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Original article.

Crude pineapple extract inhibits WHO priority groups bacteria that are causing skin and soft tissue infections: A cost-effective alternative in the fight against AMR.

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ABSTRACT

Introduction: The escalating global crisis of antimicrobial resistance (AMR) has rendered many frontline antibiotics ineffective, particularly against multidrug-resistant (MDR) bacteria such as carbapenem-resistant *Pseudomonas aeruginosa* (CarbR), extended-spectrum β-lactamase (ESBL)-producing *Escherichia coli*, and methicillin-resistant *Staphylococcus aureus* (MRSA). With limited new antibiotics entering the pipeline and high costs of drug development, there is growing interest in affordable, eco-friendly alternatives from plant-derived compounds. Pineapple (Ananas comosus), particularly its bromelain-rich peel and crown, contains bioactive phytochemicals with reported antibacterial properties.

Objectives: This study evaluated the antibacterial activity of crude pineapple extracts against MDR pathogens associated with skin and soft tissue infections (SSTIs).

Material and methods: This laboratory-based experimental study (May–July 2025) utilized 15 archived clinical isolates of CarbR *P. aeruginosa* (5), ESBL *E. coli* (5), and MRSA (5) from the Bugando Medical Centre. Isolates were revived, re-characterized, and tested for susceptibility following CLSI guidelines. Crude bromelain extracts were prepared from pineapple fruit, peel, and crown using ethanol maceration followed by rotary evaporation, and finally drying. Extracts were tested for antibacterial activity via broth micro-dilution assays to determine minimum inhibitory concentrations (MICs), with experiments performed

in triplicate.
Results: Peel extract exhibited the strongest antibacterial activity with MICs of 12.5% for CarbR *P. aeruginosa* and 25% for both ESBL *E. coli* and MRSA. Followed by the crown extract that showed MICs of 12.5%, 25%, and 50% against the same pathogens, while fruit extract demonstrated weaker activity, requiring 100% concentration against ESBL *E. coli* and MRSA.
Conclusion: Crude pineapple peel and crown extracts demonstrated potent antibacterial activity against WHO-priority MDR pathogens. Further work should isolate and characterize bioactive compounds from crude pineapple peel and crown extracts for clinical translation.

KEYWORDS: CRUDE PINEAPPLE EXTRACT, ESBL *E. COLI*, MRSA, CARBAPENEM-RESISTANT *P. AERUGINOSA*, MULTIDRUG-RESISTANT BACTERIA

INTRODUCTION

The discovery of antibiotics marked a pivotal moment in medical history. In 1928, Alexander Fleming discovered penicillin, the first true antibiotic, derived from the *Penicillium notatum*. By the 1940s, penicillin was mass-produced and widely deployed during World War II and significantly reduced the death rates from bacterial infections and battlefield wounds. It was hailed as a “wonder drug” that transformed modern medicine, drastically improving life expectancy and survival from once-lethal infections such as sepsis and pneumonia(Aminov, 2010, Gaynes, 2017).

However, within just a few years of its introduction, the first case of antibiotic resistance was reported. In 1942, *Staphylococcus aureus* resistant to penicillin was observed and by the late 1940s, resistant strains had become widespread, compromising the efficacy of this revolutionary drug (Laxminarayan et al., 2013). This marked the beginning of a global health crisis of antimicrobial resistance (AMR) that has escalated dramatically over the decades due to the overuse, misuse, and environmental contamination of antibiotics(Irfan et al., 2022, Reghukumar, 2023).

Today, AMR is one of the top ten global public health threats, as declared by the World Health Organization (WHO). AMR has rendered many antibiotics ineffective leading to longer hospital stays, increased medical costs, and higher mortality(Dadgostar, 2019, Tansarli et al., 2013, Vallejo-Torres et al., 2018). Among the most alarming are the WHO’s priority pathogens, which include: Extended-Spectrum Beta-Lactamase (ESBL)-producing *Escherichia coli*, Carbapenem-resistant (CarbR) *Pseudomonas aeruginosa* and Methicillin-resistant *Staphylococcus aureus* (MRSA) which have been linked to severe skin and soft tissue infections (SSTIs) globally (Jesudason, 2024, Tacconelli et al., 2018).

According to WHO’s 2023 AMR Surveillance Report, more than 1.27 million deaths globally are directly attributable to resistant bacterial infections, with low- and middle-income countries (LMICs) bearing the heaviest burden. Projections suggest that if current trends persist, AMR could lead to 10 million deaths annually by 2050 and a cumulative economic loss of up to $100 trillion USD (O'Neill, 2016, Organization, 2023). In response, the WHO published the global action plan on AMR which advocates for the development of sustainable investment in new medicines and diagnostics as one of its priorities in 2015 (Organization, 2015). Despite these efforts, the antibiotic development pipeline remains limited. Only 12 new antibiotics were approved globally between 2017 and 2021, most of which offer minimal clinical advantage over existing drugs and show limited efficacy against priority pathogens like carbapenem-resistant *P. aeruginosa* and MRSA (Organization, 2022, Butler et al., 2022). A key challenge is the high cost of drug development, estimated to range from $1 billion to $2 billion per antibiotic, compounded by low financial returns and a high failure rate (Renwick et al., 2016, Payne et al., 2007).

In light of these challenges, there is growing interest in plant-based antimicrobials as affordable, eco-friendly alternatives. Crude pineapple (*Ananas comosus*) extract has emerged as a promising candidate due to its rich content of bromelain, a proteolytic enzyme with documented antibacterial, anti-inflammatory, and wound-healing properties, making it a promising candidate for treating SSTIs, especially in LMICs where access of the effective treatment options is limited (Putri et al., 2018, Ogwu et al., 2019).

Therefore; this study was designed to contribute to the global fight against AMR by evaluating the efficacy and potential use of crude pineapple extract as a biodegradable, low-cost, and readily available antimicrobial agent, particularly for the management of skin and soft tissue infections caused by MDR pathogens. This could provide a sustainable treatment alternative and boost the global efforts of derailing the progression of AMR by the discovery of effective and cost effective antibacterial agents particularly in regions with limited healthcare infrastructure.

MATERIALS AND METHODS

MATERIALS

Isolate retrieval and characterization.

This study retrieved and utilized archived ESBL producing *E. coli* (6), carbapenem-resistant *P. aeruginosa* (6), and MRSA (6) isolated from patients with SSTIs who had previously attended Bugando Medical Centre (BMC). The isolates were archived at -80°C, the cryovials were thawed at room temperature for 30 minutes, thereafter; the isolates were subcultured onto blood agar (BA) and MacConkey agar (MCA) isolates and incubated at 35–37°C for 18–24 hours. Antimicrobial susceptibility testing and MDR phenotypes were re-confirmed as per the Clinical and Laboratory Standards Institute (CLSI) guidelines for comparative purpose(C-CaLS, 2020, Jorgensen and Turnidge, 2015).

Plant materials

A fresh, ripe pineapple was sourced from the Mwanza local market (latitude -2.51667, longitude 32.90000) and promptly transported to the laboratory for processing. The fruit was thoroughly washed with clean water and weighed using an electronic balance (Mettler Toledo, Greifensee-Switzerland). The pineapple was dissected into three anatomical parts: the fruit pulp, peel, and crown. Each component was individually weighed, and the percentage mass loss during separation was recorded.

Using a sterilized kitchen knife (Victorinox AG, Ibach-Schwyz, Switzerland), each pineapple part was finely chopped and transferred into separate, pre-labeled 1,000 mL narrow-neck conical flasks (Simax Glassware, Central Bohemian Region, Czech Republic).

Absolute ethanol (99%) was added up to the neck of the flask to serve as the extraction solvent. The flasks were sealed with aluminum foil to minimize solvent evaporation and left to macerate at room temperature (≈25°C) for or 48 hours (Saptarini et al., 2023). After maceration, the mixtures were filtered through a double-layered cheesecloth to separate the crude liquid extracts from solid residues. The residues were re-macerated under identical conditions to maximize yield. Combined filtrates from each part were then concentrated using a rotary vacuum evaporator (Heidolph Instruments GmbH & Co. KG, Schwabach, Germany) at 40-50°C for 1 hour, under reduced pressure of 150 mbar at a rotation speed of 80-100 rpm(Saptarini et al., 2023).

The extracts were transferred into wide-mouthed beakers and further incubated in a 50°C water bath for an additional 6 hours to facilitate complete removal of ethanol and excess water by evaporation(Saptarini et al., 2023). Once evaporation was complete, the final crude bromelain extracts from the fruit, peel, and crown

(in paste form) were carefully collected, weighed, and stored at 4°C to preserve enzymatic activity for subsequent analysis (Ketnawa et al., 2011, Gautam and Gabrani, 2024, Chua and Leong, 2022).

Determination of minimum inhibitory concentration of crude pineapple extracts against MDR bacteria.

The initial crude bromelain extracts were divided into two sets. One set was retained as the undiluted concentrate (100%), while the second set was subjected to serial two-fold dilutions. For each dilution step, an equal volume of sterile distilled water was added to the previous concentration, resulting in progressive dilutions of 1:2 (50%), 1:4 (25%), 1:8 (12.5%), and finally 1:16 (6.25%). This approach yielded a range of bromelain concentrations suitable for comparative activity testing.

Each bacterial strain was emulsified in sterile normal saline to a concentration equivalent to 0.5 McFarland standard (~1.5 × 10^8 CFU/mL). Three sets of micro titter plates with a 300 µl (12×8) wells were employed (one for each MDR phenotype), 100 µl of crude bromelain extract were pipetted into columns of the micro-titter plates (column A-L, starting with 100% to 12.5%) this was followed by 150 µl of brain heart infusion (BHI) broth which was pipetted into the respective wells. Lastly; 10 µl of the bacterial suspension were pipetted into each row (1-8, one bacterial strain per row). These steps were done for each bacterial strain against all concentration of the extracts. To ensure reproducibility the experiments were done in triplicates.

The micro titter plates were then incubated at 35–37°C for 18–24 hours. Using sterile disposable loops, an inoculum from each well were sub-cultured onto BA and MCA then incubated at 35-37°C for 18-24 hours (Pankey and Sabath, 2004). The MIC was defined as the lowest concentration of the crude bromelain extract that resulted in no visible bacterial growth (99.9% reduction in colony-forming units compared to the initial inoculum) on both BA and MCA agar plates.

Quality Control.

The 2 last rows of wells were used as control wells; positive controls contained bacteria suspensions and BHI without bromelain, while the negative control contained BHI broth and bromelain extract without bacteria suspension. After incubation these wells were subculture onto BA and MCA. *Staphylococcus aureus* (ATCC 25923), *Pseudomonas aeruginosa* (ATCC 27853) and *Escherichia coli* (ATCC 25922) were used for quality control of the culture media and the antibiotic discs.

Ethical approval for research methods

This study was approved by the joint Catholic University of Health and Allied Sciences and Bugando Medical Centre (CUHAS&BMC) joint Research Ethics and Review Committee with the certificate number (CREC 3646/2025).

Statistical Analysis

The data collected were recorded using research books and later exported to Microsoft Excel 2016 for analysis and summarization. Categorical variables were analyzed and presented as proportions (percentages).

RESULTS AND DISCUSSION

Bromelain extraction and retrieval from Pineapple

A whole pineapple weighing 1330.1 grams, was separated into fruit, peel, and crown, weighing 940g, 296.8g, and 92.5g respectively. The final combined mass of all parts was 1329.3 grams after separation,

indicating a minimal mass loss of only 0.05%. The extract yield varied by pineapple part with the fruit producing the highest absolute and percentage yield at 101.5g (10.8%) as shown in table 1.

1. **Table 1** Crude bromelain Extraction Yield from Pineapple Components

Part of Pineapple	Initial Weight (g)	Extracted Mass (g)	Percentage Yield
Fruit	940.09	101.5	10.8%
Peel	296.8	23.7	8.0%
Crown	92.54	9.0	9.7%
Whole Pineapple	1330.1	134.177	10.1%

Characterization and Antimicrobial Susceptibility Profile of Bacterial Isolates

This study utilized 15 bacterial isolates from 3 pathogenic species namely, *S. aureus* (5 MRSA), *E. coli* (5 ESBL producers) and *P. aeruginosa* (5 CarbR). Antimicrobial susceptibility profiles of these isolates were established for comparative purposes, high levels of resistance were observed among ESBL *E. coli* and CarbR *P. aeruginosa* towards 3rd gen cephalosporins, gentamicin and meropenem (100% resistance in CarbR *P. aeruginosa*) as detailed in figure 1. Similarly, MRSA displayed high levels of resistance up to 100% towards trimethoprim/sulfamethoxazole and clindamycin as detailed in Table 2.

Table 2 Antimicrobial Susceptibility Profile of Bacterial Isolates

Antibiotic	Bacteria isolates		
	CarbR *P.aeruginosa*, n=5 (%)	**ESBL *E.coli*, n=5 (%)**	**MRSA, n=5 (%)**
AMC	NA	5 (100)	NA
CRO	NA	5 (100)	NA
CAZ	5 (100)	5 (100)	NA
SXT	NA	5 (100)	5 (100)
CIP	3 (60)	4 (80)	NA
TZP	3 (60)	4 (80)	NA
MEM	4 (80)	3 (60)	NA
CN	4 (80)	5 (100)	4 (80)
FOX	NA	NA	5 (100)
E	NA	NA	5 (100)
TE	NA	5 (100)	3 (60)
CD	NA	NA	5 (100)

Key: AMC: amoxicillin–clavulanic acid, CRO: ceftriaxone, CAZ: ceftazidime. SXT: trimethoprim–sulfamethoxazole,CIP: ciprofloxacin. TZP: piperacillin–tazobactam, MEM: meropenem, CN: gentamicin, FOX: cefoxitin, E: erythromycin, TE: tetracycline, CD : clindamycin.

Minimum inhibitory concentration of constituent pineapple parts

Crude pineapple extract from the crown, peel, and fruit were tested for antibacterial activity against carbapenem-resistant (CarbR) *P. aeruginosa*, ESBL *E. coli*, and MRSA so as to establish their respective MIC. The crown extract exhibited MIC values of 12.5% (1:4) for CarbR *P. aeruginosa*, 25% (1:2) for ESBL

E. coli, and 50% (1:1) for MRSA. The peel extract demonstrated MIC values of 12.5% (1:4) for CarbR P. aeruginosa and 25% (1:2) for both ESBL *E. coli* and MRSA. The fruit extract showed MIC values of 12.5% (1:4) for CarbR *P. aeruginosa* but required undiluted concentrations (100%) to inhibit ESBL *E. coli* and MRSA as detailed in fig 1.

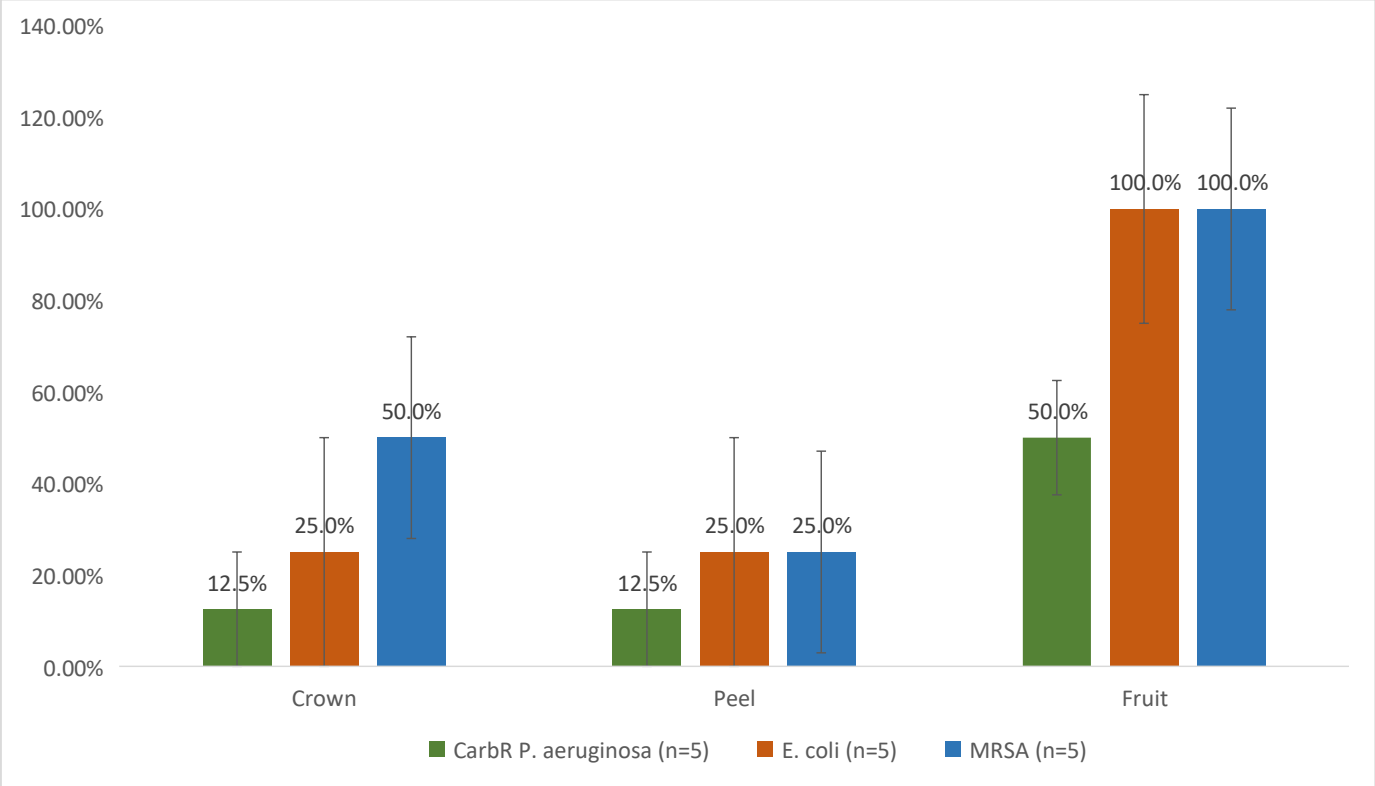

Figure 1 Minimum inhibitory concentration of crude pineapple extract against MDR bacteria, error bars indicate standard deviation

Discussion

This study examined the antibacterial properties of crude pineapple extract of crown, peel and fruit by determining their respective MICs against WHO priority pathogens (CarbR *P.aeruginosa*, ESBL *E. coli* and MRSA)(Jesudason, 2024). Out of the three pineapple components, the crude pineapple peel extract had the lowest MIC against CarbR *P.aeruginosa*, ESBL *E. coli* and MRSA at 12.5%, 25% and 25% respectively. The crown exhibited the second-best antibacterial effect with MICS of 12.5%, 25% and 50% against CarbR *P.aeruginosa*, ESBL *E. coli* and MRSA respectively. The fruit displayed the lowest antibacterial activity of all the pineapple components with MICs of 12.5%, 100% and 100% against CarbR *P.aeruginosa*, ESBL *E. coli* and MRSA respectively.

The superior antibacterial activity of the pineapple peel extract, as reflected by its lower MIC values compared to extracts from the crown and fruit, may be attributed to its higher concentration of bioactive secondary metabolites. Available data shown that pineapple peel contains abundant Phyto-chemicals such as flavonoids, phenolic acids, tannins, and saponins, all of which have been reported to disrupt bacterial cell walls, inhibit nucleic acid synthesis, and interfere with quorum sensing mechanisms in pathogenic bacteria(Daglia, 2012, Cushnie and Lamb, 2011). Several studies have shown that fruit peels generally contain higher concentrations of bioactive compounds than the edible portions of the fruit, as these phyto-chemicals serve as a natural defense against microbial invasion and environmental stressors. For example, pineapple peel has been reported to contain higher levels of phenolics, flavonoids, and organic acids

compared to the pulp(Hossain and Rahman, 2011, Sharma et al., 2024). Such compounds may synergistically contribute to the enhanced antibacterial activity observed in the peel extract.

The crown also demonstrated very good antibacterial activity against MDR bacteria. This bio-activity can be attributed to its rich phyto-chemicals profile, which includes phenolic compounds, flavonoids, tannins, and bromelain, a cysteine protease unique to pineapple(Kumar et al., 2025, Mehraj et al., 2024).

Compared to the fruit pulp, the crown contains higher concentrations of bioactive compounds, which may account for its stronger antibacterial effects(Steingass et al., 2015). This can be attributed to the crown's physiological role as a site of active growth and regeneration. Both crown and peel tissues undergo rapid cell proliferation and differentiation, processes commonly linked with elevated bio-synthetic activity and the accumulation of secondary metabolites (Verpoorte and Memelink, 2002). These metabolites not only protect the plant against biotic and abiotic stresses but also contribute to the enhanced antibacterial activity observed in the extracts. Moreover, because the crown is directly exposed to the external environment and frequently subjected to microbial colonization, the plant may allocate higher levels of antimicrobial secondary metabolites to this tissue as a natural defense mechanism (Hossain and Rahman, 2011). Such ecological adaptation enhances the antimicrobial reservoir of the crown compared to the more protected inner edible portions of the fruit.

In contrast, the fruit pulp is primarily designed for nutrient storage and consumption to facilitate seed dispersal, and thus generally contains lower levels of antimicrobial phyto-chemicals. Instead, it is enriched with sugars, organic acids, and vitamins that serve nutritional rather than defensive purposes (Sharma et al., 2017).

These findings highlight the potential of non-edible pineapple parts, particularly the peel and crown, as valuable sources of antimicrobial agents against MDR bacteria. These tissues, often discarded as waste, are rich in bio-active compounds with demonstrated antibacterial activity, making them a cheap, effective, and environmentally friendly alternative to conventional antimicrobials. Their biodegradability further enhances their suitability as sustainable options for developing novel therapeutic agents or adjunct treatments in the fight against MDR infections.

CONCLUSIONS

Crude pineapple extracts from the peel and crown exhibit excellent antibacterial activity with low MICs against CarbR Pseudomonas aeruginosa, ESBL Escherichia coli, and MRSA. These findings not only validate the potential of non-edible pineapple byproducts as cost-effective, eco-friendly, and biodegradable antimicrobial agents, but also provide a much-needed boost of confidence in the global fight against antimicrobial resistance. The strong inhibitory effects observed by the peel and crown suggest that pineapple-derived compounds could serve as promising candidates for the development of novel therapeutic agents, especially in resource-limited settings where access to effective antibiotics is restricted. Future studies focusing on the isolation, structural characterization, and mechanism of action of bioactive constituents will be essential to advance these preliminary findings into clinically applicable interventions.

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Conflict of interest

Authors declare no conflict of interest in the production of this work

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