicrobial drugs, particularly from medicinal plants historically employed in ethnomedicine, has accelerated due to the limited efficacy of current antibiotics. The tropical African perennial herb *Costus afer Ker-Gawl* has long been used in traditional medical systems to treat inflammatory and infectious diseases. With a focus on its ability to combat multidrug-resistant Staphylococcus aureus, this study offers a thorough analysis of *Costus afer's* antibacterial qualities. The study looks at *C. afer's* botany, phytochemical makeup, ethnomedical significance, and antibacterial properties that have been demonstrated in experiments. There is also discussion of current research gaps, comparative effectiveness with traditional antibiotics, and mechanisms of antimicrobial activity. According to the results, *Costus afer* has strong antibacterial properties that could aid in the creation of new treatment drugs that target MDR S. aureus. To confirm its safety and effectiveness, more in vivo research, toxicology analyses, and clinical studies are necessary.

Keywords: Medicinal herbs, Antibacterial action, Multidrug Resistance, *Staphylococcus aureus*, *Costus Afer*

Introduction

One of the biggest risks to world health in the twenty-first century is antimicrobial resistance. Antibiotic-resistant bacteria have been recognized by the World Health Organization as a primary contributor to rising rates of illness, mortality, and medical expenses globally. Staphylococcus aureus is unique among these pathogens because it can quickly develop resistance to several antibiotic classes and cause a variety of illnesses, such as pneumonia, endocarditis, septicemia, and infections of the skin and soft tissues (WHO, 2020, Akinyemi et al., 2005). A frequent component of the normal human microbiota, Staphylococcus aureus is a facultative anaerobic, Gram-positive bacteria that is mostly found on the skin and nasal mucosa. Even though it is commensal, in the right circumstances it can become extremely pathogenic. Alternative antimicrobial approaches are now more important than ever because to the advent of methicillin-resistant Staphylococcus aureus (MRSA) and other multidrug-resistant bacteria, which have drastically reduced treatment options (Madigan et al., 2021). For centuries, medicinal plants have been essential to healthcare systems and are still a significant source of bioactive substances. Plant-based treatments continue to be the mainstay of care for infectious diseases in many underdeveloped nations.

More scientific research is being done on medicinal plants as possible sources of new antimicrobial drugs as a result of the resurgence of interest in ethnopharmacology and natural products research (Elnawasany et al., 2024; Asekun, 2013). The tropical plant *Costus afer Ker-Gawl*., which is found throughout West and Central Africa, is a member of the Costaceae family. In traditional medicine, it is widely used to treat diabetes, inflammation, infections, and other

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conditions. According to preliminary research, C. afer extracts have antibacterial action against a number of harmful pathogens, including Staphylococcus aureus. According to these results, C. afer might have promising therapeutic potential against bacterial strains that are resistant to many drugs (Elemike et al., 2017; Onoriasakpobare et al., 2025).

Global Burden of Multi-drugs Resistant-Staphylococcus aureus

Around the world, multidrug-resistant Staphylococcus aureus is a major contributor to infections acquired in hospitals and the community. The mecA gene, which codes for a modified penicillin-binding protein (PBP2a), makes MRSA strains resistant to β-lactam antibiotics, such as cephalosporins and penicillins. Many MRSA strains are resistant to tetracyclines, aminoglycosides, fluoroquinolones, and macrolides in addition to β-lactams (Marino et al., 2025; Boison et al., 2019). Inappropriate antibiotic use, inadequate infection control procedures, and the organism's genetic resilience have all been blamed for the rise of MDR S. aureus. Higher death rates, longer hospital stays, and higher treatment expenses are all linked to infections brought on by MDR strains. These difficulties demonstrate how urgently new antimicrobial medicines with unique modes of action are needed (WHO, 2023; Ofesi et al., 2025).

Medicinal Plants as Sources of Antibacterial Agents

Secondary metabolites include alkaloids, flavonoids, phenolic chemicals, terpenoids, and saponins many of which have antibacterial qualities are abundant in medicinal plants. Plant extracts often include several bioactive chemicals that may work in concert to limit microbial development, in contrast to conventional antibiotics that frequently target a single bacterial pathway (Sofowora, 2008). Plant-derived chemicals have been demonstrated to limit the formation of virulence factors, interfere with the synthesis of nucleic acids, disrupt bacterial cell membranes, and reduce enzyme activity. Medicinal plants are interesting options for treating multidrug resistance because of these various processes (Akani et al., 2020; Eze et al., 2009).

Ethnomedicinal Importance of *Costus Afer*

African traditional medicine has made considerable use of costus afer to treat a variety of infectious disorders. The plant's leaves, stems, rhizomes, and roots are among its several sections that are used either alone or in conjunction with other plants. Antimicrobial and anti-inflammatory qualities are suggested by traditional uses, which include the treatment of cough, sore throat, wound infections, fever, and gastrointestinal disorders (Peter et al., 2022; Tennyson et al., 2025). The extensive usage of C. afer in ethnomedicine offers compelling justification for a scientific assessment of its antibacterial efficacy, especially against resistant bacterial strains such MDR Staphylococcus aureus (Doughari, 2012).

Botanical Description and Geographical Distribution of *Costus afer*

The monocotyledonous perennial herb Costus afer Ker-Gawl. is a member of the Costaceae family. Its long, unbranched, spiral-shaped stems, which can reach a height of 4 meters, are its defining feature. Simple, broad, and placed alternately, the leaves have a glossy green appearance. Cone-shaped inflorescences with dazzling yellow or white flowers are produced by the plant. According to Muhammad and Zaku (2015), Costus afer is a member of the kingdom Plantae, division Magnoliophyta, class Liliopsida, order Zingiberales, family Costaceae, genus Costus, and species Costus afer. Throughout tropical Africa, including Nigeria, Ghana, Cameroon, Uganda, and the Democratic Republic of the Congo, Costus afer is abundantly found. It grows best in damp places like riverbanks, cultivated farmlands, and the edges of forests.

Phytochemical Composition of Costus afer

Numerous bioactive substances that provide Costus afer its therapeutic qualities have been found through phytochemical analyses. The following groups of phytochemicals have been reliably identified through qualitative and quantitative investigations of aqueous, ethanolic, and methanolic extracts: Flavonoids: renowned for their anti-inflammatory, antibacterial, and antioxidant qualities. Alkaloids: Able to disrupt the enzyme and DNA systems of bacteria. The membranes of bacteria are disrupted by saponins. Tannins: Block microbial enzymes and precipitate proteins. According to Uchegbu et al. (2016), terpenoids have antibacterial and anti-inflammatory properties. Given the variety of these phytochemicals, it is possible that Costus afer has antibacterial properties through a number of different routes, which would make it especially efficient against bacteria that are resistant to drugs.

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Experimental Evidence of Antibacterial Activity of *Costus afer* against Staphylococcus aureus

In Vitro Antibacterial Studies

The antibacterial efficacy of *Costus afer* extracts against Staphylococcus aureus, particularly strains that are resistant to multiple drugs, has been the subject of numerous in vitro investigations. To assess antimicrobial activity, these investigations frequently use broth dilution, disk diffusion, agar well diffusion, and microdilution techniques. It has been demonstrated that the growth of S. aureus is inhibited in a concentration-dependent manner by aqueous, ethanolic, and methanolic extracts of the leaves, stems, and rhizomes of *Costus afer*. These investigations describe moderate to high zones of inhibition, which are frequently similar to those generated by common antibiotics in similar experimental settings. Because bioactive phytochemicals are more soluble in organic solvents, ethanolic extracts often exhibit greater antibacterial activity than aqueous extracts (Uchegbu et al.2016).

Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC)

Values for the minimum inhibitory concentration (MIC) are important markers of the effectiveness of antibiotics. Significant antibacterial activity is suggested by reported MIC values for *Costus afer* extracts against Staphylococcus aureus, which normally lie within low to moderate concentration ranges. Depending on the plant part and extraction technique, MIC values varied from 6.25 mg/mL to 50 mg/mL in multiple investigations. At greater concentrations, extracts of Costus afer may exhibit bactericidal effects rather than just bacteriostatic activity, according to minimum bactericidal concentration (MBC) evaluations. Numerous studies' MBC to MIC ratios imply that plant extracts have the ability to kill bacterial cells in addition to preventing their development (Peter et al., 2022).

Activity against Multidrug-Resistant and MRSA Strains

The documented efficacy of *Costus afer* against strains of Staphylococcus aureus that are resistant to many drugs, including MRSA, is especially noteworthy. Clinical isolates that are resistant to several antibiotic classes have been used in lab research to show that they are susceptible to *C. afer* extracts. These results demonstrate the plant's potential use as a complementary or alternative treatment for infections that are resistant to treatment (Marino et al., 2025). Because of its complex phytochemical profile, which lowers the chance of resistance development, *Costus afer* is effective against MDR strains. Plant extracts frequently affect several cellular targets at once, in contrast to manufactured antibiotics that target certain bacterial pathways (Uchegbu et al., 2016).

Mechanisms of Antibacterial Action

Disruption of Bacterial Cell Walls and Membranes

The breakdown of bacterial cell walls and cytoplasmic membranes is one of the main ways that *Costus afer* has antibacterial properties. It is well known that the plant's saponins and terpenoids interact with lipid bilayers to increase membrane permeability and cause vital intracellular components to flow out. Bacterial integrity is compromised by damage to the cell membrane, which results in cell lysis and death. Because Gram-positive bacteria, like Staphylococcus aureus, have a thick peptidoglycan coating that phytochemicals can target, this technique works very well against them.

Inhibition of Enzymatic and Metabolic Pathways

Costus afer contains flavonoids and alkaloids that may block important bacterial enzymes involved in protein synthesis, DNA replication, and metabolic activities. The plant chemicals prevent bacterial growth and survival by interfering with these vital processes. It is also known that tannins can inactivate bacteria by forming complexes with their structural and enzyme proteins. The total antibacterial effectiveness of *C. afer* extracts is influenced by this multi-targeted enzymatic inhibition (Uchegbu et al., 2016).

Antioxidant and Anti-Virulence Effects

Apart from its direct antibacterial activity, *Costus afer* has antioxidant qualities that could potentially improve antimicrobial efficacy in an indirect manner. Bacterial pathogenicity and survival are influenced by oxidative stress, and antioxidants can upset the redox balance in microbial cells. Inhibiting bacterial virulence factors such adhesion, biofilm formation, and toxin generation is another possible use of some phytochemicals. The capacity of *C. afer* to disrupt biofilm formation is of significant therapeutic significance because biofilms are a primary cause of antibiotic resistance in S. aureus (Marino et al., 2025).

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Comparative Evaluation with Conventional Antibiotics

There are advantages and disadvantages of using *Costus afer* extracts in comparison to traditional antibiotics. Extracts from *C. afer* have broader modes of action and a lesser chance of developing resistance, whereas antibiotics like vancomycin and linezolid typically have lower MIC values. The use of plant extracts and antibiotics together has demonstrated synergistic benefits in certain experimental setups, increasing antibacterial efficacy against MDR S. aureus. By reducing antibiotic dosages, these combinations may minimize side effects and delay the evolution of resistance. However, direct comparison with prescription antibiotics is difficult due to variations in extract potency, a lack of standardization, and disparities in experimental techniques (Omotayo et al., 2018).

Safety, Toxicity, and Pharmacological Considerations

Toxicological Studies

At therapeutic dosages, *Costus afer* extracts appear to be somewhat safe, according to preliminary toxicological research. When given orally at reasonable dosages, acute and subacute toxicity assessments in animal models have shown little negative side effects. However, excessive dosages may result in modest physiological changes, highlighting the significance of dosage control (Akani et al., 2020).

Pharmacokinetics and Bioavailability

Lack of understanding of the pharmacokinetics and bioavailability of *C. afer* phytochemicals is one of the main obstacles to converting in vitro antibacterial results into therapeutic uses. The efficiency of treatment is influenced by factors like absorption, metabolism, and excretion, all of which need careful research. Standardized extract preparations, nanoformulations, and encapsulation methods may increase antibacterial activity and bioavailability (Sofowora, 2008).

Clinical Relevance and Public Health Implications

Burden of MDR Staphylococcus aureus in Healthcare Settings

Hospital-acquired and community-associated infections are still largely caused by multidrug-resistant Staphylococcus aureus, especially in low- and middle-income nations with limited access to sophisticated antibiotics. MRSA infections are linked to longer hospital stays, more expensive medical care, and higher death rates. The effectiveness of last-line antibiotics is threatened by the ongoing evolution of resistance mechanisms in S. aureus, highlighting the need for alternate antimicrobial treatments. Antimicrobial drugs originating from plants, including *Costus afer,* provide a locally available and potentially sustainable alternative. Particularly in areas with limited resources, the use of medicinal plants that are already included into conventional healthcare systems may increase treatment accessibility and affordability (Marino et al., 2025).

Role of *Costus afer* in Complementary and Alternative Medicine

Traditional African medicine has long used *costus afer* to treat inflammatory and infectious diseases. Its incorporation into frameworks for complementary and alternative medicine (CAM) emphasizes both its therapeutic value and cultural acceptability. Evidence-based integration into contemporary healthcare systems is supported by scientific confirmation of its antibacterial action, which enhances the legitimacy of conventional procedures (Okwu, 2005). For S. aureus-induced skin and wound infections, *C. afer* may be especially helpful when applied as a topical antibacterial agent. Topical treatments target localized infections, particularly those brought on by MDR strains, while lowering systemic exposure and toxicity (Elnawasany et al., 2024).

Potential Role in Antimicrobial Stewardship

The overuse of traditional antibiotics may be lessened by incorporating potent plant-based antimicrobials into therapy regimens. The effectiveness of current antibiotics may be maintained and resistance may be slowed by using medicinal herbs like *Costus afer* as first-line treatments or adjunct therapy for minor illnesses (Madigan et al., 2021, Onojafe et al., 2025, Doughari, 2012).

Research Gaps and Limitations

Despite encouraging in vitro results, a number of restrictions prevent *Costus afer* from being used as an antibacterial agent in clinical settings. The absence of standardized extraction techniques, doses, and formulations is one of the biggest obstacles. Inconsistent phytochemical profiles and antibacterial efficacy among investigations are caused by variations in plant age, harvesting season, geographic origin, and extraction solvent. The majority of research on the

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antibacterial activity of *Costus afer* is restricted to in vitro tests. Clinical trials in humans are almost nonexistent, and there are few in vivo research assessing its effectiveness in animal infection models. Conclusions about the safety and efficacy of treatments remain tentative in the absence of these evidence. Furthermore, although broad antibacterial mechanisms have been suggested, there aren't enough thorough molecular studies that clarify particular targets in Staphylococcus aureus. Its potential for medication discovery would be greatly increased by knowing how *C. afer* phytochemicals interact with bacterial genes, proteins, and resistance pathways. Comprehensive research on chronic toxicity, genotoxicity, and reproductive toxicity is required, even though initial toxicological investigations indicate relative safety. To guarantee safe combination use, any interactions between *C. afer* extracts and traditional antibiotics must also be assessed.

Future Prospects and Drug Development Potential

Isolating and describing the distinct bioactive substances that give off antibacterial activity should be the main goals of future studies. Compound identification and structural clarification can be aided by sophisticated methods like nuclear magnetic resonance spectroscopy, mass spectrometry, and chromatography. Additionally, examining the synergistic effects of *Costus afer* extracts with already available antibiotics may uncover new combination treatments. These methods could lessen the need for antibiotic dosages, improve antibacterial efficacy, and slow the emergence of resistance. The creation of standardized pharmaceutical formulations, such as gels, ointments, capsules, and nano formulations, may enhance patient compliance, stability, and bioavailability. Particularly promising are topical preparations for the treatment of MDR S. aureus infections of the skin and soft tissues. Regulations must be put in place to guarantee efficacy, safety, and quality control if C*ostus afer*-based treatments are to become widely accepted in medicine.

Conclusion

The investigation of new and additional antibacterial methods is required due to the increasing threat posed by multidrug-resistant *Staphylococcus aureus.* African traditional medicine makes extensive use of the medicinal plant *Costus afer,* which exhibits strong antibacterial action against S. aureus, including strains that are resistant to multiple drugs. Multi-targeted methods of action are made possible by its extensive phytochemical content, which lowers the possibility of resistance development. Despite the encouraging in vitro findings currently available, there are still significant research gaps. Moving *C. afer* from lab research to therapeutic application requires addressing concerns with uniformity, toxicity, pharmacokinetics, and clinical efficacy. In the battle against antibiotic resistance, *costus afer* has a lot of potential as a source of new antimicrobial agents with careful scientific research and interdisciplinary cooperation. The results presented in this study provide compelling evidence that medicinal plants continue to be an important source of antibacterial compounds. *Costus afer's* antibacterial activity against multidrug-resistant Staphylococcus aureus is consistent with international research initiatives to find substitute treatments that can combat antibiotic resistance. The structural features of the bacterial cell wall may be related to C. afer's efficacy against Gram-positive bacteria, especially S. aureus. Gram-positive organisms are more vulnerable to phytochemicals that interfere with the formation of cell walls or the integrity of their membranes because they have a thick coating of peptidoglycan but no outer membrane. Compared to certain Gram-negative bacteria, *C. afer* has more activity against S. aureus, which could be explained by this structural susceptibility. The synergistic nature of the phytochemicals found in *Costus afer* is another crucial factor. Plant extracts have several bioactive components that may cooperate to strengthen antibacterial activity, in contrast to single-compound antibiotics. The observed efficacy against MDR organisms that are otherwise resistant to conventional antibiotics may be explained by this synergy, which lowers the likelihood of resistance development. Additionally, *C. afer's* ethnomedical significance justifies further research into it. This plant has long been used in traditional knowledge systems to cure infections, and scientific confirmation of these uses helps to close the gap between traditional medicine and contemporary pharmacology. In areas with limited access to synthetic antibiotics, this integration is especially crucial. Notwithstanding these encouraging results, care must be taken when extending in vitro findings to clinical contexts. Variations in immune responses, metabolism, and drug bioavailability can have a big impact on how well a treatment works. Therefore, before *costus afer*-based treatments can be suggested for routine clinical usage, strong in vivo research and carefully planned clinical trials are necessary.

Recommendations

1. Further experimental studies should be conducted to isolate and characterize the specific bioactive compounds in *Costus afer* responsible for antibacterial activity against multidrug-resistant *Staphylococcus*

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aureus. Standardized extraction procedures should be developed because variations in extraction methods and solvent types may influence the antibacterial effectiveness of *Costus afer* extracts.

2. Additional in vitro and in vivo investigations are needed to determine the efficacy, safety, dosage range, and toxicity profile of *Costus afer* before clinical application.
3. Research should assess the synergistic effects of *Costus afer* extracts when combined with conventional antibiotics to determine whether resistance can be reduced and treatment effectiveness improved.
4. Molecular studies should be carried out to understand the mechanisms through which *Costus afer* inhibits or suppresses multidrug-resistant *Staphylococcus aureus* strains.

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