Bindura University of Science Education



ANTIMICROBIAL ACTIVITY OF ALOE VERA (*Aloe barbadensis Miller*), *CURCUMA LONGA* (TURMERIC) AND BANANA PEELS AGAINST SELECTED COMMON WOUND OPPORTUNISTIC BACTERIA, BOTH INDIVIDUALLY AND IN COMBINATION

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ABSTRACT

Wound healing is frequently compromised by microbial infection, particularly when the causative organisms are multidrug-resistant. Methicillin-resistant *Staphylococcus aureus*, multidrug-resistant *Pseudomonas aeruginosa*, and multidrug-resistant *Escherichia coli* can delay tissue repair, prolong treatment, and reduce the effectiveness of conventional antibiotics. This research explored how extracts of Aloe vera, turmeric, and banana peels, tested alone and together, affected specific multidrug-resistant bacteria found in wounds. Laboratory-cultured isolates of *S. aureus*, *P. aeruginosa*, and *E. coli* were screened by agar well diffusion according to CLSI guidelines, and isolates resistant to three or more antibiotic classes were classified as multidrug resistant and used in the in vitro assays. Plant materials were extracted using methanol, acetone, and water. Antimicrobial activity was evaluated by agar well diffusion for zone of inhibition, broth microdilution for minimum inhibitory concentration (MIC), and subculture for minimum bactericidal concentration (MBC). Synergistic activity was assessed using selected extract combinations and combinations with ampicillin, while standard qualitative assays were used for phytochemical screening. Each experiment was carried out three times to ensure consistency, and the resulting data were analysed using one-way ANOVA followed by Tukey's HSD post-hoc test ($p < 0.05$). Turmeric acetone extract showed the strongest antibacterial activity, with MIC values of 0.15625 mg/mL against *P. aeruginosa*, 0.078125 mg/mL against *S. aureus*, and 0.625 mg/mL against *E. coli*. For most organic solvent extracts, MBC/MIC ratios were 1, indicating bactericidal activity. The combination of acetone extracts of Aloe vera and turmeric with ampicillin produced the lowest MICs, reaching 0.0098 mg/mL against *E. coli* and *P. aeruginosa*. Phytochemical screening detected flavonoids, saponins, alkaloids, and tannins, except that tannins were not detected in turmeric. The activity index of turmeric acetone extract was 1.0 against *S. aureus* and *E. coli*. Overall, the findings indicate that turmeric, especially in acetone extract, has strong antibacterial activity against multidrug-resistant wound pathogens, while Aloe vera also shows useful activity and can enhance ampicillin in selected combinations. These results support the potential use of plant extracts as low-cost alternatives or adjuncts to conventional antibiotics in wound care. Moving forward, it is advisable to pursue live-subject testing and the creation of specific therapeutic formulations.

APPROVAL FORM

Title of dissertation: Antimicrobial activity of Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (Turmeric) and Banana peels *Musa acuminata* against selected common wound opportunistic bacteria, both individually and in combination.

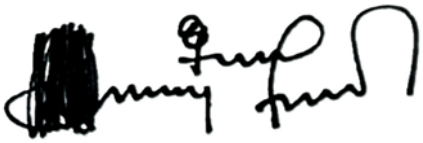
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The undersigned certify that they have read this dissertation, found it suitable for submission to the Faculty of Science and Engineering, and confirmed that it complies with Faculty requirements.



…….. Date: 24 May 2026

Signature of student



..... Date: 26 May 2026.

Signature of Supervisor

Signature of Department Chairperson:  Date: 13 August 2026

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Meaning
AI	Activity Index
ANOVA	Analysis of Variance
ATCC	American Type Culture Collection
CFU	Colony Forming Units
CLSI	Clinical and Laboratory Standards Institute
DMSO	Dimethyl Sulfoxide
FIC	Fractional Inhibitory Concentration
HSD	Honest Significant Difference
MBC	Minimum Bactericidal Concentration
MDR	Multidrug-Resistant
MIC	Minimum Inhibitory Concentration
MRSA	Methicillin-Resistant *Staphylococcus aureus*
PBS	Phosphate Buffered Saline
PDGF	Platelet-Derived Growth Factor
Sxt	Sulfamethoxazole-Trimethoprim
TGH-β	Transforming Growth Factor Beta
VEGF	Vascular Endothelial Growth Factor
ZOI	Zone of Inhibition

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CHAPTER 1

Introduction

1.0 Chapter Introduction

Wound infections remain difficult to manage, and the challenge is intensified by the growing prevalence of multidrug-resistant (MDR) pathogens, particularly in settings where access to a broad range of antimicrobial agents is limited (Wang et al., 2018). Resistant strains of *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Escherichia coli* are well-documented causes of delayed tissue repair, prolonged hospital stays, and treatment failure (Uberoi et al., 2024). As resistance continues to increase and the development of new antibiotics remains slow, there is a clear need to investigate antimicrobial approaches that are both effective and accessible in resource-constrained environments (Hill et al., 2025).

Medicinal plants represent one such option. Aloe vera (*Aloe barbadensis Miller), Curcuma longa* (turmeric), and banana peels (*Musa acuminata*) have attracted scientific interest because of their reported antimicrobial, anti-inflammatory, and wound-supportive properties (Vitale et al., 2022). These effects are linked to diverse phytochemical constituents rather than to a single active agent (Kumar et al., 2021). Importantly, the plants are also widely available in many of the settings where pharmaceutical products are difficult to obtain, making them relevant not only scientifically but also practically.

In this chapter, I establish the study's clinical background, define the core problem, and lay out the specific goals, questions, and hypotheses driving the research. This study focuses on the phytochemical characterization and in vitro antibacterial evaluation of Aloe vera, turmeric, and banana peel extracts, tested individually and in combination against MDR isolates *of S. aureus, P. aeruginosa*, and *E. coli* (Wu et al., 2024*)*.

1.1 Background

Wound healing is a coordinated biological process involving haemostasis, inflammation, proliferation, and remodelling, with each phase depending on successful progression through the previous one (Seepe et al., 2021). Infection can disrupt this sequence by prolonging inflammation, increasing tissue damage, and diverting cellular resources away from repair (Owusu et al., 2021). The problem becomes more serious when the infecting organisms are resistant to conventional antibiotics. Globally, resistant wound pathogens, especially *S. aureus, P. aeruginosa*, and *E. coli*, have exposed important limitations in standard wound management. In addition to resistance itself, conventional antimicrobial therapy may be constrained by adverse effects and reduced effectiveness against persistent infections (Seepe et al., 2021). Given these challenges, it is important to scientifically scrutinize the traditional use of medicinal plants for treating wounds. Plant-derived preparations contain structurally diverse phytochemicals, including flavonoids, alkaloids, and terpenoids, that may contribute to antimicrobial and wound-healing effects reported in the literature (Smythe & Wilkinson, 2023).

While existing studies show potential, the current body of evidence is somewhat inconsistent. A considerable body of work shows that phytochemicals from different plant species can inhibit bacterial growth and support tissue repair (Nunes et al., 2024), yet in many cases, the underlying mechanisms are still not well defined. The three plant materials selected for this dissertation, Aloe vera (*Aloe barbadenesis* Miller), *Curcuma longa*, and banana peels, were chosen partly because they are readily available in resource-limited settings and partly because each has been associated with antimicrobial potential in previous studies (Lawal et al., 2021; Vijayakumar & Ramanathan, 2020). Aloe vera (*Aloe barbadensis Miller*) is perhaps the most extensively studied of the three plants. Its leaves contain anthraquinones, glycoproteins, and polysaccharides that may contribute to antimicrobial and anti-inflammatory effects through multiple mechanisms. Although reported activity against wound-relevant pathogens is generally consistent, important differences related to extraction method and study design remain, and these are considered further in Chapter 5.

Curcuma longa is widely recognised for curcumin, a polyphenolic compound with antioxidant, anti-inflammatory, and antimicrobial properties described in many experimental models (Niu et al., 2024). Proposed antibacterial mechanisms include membrane disruption and interference with virulence pathways. However, translating these in vitro observations into clinical usefulness remains challenging, as discussed later in this dissertation.

Banana peels occupy a more exploratory position in this literature. The peel of *Musa acuminata* contains flavonoids, tannins, and other phenolic compounds (Vijayakumar & Ramanathan, 2020), but the evidence for consistent antimicrobial activity against wound pathogens such as *E. coli* and *S. aureus* is less robust than for Aloe vera and turmeric (Waditzer & Bucar, 2021). This makes banana peel an important comparative component of the present investigation.

1.2 Problem statement

Despite advances in modern medicine, increasing resistance among wound pathogens continues to compromise conventional antibiotic therapy. This has created a need to investigate medicinal plants as possible alternative or complementary antimicrobial agents. In addition, limited information is available on the possible synergistic effects of combining different plant extracts. Understanding these interactions may help to improve activity against multidrug-resistant microorganisms associated with wound infections.

1.3 AIM

1.3.1 Aim/main objective

The main aim of this study was to determine the antimicrobial activity of selected plant extracts, both individually and in combination, against common multidrug-resistant wound pathogens, namely *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Escherichia coli*.

1.3.2 Specific Objectives

1. To determine the phytochemical constituents of the plant extracts from Aloe vera (*Aloe barbadensis Miller)*, *Curcuma longa* (turmeric) and banana peels using chemical testing.
2. To evaluate the *in vitro* antimicrobial activity of each extract against common wound pathogens, *S. aureus, P. aeruginosa* and *E. coli*, individually.
3. To assess the interactions of these extracts in combination against *S. aureus, P. aeruginosa* and *E. coli* in *in vitro* experiments.

1.4 Research questions.

1. Do extracts of Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (turmeric), and banana peels contain phytochemical constituents such as flavonoids, alkaloids, terpenoids, and saponins that are detectable by standard chemical tests?
2. Which of the three plant extracts, Aloe vera, *Curcuma longa* (turmeric), or banana peels, shows the strongest antimicrobial activity against *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Escherichia coli*?
3. What minimum concentrations of Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (turmeric), and banana peel extracts, used alone or in combination, are required to inhibit or kill *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*?

1.5 Justification/Significance of the study

There are both scientific reasons and practical motivations for choosing to study these particular plant materials. They are inexpensive and widely available, which is especially important in low-resource settings where pharmaceutical antibiotics may be scarce or unaffordable (Hill et al., 2025). In some communities, these plants can also be cultivated locally, offering a degree of self-sufficiency that imported pharmaceutical products cannot provide. Scientifically, traditional medicine has long associated Aloe vera, turmeric, and banana peels with wound care, but ethnobotanical use does not by itself establish efficacy or mechanism. This study, therefore, applies phytochemical screening and controlled antimicrobial assays to provide a more evidence-based assessment of their activity (Wu et al., 2024). By identifying major phytochemical classes and comparing extraction conditions,

the study contributes to a clearer understanding of which plant materials and solvent systems are most promising. Such knowledge may support future work on topical formulations, wound dressings, or other plant-based therapeutic applications (Kumar et al., 2021; Patel, 2022; Singh et al., 2025).

1.6 Hypotheses

- H0: There is no significant difference, at the 95% confidence level, in the antimicrobial activity of the selected medicinal plants against common wound pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli.*
- H_1: There is a significant difference at 95% confidence level in terms of the antimicrobial activity of the selected medicinal plants against common wound pathogens such as *Staphylococcus aureus, Pseudomonas aeruginosa,* and *Escherichia coli*.

1.7 Delimitations of the study

This was limited to in vitro evaluation of antimicrobial activity and phytochemical screening of three selected plant materials (Aloe vera leaves, *Curcuma longa* rhizomes and banana peels) using three extraction solvents (methanol, acetone and water). Only three common wound opportunistic bacteria (multidrug-resistant clinical isolates of *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*) were tested; other wound pathogens and fungal agents were not included. The study evaluated crude extracts and simple combinations of extracts and did not perform bioassay-guided fractionation, isolation of individual compounds, in vivo testing, pharmacokinetics, toxicity or formulation development. Consequently, these findings suggest early antimicrobial promise but should not be taken as a final measure of clinical safety or success.

1.8 Definition of terms

Antimicrobial activity: the ability of a substance to inhibit the growth of, or kill, microorganisms (bacteria in this study), measured using zone of inhibition, MIC, and MBC.

Minimum Inhibitory Concentration (MIC): The lowest concentration of an extract that visibly inhibits microbial growth under specified conditions.

Minimum Bactericidal Concentration (MBC): The lowest concentration of an extract that kills a specified percentage (commonly ≥ 99.9%) of the initial inoculum, determined by subculture.

Zone of inhibition (ZOI): Diameter (mm) of clear area around a well or disk on agar where bacterial growth is prevented.

Activity Index (AI): the ratio of the inhibition zone produced by a test extract to that produced by a standard antibiotic (AI = ZOIextract / ZOIantibiotic).

Multidrug-resistant (MDR): Non-susceptibility of a bacterial isolate to at least one agent in three or more antimicrobial categories.

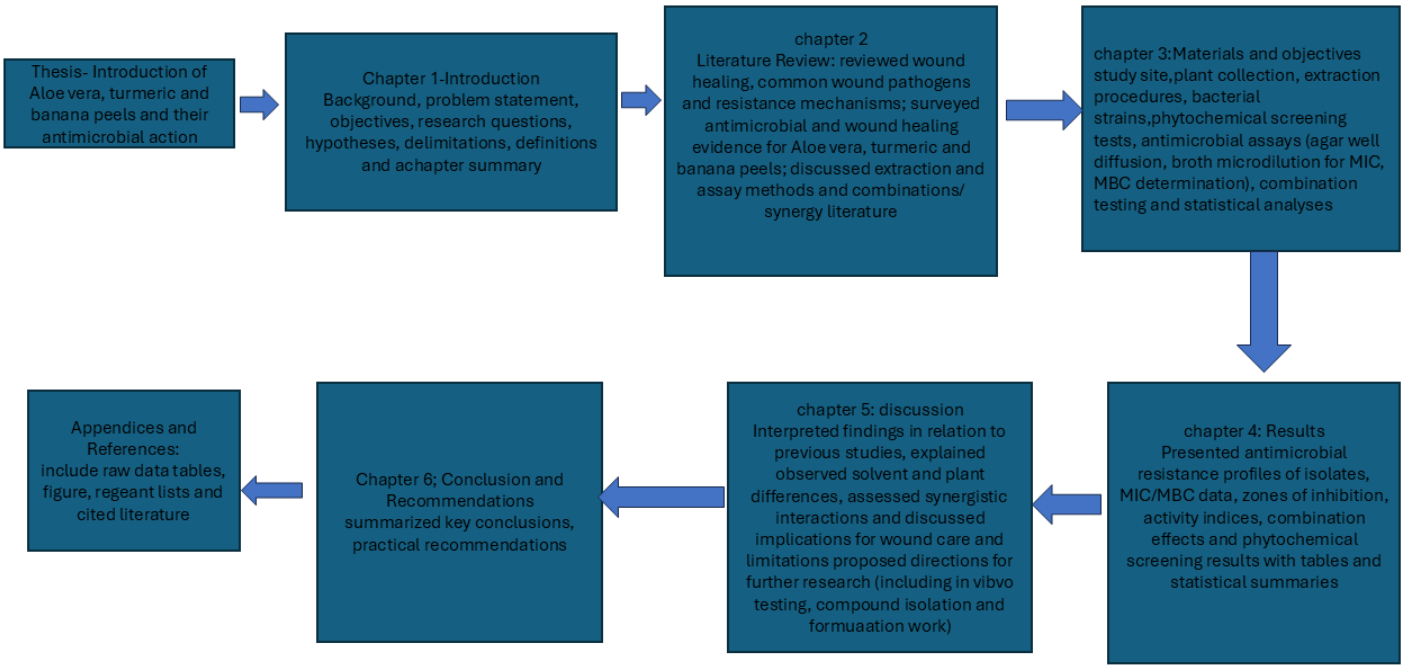
Synergy: Interaction between two or more agents that produces an effect greater than the sum of their individual effects, commonly assessed using the fractional inhibitory concentration index (FICI).

Crude extract: Unfractionated mixture after solvent extraction of plant material, containing multiple phytochemicals.

1.9 Summary of Chapter One

The opening chapter detailed the issues surrounding antibiotic-resistant wound infections and justified the search for plant-derived solutions. It presented the study aim, specific objectives, research questions, hypotheses, significance, and delimitations, and defined key terms used throughout the dissertation. The remaining chapters present the literature review, materials and methods, results, discussion, conclusion, and recommendations arising from the study.

1.10 Synopsis of the thesis (flow and chapter map)



This dissertation is organized into six chapters. Chapter One introduces the research problem, study objectives, hypotheses, significance, and delimitations. Chapter Two reviews the literature on wound healing, opportunistic wound pathogens, conventional wound care, phytochemical-rich medicinal plants, and the methods used to evaluate antimicrobial activity. Chapter Three describes the materials and methods, including plant collection, extraction procedures, bacterial strain preparation, phytochemical screening, and antimicrobial assays. Chapter Four presents the results of susceptibility testing, MIC and MBC determinations, activity indices, combination studies, and phytochemical analysis. Chapter Five discusses the findings in relation to previous studies and highlights their relevance to wound management. Chapter Six concludes the study and offers recommendations for future research and possible formulation development to translate these findings into safe, efective wound healing products.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Wound infection is challenging not simply because bacteria are present, but because they may persist through biofilm formation, resistance mechanisms, and organism-specific survival strategies. The following sections examine the existing body of research and literature that informs this study. It begins with the physiology of wound healing and the factors that disrupt it, then considers the pathogenic characteristics of *Staphylococcus aureus, Pseudomonas aeruginosa,* and *Escherichia coli*, together with the strengths and limitations of conventional wound management. The chapter then examines Aloe vera, *Curcuma longa* (turmeric), and banana peels in relation to their botanical features, traditional uses, phytochemical composition, antimicrobial properties, and potential relevance to wound care. It concludes with an overview of extraction methods and laboratory approaches used to evaluate antimicrobial activity and combination effects (Balouiri et al., 2016).

2.1 Wound Healing

Normal wound healing proceeds through four overlapping phases: haemostasis, inflammation, proliferation, and remodelling, each of which depends on satisfactory progression through the previous phase (Wilkinson & Hardman, 2020). Haemostasis limits blood loss, inflammation clears debris and microorganisms, proliferation restores tissue through angiogenesis and matrix formation, and remodelling strengthens the repaired tissue. When infection occurs, this orderly sequence can be interrupted, and healing may be delayed (Wang et al., 2018).

From a clinical perspective, infection stands as a major obstacle to successful tissue repair. Colonization by organisms such as *S. aureus, P. aeruginosa*, and *E. coli* can prolong inflammation and shift the wound environment away from tissue reconstruction (Uberoi et al., 2024). Biofilm formation intensifies this problem because bacterial communities embedded in a matrix are more difficult to eliminate than planktonic cells (Dekker et al., 2021). As a result, chronic infection, delayed epithelial closure, and recurrent inflammatory cycles may develop. Effective wound healing, therefore, depends not only on normal host physiology but also on adequate microbial control, a challenge that becomes even greater when the organisms involved are resistant to standard antibiotics (Wang et al., 2018).

2.1.1 Wound Opportunistic Bacteria

Wound opportunistic bacteria are microorganisms that normally do not cause disease in healthy individuals but can take advantage of compromised tissue or immune defences to establish infections (Alves et al., 2023). These

bacteria are frequently part of the human microbiota or are environmental pathogens that become pathogenic under specific conditions, such as tissue or immunosuppression. In the context of wounds, these bacteria can colonize the damaged tissue, forming biofilms and producing virulence factors that hinder the natural healing process (Wang et al., 2018).

2.1.2 Common Pathogens

S. aureus, P. aeruginosa, and *E. coli* differ in biology *S. aureus* is a Gram-positive cocci often causing skin infections, while *P. aeruginosa* and *E.coli* are Gram negative rods with *P. aeruginosa* being motile, and *E.coli* commonly part of gut flora but capable of causing diverse infections, but all are clinically important in wound infection. *Pseudomonas aeruginosa* is especially notable for its environmental resilience and ability to survive in diverse settings, including soil, water, hospital equipment, and wound beds (Alves et al., 2023). In susceptible patients, it can shift from an environmental organism to an aggressive pathogen that is difficult to eliminate. Its intrinsic and acquired resistance is extensive, and its well-established capacity for biofilm formation further reduces susceptibility to treatment. Pyocyanin-associated greenish exudate may be a visible sign of *P. aeruginosa* infection, although infection is often well established by the time it appears (Altinkaynak et al., 2023). If inadequately managed, *P. aeruginosa* infection can result in tissue necrosis, delayed wound closure, and systemic spread (Alves et al., 2023).

Found globally, the Gram-positive bacterium *Staphylococcus aureus* is a leading pathogen in wound-related infections. It is part of the normal flora of many individuals, residing harmlessly on the skin and mucous membranes. However, when the skin barriers are breached, *S. aureus* can invade tissues and cause infections ranging from mild impetigo to severe conditions such as cellulitis, abscesses and necrotizing wounds. Notably, methicillin-resistant *S. aureus* (MRSA) strains have emerged as a significant challenge in healthcare facilities, owing to their resistance to multiple antibiotics. *S. aureus* produces various virulence factors, including toxins, enzymes, and surface proteins that facilitate adherence, immune evasion, and tissue destruction. Its ability to form biofilms on wound surfaces further complicates treatment, leading to chronicity of infections and delayed healing (Wang et al., 2018).

Escherichia coli is a Gram-negative rod-shaped bacterium that may be recovered from wounds, particularly where contamination from the gastrointestinal environment or poor hygiene is involved (Wang et al., 2018). Although it is more commonly discussed in enteric disease, *E. coli* can act as an opportunistic wound pathogen by adhering to damaged tissue, sustaining inflammation, and contributing to purulent infection. Its clinical importance increases when isolates carry resistance determinants or coexist with other wound pathogens in polymicrobial

infections. For this reason, *E. coli* should not be dismissed as a secondary contaminant in wound microbiology; in some settings, it can meaningfully delay healing and complicate antibiotic selection. Taken together, *S. aureus*, *P. aeruginosa*, and *E. coli* represent a clinically important group of wound-associated bacteria whose persistence can prolong inflammation, impair tissue repair, and worsen patient outcomes (Wang et al., 2018).

2.1.3 Conventional wound treatment

Standard care for wounds usually involves cleaning, removing dead tissue, managing infection, and using appropriate dressings or antibiotics. Cleansing removes debris and reduces surface contamination, while debridement eliminates necrotic tissue and improves the wound bed. Dressings are then selected according to wound depth, exudate, and infection risk. In infected wounds, topical antiseptics and systemic antibiotics may be used, but these approaches are not always effective when biofilms are established or when the causative organisms are multidrug resistant (Andleeb et al., 2024). For this reason, modern wound care increasingly emphasizes both microbial control and support of the wound-healing environment rather than reliance on antibiotics alone (Andleeb et al., 2024).

2.1.4 Mechanisms of Resistance

Antibiotic resistance in wound pathogens arises through several interacting mechanisms, including enzymatic drug inactivation, modification of antibiotic targets, reduced membrane permeability, active efflux, horizontal transfer of resistance genes, and biofilm-associated protection (Uberoi et al., 2024). Biofilms are especially important because they create a structured matrix that shields bacteria, slows antimicrobial penetration, and promotes physiological states that are less susceptible to treatment (Dekker et al., 2021). In practical terms, this means that a wound may remain infected even when an antimicrobial agent appears appropriate on paper. The persistence of resistant, biofilm-forming organisms is one reason why alternative or adjunctive antimicrobials, including phytochemical-rich plant extracts, continue to attract research interest in wound care (Hurlow & Bowler, 2022).

2.2 Herbal wound treatment

Wound infections caused by opportunistic pathogens such as *S. aureus* and *P. aeruginosa* present a significant clinical challenge, particularly with the rise of multidrug-resistant bacteria. As a result, attention has increasingly turned to natural products that combine antimicrobial and wound-healing activity. Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (turmeric), and banana peels contain bioactive constituents such as polysaccharides, curcuminoids, and phenolic compounds that may disrupt microbial growth while also supporting tissue repair (Vitale et al., 2022). These extracts can be investigated individually or in combination, and improvements in

extraction methods and formulation may further enhance their usefulness in wound management (Lambrechts & Lall, 2021).

2.2.1 Aloe Vera (*Aloe barbadensis Miller*)

In this study, Aloe vera is considered because of its well-documented antimicrobial and wound-healing properties. Its gel contains bioactive compounds that can inhibit common wound pathogens such as *S. aureus, E. coli*, and *P. aeruginosa*, while also supporting tissue regeneration through effects on collagen production and inflammation (Lawal et al., 2021). This combination of antimicrobial and tissue-supportive effects makes Aloe vera a promising plant-based agent for infected wound management.

2.2.1.1 Botanical Description

Aloe vera is a succulent species in the family Asphodelaceae. It is easily recognized by its fleshy, lanceolate leaves arranged in a rosette. The leaves contain the gel that is widely used in medicinal, cosmetic, and health-related applications (Crous et al., 2025). Although often associated with North Africa, Aloe vera is now cultivated widely in dry and semi-arid regions of the world. It grows best in well-drained sandy or gravelly soils and tolerates low rainfall, high temperatures, and poor soils, characteristics that contribute to its broad availability and practical value.

2.2.1.2 Traditional and Medicinal Uses Aloe vera (*Aloe barbadensis Miller*)

For centuries, Aloe vera has been a staple in various traditional healing practices. The gel has commonly been applied topically to cuts, wounds, burns, and inflammatory skin conditions because of its soothing properties and perceived ability to reduce infection risk. In addition to topical use, it has also been used internally in some traditions for laxative and anti-inflammatory purposes. Historical use in Egyptian, Chinese, and Indian medical traditions reflects its long-standing reputation as a versatile medicinal plant.

2.2.1.3 Antimicrobial Properties

A wide range of research has documented the ability of Aloe vera extracts to fight microbes. For example, Kim et al. (2018) reported inhibitory effects of Aloe vera gel against pathogenic bacteria, including *S. aureus, P. aeruginosa*, and *E. coli.* This activity has been linked to constituents such as anthraquinones, including aloin and aloe-emodin, as well as saponins and polysaccharides, which may affect cell wall integrity and other bacterial functions.

Beyond direct growth inhibition, Aloe vera may also help limit the establishment of wound-associated biofilms. This is important because biofilms allow bacteria to persist on wound surfaces, evade host defences, and tolerate antimicrobial exposure more effectively than planktonic cells. Evidence from the literature suggests that Aloe vera-derived products can reduce microbial burden while also supporting a wound environment that favours tissue repair. Its value, therefore, lies not only in antimicrobial action, but also in its combined anti-inflammatory, moisturizing, and regenerative effects, which are particularly relevant in topical wound care (Bodinet & Wölfle, 2013).

In addition to antibacterial effects, Aloe vera has been reported to exhibit broader biological activity, including antioxidant, anti-inflammatory, and tissue-protective properties. These overlapping actions help explain why Aloe vera remains one of the most frequently discussed medicinal plants in wound-healing research. Rather than acting through a single pathway, it appears to contribute to wound management through multiple complementary mechanisms, including support for re-epithelialization, modulation of inflammation, and suppression of microbial growth (Nayak, 2010). This multifunctional profile makes Aloe vera a credible candidate for affordable, plant-based wound applications and for combination studies with other natural products or conventional antimicrobials (Moghadam, 2015).

2.2.2 *Curcuma longa* (Turmeric)

Turmeric is a widely used culinary spice and medicinal plant valued mainly for curcuminoids, especially curcumin, together with volatile oils and other phenolic constituents. In traditional medicine, it has long been applied to inflamed skin, minor wounds, and infected lesions (Kabak & Dobson, 2017). Contemporary research supports this longstanding use by showing that turmeric possesses antimicrobial, antioxidant, and anti-inflammatory properties that are highly relevant to wound care. These properties, taken together, make turmeric particularly attractive in studies that seek agents capable of reducing bacterial load while also supporting tissue recovery (Farhat et al., 2023).

2.2.2.1 Botanical Description

Curcuma longa L. is a perennial herb of the family Zingiberaceae, the same family that includes ginger. The plant is distinguished by its underground rhizomes, which are thick, aromatic, and characteristically yellow to orange within (Farhat et al., 2023). These rhizomes are the principal medicinal and culinary part of the plant. Turmeric also bears broad lanceolate leaves arising from a pseudostem formed by leaf sheaths, and it thrives best in warm, humid tropical environments. Because the rhizome is the main storage organ and the richest source of

curcuminoids and essential oils, it is the part most commonly processed for antimicrobial and wound-healing studies (Rahmat et al., 2021).

2.2.2.2 Traditional and Medicinal Uses

Turmeric (*Curcuma longa*) has an extensive history of medicinal use. In Ayurvedic practice, it is widely applied in wound care, skin disorders, and inflammatory conditions, and related traditions in Asia have similarly used turmeric paste on cuts, burns, and infected wounds (Niu et al., 2024; Rupani & Chavez, 2018). Long before curcumin was chemically identified, its antiseptic and healing effects were recognized empirically. Turmeric is also valued in traditional medicine for broader anti-inflammatory and health-supportive roles (Li et al., 2021).

The medicinal use of turmeric extends beyond its culinary application; it is used both topically and internally. Typically, turmeric paste is applied directly to skin infections, cuts, burns and wounds to accelerate healing, reduce inflammation and prevent infection due to its antiseptic qualities (Wang et al., 2016). The active compounds in turmeric, especially curcumin, are believed to inhibit bacterial growth and promote tissue repair, making it a natural remedy for wounds and ailments. Despite the availability of modern pharmaceuticals, turmeric continues to be valued in many cultures for its natural healing properties, often integrated into holistic health practices (Zhou et al., 2024).

2.2.2.3 Antimicrobial Properties

The antibacterial activity of turmeric has been reported against *S. aureus, P. aeruginosa,* and *E. coli* (Vaughn et al., 2016), with curcumin frequently identified as a major contributor to this effect. Reported mechanisms include membrane disruption, interference with biofilm development, and possible effects on quorum sensing in *P. aeruginosa,* a system involved in virulence regulation (Crous et al., 2025). Against *E. coli*, proposed effects include interference with DNA replication and related metabolic processes (Nguyen et al., 2023). These findings help explain why turmeric is often regarded as a particularly promising plant in antimicrobial wound-care research.

2.2.3 Banana Peels

Banana peels are abundant agricultural by-products with increasing relevance in phytochemical and biomedical research. Although commonly discarded as waste, they contain phenolics, flavonoids, tannins, carotenoids, and other metabolites that may contribute to antioxidant and antimicrobial activity (Pereira & Maraschin, 2015). In wound-care research, banana peels are of interest not only because they are inexpensive and widely available, but

also because they represent a potentially sustainable source of bioactive material (Vijayakumar & Ramanathan, 2020).

2.2.3.1 Botanical Description

Banana peel is the outer protective covering of the fruit produced by species of the genus Musa, family Musaceae. Structurally, the peel protects the pulp during growth, transport, and ripening, and it changes markedly in colour and texture as ripening progresses. Unripe peels are usually green and firmer because of higher chlorophyll content and cell-wall integrity, whereas ripe peels become yellow as chlorophyll degrades and carotenoid pigments become more visible (Vijayakumar & Ramanathan, 2020). These structural and biochemical changes are important because the phytochemical composition of the peel varies with maturity and can influence the antioxidant and antimicrobial properties reported in extraction studies (Ferreira et al., 2022).

The banana plant itself is a large perennial herb rather than a true tree, with a pseudo-stem formed by overlapping leaf sheaths and an underground corm from which the leaves and inflorescence arise. As the fruit develops, the peel accumulates fibre, phenolics, pigments, and other compounds that contribute to both protection and post-harvest physiology. Reports on banana peel chemistry consistently highlight the presence of phenolic acids, flavonoids, carotenoids, and minerals, while also noting that composition varies with cultivar, growing conditions, and ripeness. These features help explain why banana peel has attracted interest as a low-cost source of compounds with nutritional, antioxidant, and possible antimicrobial value (Barroso et al., 2019).

2.2.3.2 Traditional and Medicinal Uses

Banana peels have been used traditionally for minor skin complaints and as household remedies for irritated or damaged skin. Although such use should not be treated as equivalent to modern clinical evidence, it suggests long-standing recognition of banana peel as a soothing plant material (Phuaklee et al., 2012). Current scientific interest is driven more by its phytochemical richness and by the possibility of converting an agricultural by-product into a useful biomedical resource, especially in resource-limited settings.

2.2.3.3 Antimicrobial Properties

Banana peel extracts have shown antimicrobial activity against a range of bacteria in laboratory studies, including organisms associated with wound contamination. Their activity is generally attributed to phenolics, flavonoids, tannins, and related compounds that may affect cell membranes, proteins, oxidative balance, and microbial

adhesion. However, the strength of activity varies substantially with extraction solvent, peel maturity, and bacterial species, suggesting that banana peel should be viewed as a promising but still developing antimicrobial source rather than as a uniformly potent remedy (Vu et al., 2018).

For wound-care research, the value of banana peel lies not only in possible antimicrobial effects but also in its antioxidant profile and its potential to support the design of low-cost biomaterials. Experimental work has suggested that banana-derived materials may contribute to wound management by combining moisture support, biocompatibility, and bioactive phytochemicals. Even so, stronger evidence is still needed to define which extract types, doses, and formulations are most effective against specific wound pathogens. A balanced reading of the literature therefore supports cautious optimism rather than exaggerated claims (Hanafy et al., 2021).

2.3 Synergistic Effects of Combinations

By mixing different plant extracts, one might achieve better results as various chemicals attack different parts of the bacteria simultaneously. For this reason, combination studies are increasingly used in natural-product screening against resistant bacteria (Aly et al., 2023). However, synergy should be demonstrated experimentally rather than assumed, since some combinations are only additive and others may reduce activity (Huang et al., 2024). In the present study, combinations of Aloe vera, turmeric, and banana peel extracts were investigated because the three plants differ in phytochemical profile and may therefore provide complementary antimicrobial effects (Chen et al., 2024).

2.4 Extraction methods used in assessing antimicrobial activities of plants

How a plant is extracted largely dictates the chemical makeup and effectiveness of the resulting antimicrobial. The same plant can produce markedly different extracts depending on the solvent used, extraction time, temperature, particle size, and level of agitation. For this reason, literature on medicinal plants routinely emphasizes that antimicrobial outcomes cannot be interpreted independently of extraction methodology. In studies involving Aloe vera, turmeric, and banana peels, extraction is not merely a preparatory step; it directly shapes which phytochemicals become available for antimicrobial testing (Windarsih et al., 2025).

Researchers often favor solvent extraction because it is versatile and effective at pulling out compounds with different chemical properties. Polar solvents such as water, methanol, and ethanol are often preferred when the target compounds include phenolics, flavonoids, tannins, or glycosides, whereas less polar solvents are better suited to more lipophilic constituents. As a result, the apparent antimicrobial performance of a plant is often partly

a reflection of solvent choice. This is one reason the present study compared different solvents rather than relying on a single extract type.

Maceration is one of the simplest extraction methods and is useful when the aim is to preserve heat-sensitive constituents. In this method, plant material is soaked in a solvent for a defined period with intermittent agitation to promote diffusion. Soxhlet extraction, by contrast, allows repeated solvent cycling through the plant matrix and often gives a more exhaustive extraction. Its main disadvantage is prolonged heating, which may degrade thermolabile compounds. The choice between these approaches, therefore, depends on the target compounds and the balance between extraction efficiency and chemical stability.

Ultrasound-assisted extraction is increasingly used because ultrasonic waves improve solvent penetration and disrupt plant tissues, thereby enhancing mass transfer and shortening extraction time. Supercritical-fluid extraction can also yield high-purity extracts with minimal solvent residue, but the equipment requirements make it less accessible in many routine laboratory settings. These newer methods are valuable, yet conventional solvent extraction remains the most realistic option for many antimicrobial screening studies in university laboratories and low-resource contexts (Eloff, 1998).

Several factors influence extraction efficiency. Solvent polarity affects which phytochemical classes are solubilized, extraction time influences yield, temperature alters both diffusion and compound stability, and the solid-to-solvent ratio determines the concentration gradient available for mass transfer. Particle size also matters because finer material exposes a greater surface area to the solvent. In practice, these variables interact with one another, so the best extraction conditions are usually those that preserve active compounds while producing reproducible yields rather than simply maximizing extract quantity.

In this study, solvent extraction using ethanol, acetone, and water was selected because these solvents are widely used in antimicrobial screening and differ sufficiently in polarity to recover different phytochemical groups. This allows comparison of aqueous and organic extracts and helps relate differences in antimicrobial activity to extraction behaviour. The approach also reflects a practical laboratory strategy that can be reproduced in comparable resource settings (Eloff, 1998).

2.5 Methods used in evaluating antimicrobial activities of plants

Studies of medicinal plant extracts commonly combine preliminary screening techniques with quantitative assays in order to assess potency and possible mode of action. Common methods include agar diffusion assays for initial

screening, broth microdilution for MIC determination, subculture-based MBC testing, checkerboard or time-kill assays for interaction studies, and more specialised methods for biofilm or quorum-sensing inhibition. Because each method measures a different aspect of antimicrobial performance, the choice of assay influences how results are interpreted (Balouiri et al., 2016).

Broth dilution methods, including macro- and microdilution, are standard approaches for determining minimum inhibitory concentrations and are recommended by bodies such as CLSI and EUCAST. Microdilution in 96-well plates is especially common in plant extract studies because it requires smaller volumes and allows many samples to be tested simultaneously (Eloff, 1998). Growth may be assessed visually, by turbidity, or with redox indicators such as INT or resazurin. Reports consistently emphasize the importance of inoculum standardization, incubation time, and solvent controls because these factors can strongly affect the outcome.

Minimum bactericidal concentration (MBC) testing is commonly performed alongside MIC determination in order to distinguish inhibitory from bactericidal activity. The usual procedure is to subculture material from wells or tubes that show no visible growth onto fresh agar and record the lowest concentration that yields no colonies after incubation. Many studies interpret MBC/MIC ratios of <= 4 as evidence of bactericidal activity, although minor variation in threshold definitions exists across the literature.

Checkerboard microdilution and calculation of the fractional inhibitory concentration index (FICI) are widely used to evaluate synergy or antagonism between extracts and antibiotics. The index is calculated from the MICs of agents alone and in combination. A common interpretation is FICI <= 0.5 for synergy, >0.5 to 1 for additivity or partial synergy, >1 to 4 for indifference, and >4 for antagonism. Time-kill assays are used less frequently but can provide useful kinetic confirmation of interaction effects (Singh et al., 2025).

Because wound pathogens commonly form biofilms and use quorum sensing to regulate virulence, many recent studies also include anti-biofilm and anti-quorum-sensing assays. Typical approaches include crystal-violet staining of microtiter-plate biofilms and viable counts from biofilm cultures. In Pseudomonas species, investigators may also measure quorum-sensing-regulated products such as pyocyanin or elastase when exploring mechanisms that do not rely solely on growth inhibition.

Mechanistic assays reported in the literature include membrane-permeability tests, electron microscopy for morphological changes, enzyme inhibition assays, and metabolomic or proteomic approaches. Chemical profiling by HPLC, LC-MS, or GC-MS, together with bioassay-guided fractionation, is especially important when the aim is to connect crude-extract activity to specific phytochemicals such as the curcuminoids of turmeric. These approaches are often necessary for moving from initial screening toward compound identification and product development.

CHAPTER 3
MATERIALS AND METHODS

3.0 Introduction

This chapter describes the materials, bacterial strains, plant extracts, and laboratory procedures used to evaluate the in vitro antimicrobial activity of Aloe vera (*Aloe barbadensis* Miller), *Curcuma longa* (turmeric), and banana peels. It covers sample collection and identification, extraction, phytochemical screening, and antimicrobial assays, including agar well diffusion, MIC determination by microdilution, and MBC determination by subculture. Quality-control procedures, replication, and the statistical methods used for data analysis are also outlined. In the diffusion assays, 6 mm wells were punched into Mueller-Hinton agar and loaded with the test extracts prepared in DMSO at a final solvent concentration not exceeding 2% v/v in the well. Solvent-only wells served as negative controls, while gentamicin served as the positive control. To ensure reliable results, all tests were carried out in triplicate and conducted at different times. Before starting the tests, bacterial concentrations were adjusted to match the 0.5 McFarland standard. For MIC testing, serial two-fold dilutions were prepared in Mueller-Hinton broth in microtiter plates, and assays included growth, sterility, and solvent controls. Zone diameters were analysed in R using one-way ANOVA per organism with Tukey's HSD when assumptions were met; where assumptions were violated, Kruskal-Wallis and Dunn's comparisons were used. MIC and MBC values were summarised descriptively, MBC/MIC ratios were calculated, and interactions were interpreted using fractional inhibitory concentration indices.

3.1 Study sites

Experimental work was carried out at Princeton Laboratory and Clinocare Laboratory located in Mutare, both of which provided the facilities and equipment necessary for plant extract preparation and microbiological evaluation. Both sites operated under controlled laboratory conditions and maintained the standard protocols required for reliable and reproducible microbiological assays.

3.2 Experimental design

This study generated both qualitative and quantitative data. The in vitro antimicrobial evaluation followed a 3 x 3 factorial arrangement in which the first factor was plant type (Aloe vera, turmeric, and banana peels) and the second factor was extraction solvent (methanol, acetone, and water). Each plant-solvent combination was tested against three bacterial strains: *S. aureus, P. aeruginosa*, and *E. coli*.

3.3 Collection and Preparation of Plant Extracts

Plant materials were collected and submitted to botanists at Mutare Botanical Garden for identification. Fresh Aloe vera leaves collected in Mutare were washed, and the gel was obtained aseptically by slicing the leaves and scooping out the inner gel. The gel was blended with solvent to form a uniform extract, filtered to remove solids, and stored in a sterile container at 4ºC. Fresh turmeric rhizomes were washed, peeled, and blended with solvent before filtration. Banana peels were placed in a beaker with solvent at a ratio of 1:10 (w/v) and allowed to stand at room temperature for 24 to 48 hours with intermittent agitation to improve extraction.

After extraction, the solvent was removed by rotary evaporation or by gentle heating in a fume hood, taking care to avoid overheating and possible degradation of active compounds. Extract yield was calculated from the initial mass of plant material used. The crude extracts were then reconstituted to 10 mg/mL in 2% DMSO for antimicrobial testing.

3.3 Bacterial strains

Bacterial strains of *S. aureus, P. aeruginosa,* and *E. coli* were obtained from a microbiology culture collection and subcultured on appropriate media before testing. Cultures were incubated at 37ºC for 18 to 24 hours and confirmed by colony morphology, Gram staining, and standard biochemical tests. Multidrug-resistant isolates were identified by disk diffusion according to CLSI guidance. ATCC reference strains*, S. aureus* ATCC 25923*, P. aeruginosa* ATCC 27853, and *E. coli* ATCC 25922, were included for quality control. The use of both reference strains and MDR wound isolates improved methodological reliability and allowed comparison with recognised laboratory standards.

3.4 Determination of MIC using microtiter plate

Minimum inhibitory concentration (MIC) testing followed the broth microdilution method of Eloff (1998). Mueller-Hinton broth (100 uL) was dispensed into each well of a 96-well plate, and 100 uL of plant extract stock solution (10 mg/mL in 2% DMSO) was added to the first row before serial two-fold dilution. For combination assays, equal volumes of two extracts, or one extract plus ampicillin at 10 ug/mL, were mixed before serial dilution. Bacterial inocula were standardized to 0.5 McFarland and diluted to approximately 5 x 10^5 CFU/mL before 100 uL was added to each test well, excluding sterility controls. Plates were incubated at 37 ºC for 24 hours, after which 40 uL of iodonitrotetrazolium chloride (INT, 0.2 mg/mL) was added, and the plates were incubated for a further 30 minutes. I identified the MIC as the minimum concentration required to stop a change in color, signaling that growth had been halted. All assays were performed in triplicate.

3.5 Determination of MBC

MBC was determined by subculturing 10 uL from wells showing no visible growth, including the MIC well and the next two higher concentrations, onto Mueller-Hinton agar and incubating at 37ºC for 24 hours (Eloff, 1998). The MBC was recorded as the lowest concentration at which no colony growth occurred, corresponding to a 99.9% reduction in the initial inoculum. MBC/MIC ratios were calculated for each extract. Ratios of <= 4 were interpreted as indicating bactericidal activity, whereas values > 4 were interpreted as indicating bacteriostatic activity.

3.6 Calculation of the activity index

The activity index (AI) was computed using the following formula:

$$\mathbf{AI} = \frac{\textbf{Inhibition zone developed by extract}}{\textbf{Inhibition zone developed by standard antibiotic}}$$

The comparison was conducted using the same bacterial strain and concentration (10 mg/mL extract vs. 10 µg/mL gentamicin). An AI close to one implies equivalent activity to the conventional antibiotic.

3.7 Calculation of the Fractional Inhibitory Concentration Index (FICI)

The FICI was calculated using MIC values obtained for each agent alone and in combination to classify the interaction between extracts or between extracts and antibiotics.

FICI=$FIC_A + FIC_B = \left(\frac{MIC_{A\ comb}}{MIC_{A\ alone}}\right) + \left(\frac{MIC_{B\ comb}}{MIC_{B\ alone}}\right)$

For each combination of plant extracts and antibiotics, FICI was calculated to assess the interaction. The MIC of each agent alone and in combination were obtained from the microdilution assays.

3.8 Agar well diffusion method

For agar well diffusion, bacterial suspensions were prepared in nutrient broth and adjusted to the turbidity of a 0.5 McFarland standard. Mueller-Hinton agar was poured into sterile Petri dishes and allowed to solidify, after which the surface was inoculated evenly with the standardized suspension using sterile swabs. After 10 to 15 minutes of surface drying, 6 mm wells were punched aseptically with a sterile cork borer. Each well received 100 uL of the appropriate Aloe vera, turmeric, or banana peel extract. Plates were refrigerated at 2 to 8 ºC for 4 hours to allow diffusion and then incubated inverted at 37ºC for 24 hours. Control wells containing the relevant solvent were included. Zones of inhibition were measured in millimetres using a ruler or calliper.

3.9 Determination Tests for the phytochemical composition of the extracts

Phytochemical screening of Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (turmeric), and banana peel extracts was carried out using standard qualitative tests for major classes of bioactive compounds, including flavonoids, tannins, terpenoids/steroids, phlobatannins, alkaloids, glycosides, and saponins. Methanol, acetone, and water extracts were tested in triplicate. Positive and negative controls were included where appropriate, and colour changes, precipitates, or frothing were recorded and related to antimicrobial activity.

3.9.1 Flavonoids

Flavonoids were assessed using the Shinoda test. In one procedure, diluted ammonia solution was added to the aqueous filtrate of each extract, followed by concentrated sulfuric acid; a transient yellow colour indicated flavonoids. In the second procedure, 1.5 mL of 50% ethanol was added to 4 mL of extract solution, the mixture was warmed, and magnesium metal was added. After the addition of 5 to 6 drops of concentrated hydrochloric acid, a red colour indicated flavonoids, while an orange colour suggested flavones.

3.9.2 Tannins

Following Kumar et al. (2018), 0.5 g of dried, powdered Aloe vera, turmeric, or banana peel was boiled in 20 mL of distilled water, cooled, and filtered. A few drops of 0.1% ferric chloride were added to the filtrate. Brownish-green or bluish-black coloration indicated the presence of tannins. No colour change was recorded as a negative result (Sharma et al., 2016).

3.9.3 Terpenoids and Steroids

For terpenoids and steroids, 4 mg of each extract was mixed with 0.5 mL acetic anhydride and 0.5 mL chloroform, after which concentrated sulfuric acid was added carefully. A red-violet colour indicated terpenoids, while a green-blue colour indicated steroids (Sharma et al., 2016). Absence of a colour change was recorded as negative.

3.9.4 Phlobatannins

To test for phlobatannins, aqueous extracts were prepared by boiling 0.5 g of dried powder in 20 mL of distilled water. Hydrochloric acid (1%) was added, and the mixture was reboiled. Formation of a red precipitate after acidification indicated the presence of phlobatannins, while no precipitate or no visible change was recorded as negative (Nahrin et al., 2020).

3.9.5 Alkaloids

The alcoholic extract was evaporated to dryness, heated with 2% hydrochloric acid, cooled, filtered, and treated with a few drops of Mayer's reagent; turbidity or yellow precipitation was recorded as positive for alkaloids (Mishra et al., 2018).

3.9.6 Glycosides

For glycosides, the extract was mixed with glacial acetic acid, and ferric chloride was followed by concentrated sulfuric acid, which was added carefully (Kumar et al., 2018). The appearance of a reddish-brown ring at the interface, together with a bluish-green upper layer, indicated the presence of glycosides.

3.9.7 Saponins

For saponins, approximately 2 g of powdered banana peel, turmeric, or Aloe vera sample was boiled in 20 mL of distilled water and filtered (Sharma et al., 2016). Ten millilitres of filtrate was mixed with 5 mL of distilled water and shaken vigorously. Persistent stable foam indicated preliminary saponin presence (Mishra et al., 2019). Addition of three drops of olive oil followed by vigorous shaking, with formation of a stable emulsion, confirmed the result (de Araujo et al., 2015).

3.10 Data quality

Data integrity was maintained by running every experiment three times and repeating the entire process at least twice. Procedures, observations, and results were recorded , and both positive and negative controls were included in every run.

3.11 Data analysis

All data were captured in Excel and analysed using the relevant formulae for MBC/MIC ratio and activity index. Statistical analysis focused on the zones of inhibition produced by the different plant extracts against the three bacterial isolates. One-way ANOVA was performed in R to determine whether significant differences existed among extracts for each organism at the 95% confidence level. A Shapiro test was used to assess normality before proceeding with ANOVA. Where significant differences were detected, post-hoc comparisons were used to identify the more active treatments.

CHAPTER 4

4.0 RESULTS

4.0 Chapter Introduction

This chapter presents the results of the in vitro investigation, including antibiotic resistance profiling of the test isolates, MIC and MBC values for individual extracts, MBC/MIC ratios, zones of inhibition, activity indices, combination MIC data, FICI-based interaction assessment, and qualitative phytochemical screening. The results are presented in an order that supports interpretation: resistance profiles first, followed by individual extract activity, combination effects, and finally the phytochemical findings that help to contextualize the antimicrobial patterns observed.

4.1 Antimicrobial resistance patterns of the selected multidrug-resistant bacterial isolates from wounds

The resistance profiles of bacterial isolates from wound samples are summarised in Table 4.1. The MDR isolates of *S. aureus, P. aeruginosa*, and *E. coli* were resistant to tetracycline, sulfamethoxazole-trimethoprim, penicillin, erythromycin, and ampicillin, confirming multidrug resistance and indicating that these antibiotics were ineffective against the isolates tested. This resistance typically occurs due to mechanisms like the production of specific eenzymes (e.g., beta-lactamases) alteration of antibiotic target sites, efflux pump activation, or biofilm formation, which prevent the antibiotics from effectively inhibiting bacterial growth or killing the bacteria.. All three MDR isolates remained susceptible to gentamicin, suggesting that this antibiotic retained activity under the test conditions. The reference strains, *S. aureus* ATCC 25923, *P. aeruginosa* ATCC 27853, and *E. coli* ATCC 25922, were generally susceptible to the antibiotics tested, although *E. coli* ATCC showed resistance to penicillin, ampicillin, and sulfamethoxazole-trimethoprim.

Table 4.1: Antimicrobial resistance patterns of selected multidrug-resistant bacterial isolates from wounds

Bacterial isolates	**Tetracycline**	**Sxt**	**Penicillin**	**Ampicillin**	**Gentamycin**	**Erythromycin**
S. aureus (clinical MDR wound isolate)	R	R	R	R	S	R
P. aeruginosa (clinical MDR wound isolate)	R	R	R	R	S	R
E. coli	R	R	R	R	S	R

(clinical MDR wound isolate)						
S. aureus (ATCC 25923)	S	S	S	S	S	S
P. aeruginosa (ATCC 27853)	S	S	S	S	S	S
E. coli (ATCC 25922)	S	R	R	R	S	R

R-resistant; S- susceptible

4.2 Antimicrobial Activity using Minimum Inhibitory Concentration (MIC)

The MIC values of the different plant extracts are presented in Table 4.2. Overall, turmeric extracts showed the lowest MIC values and therefore the strongest inhibitory activity, particularly against *P. aeruginosa* and *S. aureus*. Aloe vera extracts showed moderate activity, whereas banana peel extracts were generally less potent. For Aloe vera, the methanol extract showed MIC values of 2.5 mg/mL against all three MDR wound pathogens. The acetone extract was more active, with MIC values of 1.25 mg/mL against *P. aeruginosa*, 0.625 mg/mL against *S. aureus,* and 1.25 mg/mL against *E. coli*. The water extract showed the highest MIC values at 5 mg/mL for all three bacteria, indicating lower activity.

Turmeric showed strong antibacterial effects, particularly in the acetone and methanol extracts. The methanol extract had MIC values of 0.625 mg/mL against *P. aeruginosa*, 0.3125 mg/mL against *S. aureus*, and 1.25 mg/mL against *E. coli*, while the acetone extract was even more active, with MIC values of 0.15625 mg/mL, 0.078125 mg/mL, and 0.625 mg/mL against the same organisms, respectively. The water extract of turmeric had higher MIC values of 2.5 mg/mL against *P. aeruginosa*, 1.25 mg/mL against *S. aureus*, and 5 mg/mL against *E. coli*. Banana peel extracts showed weaker activity overall. The methanol extract had MIC values of 2.5 mg/mL against the Gram-positive organism and 5 mg/mL against *E. coli*. The acetone extract was reported with MIC values of 25 mg/mL against all three test organisms, while the water extract showed MIC values of 5 mg/mL throughout. Taken together, the data suggest that organic solvents recovered more active antibacterial constituents than water.

On the whole, the data show that the type of solvent used had a major impact on how well the extracts worked. Methanol and acetone generally produced more active extracts than water. Across all three bacterial strains, turmeric showed the strongest antibacterial activity, followed by Aloe vera, while banana peel extracts were the least active.

Table 4.2 Average MIC of individual plant extracts against bacterial strains

Plant Extract	***Pseudomonas aeruginosa (*mg/mL*)***	***Staphylococcus aureus* (mg/mL)**	***Escherichia coli* (mg/mL)**
Aloe vera acetone	1.25	0.625	1.25
Aloe vera methanol	2.5	2.5	2.5
Aloe vera water	5	5	5
Turmeric *(Curcuma longa*) methanol	0.625	0.3125	1.25
Turmeric acetone	0.15625	0.078125	0.625
Turmeric water	2.5	1.25	5
Banana peel methanol	2.5	2.5	5
Banana peels acetone	2.5	2.5	2.5
Banana peel water	5	5	5
Gentamycin	0.009765625	0.01953125	0.0390625

n=3

4.3 Minimum Bacterial Concentration (MBC) of Plant Extracts against Bacterial Strains

Table 4.3 presents the minimum bactericidal concentrations (MBCs) of the individual plant extracts against the three MDR bacterial strains, *P. aeruginosa, S. aureus*, and *E. coli*.

Table 4.3: MBCs of individual plant extracts against multidrug-resistant bacterial strains

Plant Extract	**Solvent**	***Pseudomonas aeruginosa* (mg/mL)**	***Staphylococcus aureus* (mg/mL)**	***Escherichia coli* (mg/mL)**
Aloe vera	Acetone	2.5	1.25	2.5
	Methanol	2.5	2.5	2.5
	Water	15	15	15
Turmeric	Methanol	1.25	0.3125	2.5
	Acetone	0.15625	0.078125	0.625
	Water	5	5	10

Banana peels	Methanol	10	5	15
	Acetone	5	5	5
	Water	15	15	15

4.4 MIC of selected plant extracts in combination against multidrug-resistant wound pathogens

Table 4.4 presents the MICs of selected plant-extract combinations against *E. coli, P. aeruginosa*, and *S. aureus*. Combinations involving Aloe vera and turmeric generally showed lower MIC values than many of the individual extracts, suggesting improved inhibitory activity. For example, methanol Aloe vera plus acetone turmeric showed lower MIC values than methanol Aloe vera plus methanol turmeric. Likewise, combinations involving acetone Aloe vera with methanol or acetone turmeric showed comparatively strong activity, especially against *P. aeruginosa* and *S. aureus*. The triple combination that included ampicillin gave the lowest MIC values reported in this study, indicating that selected plant-extract combinations may enhance antibacterial efficacy.

Table 4.4 MIC of selected plant extracts in combination against multidrug-resistant wound pathogens

Plant Extract	***Escherichia coli* (mg/mL)**	***Pseudomonas aeruginosa* (mg/mL)**	***Staphylococcus aureus* (mg/mL)**
Methanol Aloe + Methanol Turmeric	0.625	0.3125	0.3125
Methanol aloe + acetone turmeric	0.1562	0.078125	0.078125
Acetone aloe + Acetone Turmeric	0.625	0.15625	0.078125
Acetone aloe + Methanol turmeric	0.1562	0.078125	0.078125
Acetone aloe + Methanol turmeric + ampicillin	0.01953125	0.01953125	0.0390625
Acetone aloe + Acetone Turmeric + ampicillin	0.009765625	0.009765625	0.01953125

4.5 MBC/MIC ratios for different extracts against wound pathogens

Table 4.5 presents the MBC/MIC ratios for the different extracts against the wound pathogens. The ratios ranged from 1 to 4, indicating that most extracts acted bactericidally under the interpretation used in this study. Ratios of 1 suggest that bacterial killing occurred at concentrations equal to those required for growth inhibition, while ratios of 2 to 4 indicate bactericidal activity at somewhat higher concentrations. Water extracts generally showed slightly higher ratios, suggesting reduced bactericidal efficiency relative to organic solvent extracts. Banana peel extracts also tended to show higher ratios than Aloe vera and turmeric, which is consistent with their lower overall antimicrobial activity.

Table 4.5 MBC/MIC ratios for different extracts against wound pathogens

Plant Extract	**Solvent**	***Pseudomonas aeruginosa* (mg/mL)**	***Staphylococcus aureus* (mg/mL)**	***Escherichia coli* (mg/mL)**
Aloe vera	Acetone	2	2	2
	Methanol	1	1	1
	Water	3	3	3
Turmeric	Methanol	1	1	1
	Acetone	1	1	1
	Water	2	4	2
Banana peels	Methanol	4	2	3
	Acetone	2	2	2
	Water	3	3	3

4.6 Zone of inhibition of extracts against wound pathogens

Table 4.6 summarises the zones of inhibition produced by the plant extracts against the test bacteria. Aloe vera extracts, particularly the acetone extract, produced relatively large zones of inhibition, indicating useful antibacterial activity. Turmeric extracts produced the largest overall inhibition zones and therefore showed the strongest activity in the diffusion assay. Banana peel extracts produced the smallest zones of inhibition, indicating comparatively weaker effects.

Table 4.6: Average diameters of the zone of inhibition of plant extracts against multidrug-resistant wound pathogens

Plant Extract	**Solvent**	***Pseudomonas aeruginosa* (mm)**	***Staphylococcus aureus* (mm)**	***Escherichia coli* (mm)**
Aloe vera	Methanol	14	20	16
	Acetone	19	22	20
	Water	8	12	10
Turmeric	Methanol	18	25	20
	Acetone	23	29	24
	Water	11	18	14
Banana peels	Methanol	10	15	12
	Acetone	19	18	15
	Water	6	7	8
Gentamycin		28	30	25

n=3

4.7 Activity Index

Table 4.7 presents the activity indices of the plant extracts relative to the standard antibiotic. Turmeric, especially the acetone extract, showed the highest activity indices, reaching 1.0 against *S. aureus* and *E. coli*. Aloe vera also showed notable activity, particularly in the acetone and methanol extracts, whereas banana peel extracts had markedly lower indices. These results are consistent with the MIC and zone-of-inhibition findings, again indicating that turmeric was the most active plant material in this study.

Banana peel extracts showed the lowest activity indices overall. Although the acetone extract performed slightly better than the other banana peel extracts, all banana peel values remained well below 1, indicating substantially lower activity than the reference antibiotic under the conditions tested.

Table 4.7 Activity index of plant extracts against wound bacteria

Plant Extract	**Solvent**	***Pseudomonas aeruginosa* (mm)**	***Staphylococcus aureus* (mm)**	***Escherichia coli* (mm)**

Aloe vera	Methanol	0.5	0.7	0.6
	Acetone	0.7	0.7	0.8
	Water	0.3	0.4	0.4
Turmeric	Methanol	0.6	0.8	0.8
	Acetone	0.8	1	1
	Water	0.4	0.6	0.6
Banana peels	Methanol	0.4	0.5	0.5
	Acetone	0.7	0.6	0.6
	Water	0.2	0.2	0.3
Gentamycin		28	30	25

Table 4.8: The Fractional Inhibitory Concentration (FICI)

Plant Extract	**Solvent**	**MIC (mg/ml) against *P.aeruginosa***	**MIC (mg/ml) against *S. aureus***	**MIC (mg/ml) against *E.coli***
Aloe vera	Methanol	2.5	2.5	2.5
	Acetone	1.3	1.3	0.7
	Water	5	5	5
Turmeric	Methanol	0.7	0.3	1.3
	Acetone	0.2	0.1	0.6
	Water	2.5	1.3	5
Banana peels	Methanol	2.5	2.5	5
	Acetone	2.5	2.5	2.5
	Water	5	5	5

4.9 Phytochemical analysis

Table 4.9 shows that Aloe vera extracts prepared in methanol, acetone, and water contained the tested phytochemicals flavonoids, saponins, tannins, and alkaloids. Turmeric extracts contained flavonoids, saponins, and alkaloids, but tannins were not detected. Banana peel extracts contained flavonoids, tannins, and alkaloids, whereas saponins were not detected. The phytochemical profile of turmeric is notable because it showed the strongest antimicrobial activity despite the absence of detectable tannins.

Table 4.9: Phytochemical Analysis of Plant Extract

Plant Extracts	**Solvent**	**Flavonoids**	**Saponins**	**Tannins**	**Alkaloids**
Aloe vera	Methanol	Positive	Positive	Positive	Positive
	Acetone	Positive	Positive	Positive	Positive
	Water	Positive	Positive	Positive	Positive
Turmeric	Methanol	Positive	Positive	Negative	Positive
	Acetone	Positive	Positive	Negative	Positive
	Water	Positive	Negative	Negative	Positive
Banana peels	Methanol	Positive	Negative	Positive	Positive
	Acetone	Positive	Negative	Positive	Positive
	Water	Positive	Negative	Positive	Negative

CHAPTER 5
DISCUSSION

5.0 Introduction

The findings from this study show that Aloe vera (*Aloe barbadensis Miller*), *Curcuma longa* (turmeric), and banana peels each exhibited measurable antimicrobial activity against multidrug-resistant bacteria associated with wound infection, namely *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Escherichia coli*. Among the three plant materials, turmeric extracts, particularly those prepared with acetone and methanol, showed the strongest activity, as indicated by low MIC and MBC values and by strong performance in the diffusion assay. Aloe vera also showed significantl activity consistent with its recognised wound-supportive phytochemicals. Banana peel extracts were less active overall, but they still demonstrated some inhibitory potential and therefore remain relevant as low-cost plant materials for further investigation in resource-limited settings.

Furthermore, the results demonstrated that certain mixtures—particularly Aloe vera and turmeric—were more effective than the plants used alone. Lower MIC values in these combinations suggest that phytochemical mixtures may sometimes act more effectively together than when used separately. This observation is important because multi-component phytotherapeutic preparations may help to improve antibacterial efficacy against resistant organisms. The detection of flavonoids, tannins, alkaloids, and saponins in the extracts provides chemical support for the biological activity observed. Overall, the findings support continued investigation of medicinal plants as affordable alternatives or adjuncts to conventional antibiotics in wound care (Huang et al., 2024; Ai et al., 2024).

The FICI findings provide additional insight into the nature of extract-extract and extract-antibiotic interactions against MDR *P. aeruginosa, S. aureus*, and *E. coli*. In this study, interactions were interpreted using the standard FICI ranges: <= 0.5 for synergy, >0.5 to 1 for additivity or partial synergy, >1 to 4 for indifference, and >4 for antagonism (Samreen et al., 2024).

5.1 Antimicrobial Activity of Plant Extracts

The results point to the potential of Aloe vera, C. longa (turmeric), and banana peels to serve as natural antimicrobial agents against MDR S. *aureus, P. aeruginosa*, and *E. coli*. Turmeric extracts, particularly those prepared with methanol and acetone, showed the strongest activity, followed by Aloe vera and then banana peels. This pattern agrees with previous reports of turmeric's broad antimicrobial activity and suggests that curcumin-rich preparations may play an important role in inhibiting bacterial growth (SeyedAlinaghi et al., 2025). The comparatively weaker performance of banana peels in the present study does not negate their relevance, but it does suggest lower potency under the extraction conditions used here (Muftah et al., 2024).

The current findings are nevertheless not entirely consistent with all published reports. Some studies have found only weak or inconsistent activity in Aloe vera extracts against certain bacteria, particularly MDR strains. Arbab et al. (2021), for example, reported that although Aloe vera gel inhibited *S. aureus and E. coli*, its activity was weaker than that of gentamicin and depended strongly on the extraction method and solvent. Such variation may reflect differences in plant source, harvest conditions, preparation, or assay design.

A similar caution applies to turmeric. Although many studies support its broad-spectrum antimicrobial activity, some have reported reduced effects against highly resistant strains. Kaur et al. (2015) found only moderate activity of turmeric extracts against *S. aureus* and *E. coli* in some circumstances, suggesting that curcumin alone may not always be sufficient for strong antibacterial action. In the present study, however, turmeric remained the most active plant despite the absence of detectable tannins, indicating that other constituents, including flavonoids, saponins, and alkaloids, may have contributed meaningfully. Questions of curcumin stability and bioavailability also remain relevant when considering translation to clinical use (Leng et al., 2020).

The discussion of banana peels must also remain balanced. Some studies, including Nwokocha et al. (2019), have reported antimicrobial activity against wound-relevant organisms, whereas others have found negligible effects, particularly with aqueous extracts (Kumar et al., 2021). Differences in phytochemical concentration, extraction procedure, and plant maturity probably contribute to these inconsistencies (Pietruczuk-Padzik et al., 2024). In the present study, banana peel extracts were active but clearly weaker than Aloe vera and turmeric. The MBC/MIC ratios, many of which remained within the bactericidal range used here, suggest that once inhibitory concentrations were reached, some preparations were still capable of bacterial killing (Brown et al., 2023).

The present data also reinforce the importance of solvent choice. Acetone and methanol extracts of Aloe vera and turmeric frequently showed MBC/MIC ratios of 1, supporting strong bactericidal activity. This agrees with the literature suggesting that organic solvents often recover more active antimicrobial constituents than water. At the same time, translation of such in vitro effects into in vivo benefit remains uncertain. Singh and Kumar (2021) emphasised that promising laboratory findings must still be evaluated in relation to bioavailability, stability, and possible toxicity before clinical application can be considered.

The FICI results add an important interpretive layer to the activity data. Several combinations, especially those involving acetone and methanol extracts of Aloe vera and turmeric with ampicillin, produced FICI values at or below the threshold for synergy. These findings indicate that some plant-derived constituents may enhance the performance of standard antibiotics. Potential explanations include improved penetration, interference with bacterial resistance mechanisms, or disruption of biofilm-associated protection, although these mechanisms were not tested directly in the present study. Other combinations fell within the additive or indifferent range, showing that not all combinations offer the same benefit.

Combinations involving water-based extracts were generally less impressive, and some gave FICI values within the indifferent range. This suggests that solvent choice remains important not only for the activity of individual extracts but also for combination performance. No clear antagonistic interactions were demonstrated in the formal FICI interpretation used here, but the weaker performance of some combinations shows that careful selection of compatible plant materials and solvents is essential.

5.2 Synergistic Effects of Combined Extracts

The combination experiments showed especially promising interactions between Aloe vera and turmeric. Reduced MIC and MBC values in some combined treatments indicate that selected mixtures enhanced antibacterial activity relative to individual extracts. Such findings are consistent with the view that phytochemicals acting on multiple bacterial targets may improve overall efficacy and may help to reduce the likelihood of resistance development (Notarangelo & Haigis, 2019). However, the results also show that improved activity cannot be assumed for every mixture. Some combinations, especially those involving water extracts, showed comparatively weaker responses, reminding us that combination therapy requires careful empirical evaluation rather than general expectation of synergy.

Combinations with ampicillin were also noteworthy. In particular, acetone extracts of Aloe vera and turmeric combined with ampicillin produced some of the lowest MIC values recorded in the study, reaching as low as

0.0098 mg/mL against *E. coli* and *P. aeruginosa*. These data suggest that selected plant-antibiotic combinations may improve antibacterial performance against resistant isolates. Although it is reasonable to hypothesize that phytochemicals could assist antibiotic entry or interfere with resistance pathways, such mechanisms were not directly examined here and should therefore be treated as possibilities rather than confirmed explanations. The broader implication is that rationally selected plant-antibiotic combinations may have therapeutic value, but each combination must still be assessed carefully to avoid ineffective or counterproductive pairings.

5.3 Phytochemical Profiles and Their Relationship to Antimicrobial Activity

The phytochemical screening results do not establish a mechanism directly, because qualitative presence-absence data are not equivalent to quantitative dose-response evidence. They do, however, provide a useful framework for interpreting the biological findings. Aloe vera showed a broad phytochemical profile across the solvent systems tested, which is consistent with the idea that its activity may result from multiple contributing constituents rather than from a single dominant compound. Flavonoids were detected across all three plant materials and all solvents, making them the most consistently distributed class of compounds in the study. Because flavonoids alone were present even in less active extracts, the results suggest that antibacterial potency depended not only on phytochemical class but also on concentration, solvent recovery, and interaction among constituents.

The phytochemical profile of banana peel may help explain its weaker activity relative to Aloe vera and turmeric. Banana peel showed tannins and flavonoids but lacked saponins, and its aqueous extract also lacked some of the broader phytochemical diversity seen in Aloe vera. While tannins can contribute to antibacterial activity through protein precipitation and enzyme inhibition, the narrower phytochemical pattern observed here may partly account for the lower antimicrobial performance of banana peel extracts in this study. Even so, banana peel may still have value in wound-care applications where antioxidant activity, low cost, or biomaterial use are important considerations.

5.4 Implications for Wound Healing

These results suggest that plant-based extracts could have value in wound management, especially where multidrug resistance and limited access to conventional treatment are major concerns. Aloe vera, turmeric, and banana peels are inexpensive and widely available, which increases their practical relevance in low-resource settings. Their combined antimicrobial, antioxidant, and anti-inflammatory properties could make them useful in strategies that aim not only to reduce bacterial load but also to support the wound-healing environment. However,

because this study was conducted in vitro, the results should be taken as preliminary evidence rather than as direct proof of clinical effectiveness.

The phytochemicals detected in these extracts may contribute not only to antimicrobial effects but also to anti-inflammatory, antioxidant, and tissue-supportive actions. If future in vivo studies confirm safety and efficacy, these combined effects may help improve wound closure, tissue quality, and overall healing outcome.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study showed that Aloe vera, turmeric, and banana peels have measurable antimicrobial activity against multidrug-resistant pathogens associated with wound infections. The first research objective was addressed through phytochemical screening, which showed that the tested plant materials contained major bioactive classes, including flavonoids, alkaloids, glycosides, tannins, and saponins, in varying patterns. Among the three plants, turmeric showed the strongest in vitro activity, especially in the acetone and methanol extracts, which produced the lowest MIC and MBC values and the largest zones of inhibition. Aloe vera also showed substantial activity, whereas banana peel extracts were comparatively weaker but still detectable in their effects.

The second research question was addressed by identifying turmeric as the most active of the three plant materials against the MDR wound pathogens tested, namely *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Escherichia coli.* The predominance of the acetone turmeric extract suggests that solvent selection strongly influenced the recovery of active compounds.

The third objective was examined through the combination studies. Selected pairings, particularly combinations of Aloe vera and turmeric extracts and combinations of selected plant extracts with ampicillin, showed reduced MIC values and evidence of synergistic or enhanced activity. These findings suggest that interactions among plant extracts and between plant extracts and conventional antibiotics can improve antibacterial performance against multidrug-resistant isolates. MBC/MIC ratios close to 1 for several of the most active extracts further indicate predominantly bactericidal action at concentrations near the inhibitory threshold.

Overall, the study shows that the extraction solvent, plant type, and combination strategy all influenced antimicrobial outcome. The results offer preliminary support for the use of selected plant extracts, particularly turmeric and Aloe vera, as low-cost sources of antibacterial agents for further wound-care research. However, because the work was limited to crude extracts and in vitro assays, the findings are better understood as a basis for later mechanistic, formulation, safety, and in vivo studies rather than as direct evidence for clinical application.

6.2 Recommendations

1. In vivo studies: Assess the safety, efficacy, and pharmacokinetics of the most promising extracts, particularly turmeric acetone extract, Aloe vera acetone extract, and their combinations with ampicillin, in animal wound-healing models.
2. Formulation development: Develop topical formulations such as creams, gels, hydrogels, or wound dressings containing the most active extracts, while giving attention to stability, bioavailability, and patient acceptability.
3. Mechanistic studies: Investigate the molecular basis of activity using methods such as membrane-damage assays, efflux-pump studies, beta-lactamase inhibition assays, electron microscopy, and related analytical approaches.
4. Clinical evaluation: If preclinical evidence is favourable, conduct controlled clinical studies to assess the safety and effectiveness of plant-based antimicrobial formulations, particularly in resource-limited settings.
5. Synergy quantification: Apply formal checkerboard microdilution and fractional inhibitory concentration analysis to a wider range of extract-extract and extract-antibiotic combinations.
6. Sustainable sourcing: Promote sustainable cultivation and harvesting practices for Aloe vera, turmeric, and banana to support a reliable supply of high-quality raw material.

6.3 Future research

Future research should build on these findings by conducting in vivo studies that assess the safety, efficacy, pharmacokinetics, and wound-healing performance of the most promising extracts and combinations. Work on topical formulations such as creams, gels, dressings, or hydrogels will also be required if these extracts are to move toward clinical application. In addition, bioassay-guided fractionation and analytical techniques such as LC-MS and GC-MS should be used to identify the compounds most responsible for activity. Exploring a broader range of plant combinations and interactions with conventional antibiotics may reveal especially useful synergistic formulations that reduce the antibiotic dose required. Further work should also include toxicity and

skin-irritation testing, sustainable cultivation studies, and expansion of antimicrobial screening to additional wound pathogens.

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APPENDICES

Appendix 1: Zone of inhition of *E. coli*

Treatment	Zone
1	20
1	19
1	17
2	20
2	19
2	21
3	9
3	10
3	11
4	19
4	20
4	21
5	23
5	25
5	24
6	15
6	14
6	16
7	11
7	12
7	13
8	14
8	15
8	16
9	8

9	9
9	7
10	25
10	24
10	26

Summary (Escherichia zone)

	Treatment	**Zone**
Min	**1.0**	**7.00**
1st quarter	**3.0**	**12.25**
Median	**5.5**	**16.00**
Mean	**5.5**	**16.50**
3rd Quarter	**8.0**	**20.75**
Max	**10.0**	**26.00**

Head(Escherichiazone)

a tibble: 6 *2

Treatment	Zone
<dbl>	<dbl>
1	15
1	16
1	17
2	20
2	19
2	21

Source variances	**ofDf**	**Sum Sq**	**Mean Sq**	**F value**	**Pr (>F)**
Treatment	**1**	**1.1**	**1.10**	**0.o34**	**0.854**
Residuals	**28**	**896.4**	**32.01**		

	Df	Sum Sq	Mean Sq	F value	1.54e 14
Factor (treatment)	**9**	**877.5**	**97.5**	**97.5**	
Residuals	**20**	**20.0**	**1.0**		
Significant codes	**0**	**0.001**	**0.01**	**0.05**	**0.1**

Tukey Hsd (re .aov.factor)

Turkey multiple comparisons of means

95% family wise confidence level

Fit: aov (formula = zone – factor (treatment), data= escherichzone)

s factor treatment

Diff	1wr	Upr	P	adj
2-1	**4.000000e +00**	**1.1086976**	**6.8913024**	**0.0027251**
3-1	**-6.000000e+00**	**-8.8913024**	**-3.1086976**	**0.0000154**
4-1	**4.000000e+00**	**1.1086976**	**6.8913024**	**0.0027251**
5-1	**8.000000e+00**	**5.1086976**	**10.8913024**	**0.0000002**
6-1	**-1.000000e+00**	**-3.8919024**	**1.8913024**	**0.9591847**
7-1	**-4.000000e+00**	**-6.8913024**	**-1.1086976**	**0.0027251**
8-1	**-1.000000e+00**	**-3.8923024**	**1.8913024**	**0.9591847**
9-1	**-8.000000e+01**	**-10.8913024**	**-5.1086976**	**0.0000002**
10-1	**-9.000000e+00**	**6.1086976**	**11.8913024**	**0.0000000**
3-2	**-1.000000e+01**	**-12.891302**	**-7.1086976**	**0.0000000**
4-2	**3.552714e+15**	**-2.89130244**	**2.8913024**	**1.0000000**
5-2	**4.000000e+00**	**1.1086976**	**6.8913024**	**0.0027251**
6-2	**-5.000000e+00**	**-7.8913024**	**-2.8913024**	**0.0001918**
7-2	**-8.000000e+00**	**-10.8913024**	**-5.1086976**	**0.0000002**
8-2	**-5.000000e+00**	**-7.8913024**	**-2.1086976**	**0.0000000**
9-2	**-1.200000e+01**	**-14.8913024**	**-9.1086976**	**0.0000000**
10-2	**5.000000e+00**	**2.1086976**	**7.8913024**	**0.0001918**
4-3	**1.000000e+01**	**7.1086976**	**12.8913024**	**0.3496987**
5-3	**1.400000e+01**	**11.1086976**	**16.8913024**	**0.0001918**
6-3	**5.000000e+00**	**2.1086976**	**7.8913024**	**0.3496987**
7-3	**2.000000e+00**	**-0.8913024**	**4.8913024**	**0.0000000**
8-3	**5.000000e+00**	**2.1086976**	**7.8913024**	**0.0001918**

9-3	**-2.000000e+00**	**-4.8913024**	**0.8913024**	**0.3496987**
10-3	**1.500000e+01**	**12.1086976**	**17.8913024**	**0.0000000**
5-4	**4.000000e+00**	**1.1086976**	**6.8913024**	**0.0027251**
6-4	**-5.000000e+00**	**-7.8913024**	**-2.8913024**	**0.0001918**
7-4	**-8.000000e+00**	**-10.8913024**	**-5.1086976**	**0.0000002**
8-4	**-5.000000e+00**	**-7.8913024**	**-2.1086976**	**0.0001918**
9-4	**-1.200000e+01**	**-14.8913024**	**-9.1086976**	**0.0000000**
10-4	**5.000000e+00**	**2.1086976**	**7.8913024**	**0.0001918**
6-5	**-9.000000e+00**	**-11.8913024**	**-6.1086976**	**0.0000000**
7-5	**-1.200000e+01**	**-14.8913024**	**-9.1086976**	**0.0000000**
8-5	**-9.000000e+00**	**-11.8913024**	**-6.1086976**	**0.0000000**
9-5	**-1.600000e+00**	**-18.8913024**	**-13.1086976**	**0.0000000**
10-5	**1.000000e+00**	**-5.8913024**	**3.8913024**	**0.9591847**
7-6	**-3.000000e+00**	**-2.8913024**	**-0.1086976**	**0.0380792**
8-6	**0.000000e+00**	**-9.8913024**	**2.8913024**	**1.0000000**
9-6	**-7.000000e+00**	**7.1086976**	**-4.1086976**	**0.0000015**
10-6	**1.000000e+01**	**7.1086976**	**12.8913024**	**0.0000000**
8-7	**-3.000000e+00**	**0.1086976**	**5.8913024**	**0.0380792**
9-7	**-4.000000e+00**	**-6.8913024**	**-1.1086976**	**0.0027251**
10-7	**1.300000e+01**	**10.1086976**	**15.8913024**	**0.0000000**
9-8	**-7.000000e+00**	**-9.8913024**	**-4.1086976**	**0.0000015**
10-8	**1.000000e+01**	**7.1086976**	**12.8913024**	**0.0000000**
10-9	**1.700000e+01**	**14.1086976**	**19.8913024**	**0.0000000**

Appendices

December

M	T	W	T	F	S	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15

16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

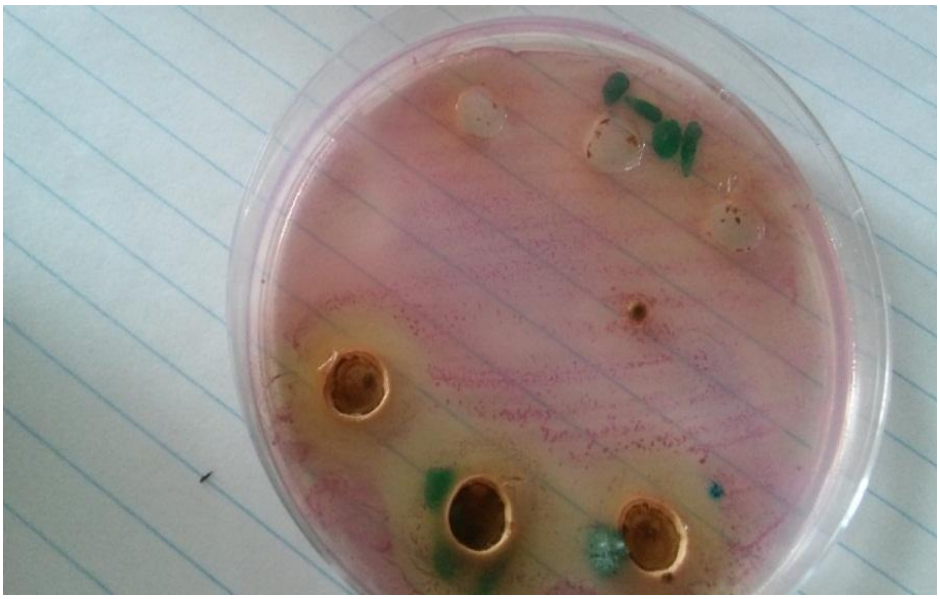


Figure 1 showing zones of inhibition of Aloe vera *(Aloe barbadensis Miller)* inhibiting growth *of E.coli.*

Appendix 2: Zone of inhibition of *Staphylococcus aureus*

View (Staphylococcus zone)

Treatment	Zone
1	**20**
1	**21**
1	**19**
2	**23**
2	**22**
2	**21**
3	**13**
3	**12**

3	**11**
4	**24**
4	**25**
4	**26**
5	**28**
5	**29**
5	**30**
6	**17**
6	**18**
6	**19**
7	**14**
7	**16**
7	**15**
8	**18**
8	**17**
8	**19**
9	**7**
9	**8**
9	**6**
10	**30**
10	**29**
10	**31**

Summary (Staphycoccuszone)

	Treatment	**Zone**
Min	**1.0**	**6.00**
1st quarter	**3.0**	**15.25**
Median	**5.5**	**19.00**
Mean	**5.5**	**19.60**
3rd Quarter	**8.0**	**24.75**
Max	**10.0**	**31.00**

Head(Staphylococcuszone)

A tibble: 6 *2

Treatment	Zone
<dbl>	<dbl>
1	20
1	21
1	19
2	23
2	22
2	21

Source variances	**ofDf**	**Sum Sq**	**Mean Sq**	**F value**	**Pr (>F)**
Treatment	**1**	**6.1**	**6.15**	**0.12**	**0.734**
Residuals	**28**	**1437.1**	**51.32**		

	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Factor (treatment)	**9**	**1423**	**158.1**	**158.1**	**<2e-16**
Residuals	**20**	**20**	**1.0**		
Significant codes	**0**	**0.001**	**0.01**	**0.05**	**0.1**

TukeyHSD()res.aov.factor

Tukey multiple comparisons of means

95% family wise confidence level

Fit: aov (formula=zone-factor (treatment), data = Staphylococcus zone)

$ factor treatment

Diff	Iwr	Upr	P	Adj

2-1	2	-0.8913024	4.8913024	0.3496987
3-1	-8	-10.8913024	-5.1086976	0.0000002
4-1	5	2.1086976	7.8913024	0.0001918
5-1	9	6.1086976	11.8913024	0.0000000
6-1	-2	-4.8913024	0.8913024	0.3496987
7-1	-5	-7.8913024	-2.1086976	0.0001918
8-1	-13	-15.8913024	0.8913024	0.3496987
9-1	10	7.1086976	-10.1086976	0.0000000
10-1	3	-12.8913024	12.8913024	0.0000000
3-2	7	0.1086976	-7.1086976	0.0000000
4-2	-4	4.1086976	5.8913024	0.0380792
5-2	7	4. 1086976	9.8913024	0.0000015
6-2	-4	-6. 8913024	-1.1086976	0.0027251
7-2	-7	-9.8913024	-12.1086976	0.0000000
8-2	-4	-6.8913024	10.8913024	0.0000002
9-2	-15	-17.8913024	15.8913024	0.0000000
10-2	8	5. 1086976	19.8913024	0.0000000
4-3	13	10. 1086976	8.8913024	0.0000154
5-3	17	14. 1086976	5.8913024	0.0380792
6-3	6	3. 1086976	8.8913024	0.0000154
7-3	3	0. 1086976	-2.1086976	0.0001918
8-3	6	3. 1086976	20.8913024	0.0000000
9-3	-5	-7.8913024	6.8913024	0.0027252
10-3	18	15. 1086976	-4.1086976	0.0000015
5-4	4	1. 1086976	-7.1086976	0.0000000
6-4	-7	-9.8913024	-4.1086976	0.00000015
7-4	-10	-12.8913024	-15.1086976	0.0000000
8-4	-7-	-9.8913024	-4.1086976	0.00001918
9-4	-18	-20.8913024	-15.1086976	0.0000000
10-4	5	2.1086976	7.8913024	0.00001918
6-5	-11	13.8913024	-8.1086976	0.0000000

7-5	-14	-16.8913024	-11.1086976	0.0000000
8-5	-11	-13.8913024	-8.1086976	0.0000000
9-5	-22	-24.8913024	-19.1086976	0.0000000
10-5	1	-1.8913024	3.8913024	0.0380792
7-6	-3	-5.8913024	-0.1086976	0.0000002
8-6	0	-2.8913024	2.8913024	0.0000000
9-6	-11	-13.8913024	-8.1086976	0.0000000
10-6	12	9.1086796	14.8913024	0.0000000
8-7	3	0.1086796	5.8913024	0.380792
9-7	-8	-10.8913024	-5.1086976	0.0000002
10-7	15	12.1086796	17.8913024	0.0000000
9-8	-11	-13.8913024	-8.1086976	0.0000000
10-8	12	9.1086796	14.8913024	0.0000000
10-9	23	20.1086796	25.8913024	0.0000000

Appendix : Zone of inhibition of Pseudomonas aeruginosa

View (Pseudomonas zone)

Treatment	**Zone**
1	**13**
1	**14**
1	**15**
2	**20**
2	**19**
2	**18**
3	**7**
3	**8**
3	**9**
4	**17**
4	**18**
4	**19**
5	**22**

5	**23**
5	**24**
6	**12**
6	**11**
6	**10**
7	**10**
7	**9**
7	**11**
8	**19**
8	**18**
8	**20**
9	**6**
9	**5**
9	**7**
10	**28**
10	**27**
10	**29**

Summary (Staphycoccuszone

	Treatment	**Zone**
Min	**1.0**	**5.00**
1st quarter	**3.0**	**10.00**
Median	**5.5**	**16.00**
Mean	**5.5**	**15.60**
3rd Quarter	**8.0**	**19.75**
Max	**10.0**	**29.00**

Head(Staphylococcuszone)

A tibble: 6 *2

Treatment	Zone

<dbl>	<dbl>
1	13
1	14
1	15
2	20
2	19
2	18

res_aov<-aov(zone ~ treatment, data = pseudomonaszone)

Source variances	**ofDf**	**Sum Sq**	**Mean Sq**	**F value**	**Pr (>F)**
Treatment	**1**	**26.5**	**26.51**	**0.562**	**0.46**
Residuals	**28**	**1320.7**	**47.17**		

res.aov. factor= aov (zone ~ factor(treatment). data = pseudomonaszone)

	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Factor (treatment)	**9**	**1327**	**147.5**	**147.5**	**2.71e-16**
Residuals	**20**	**20**	**1.0**		
Significant codes	**0**	**0.001**	**0.01**	**0.05**	**0.1**

Diff	Iwr	Upr	P	Adj
2-1	5.000000e+00	2.1086976	7.8913024	0.0001918
3-1	-6.000000e+00	-8.8913024	-3.1086976	0.0000154
4-1	4.000000e+00	1.1086976	6.8913024	0.0027252
5-1	9.000000e+00	6.1086976	11.8913024	0.0000000
6-1	-3.000000e+00	-5.8913024	-0.1086976	0.0380792
7-1	-4.000000e+000	-6.8913024	-1.1086976	0.0027251
8-1	5.000000e+00	2.1086976	7.8913024	0.001918
9-1	-8.000000e+00	-10.8913024	-5.1086976	0.0000002
10-1	1.400000e+01	11.1086976	16.8913024	0.0000000
3-2	-1.100000e+01	-13.8913024	-8.1086976	0.0000000
4-2	-1.000000e+00	-3.8913024	1.8913024	0.9591847

5-2	4.000000e+00	1.1086976	6.8913024	0.0027251
6-2	-8.000000e+00	-10.8913024	-5.1086976	0.0001918
7-2	-9.000000e+00	-118913024	-6.1086976	0.0000000
8-2	3.552714e-15	-2.8913024	2.8913024	1.0000000
9-2	-1.300000e+01	-15.8913024	-10.1086976	0.0000000
10-2	9.000000e+00	6.1086976	11.8913024	0.0000000
4-3	1.000000e+01	7.1086976	12.8913024	0.0000000
5-3	1.500000e+01	12.1086976	17.8913024	0.0000000
6-3	3.000000e+00	0.1086976	5.8913024	0.0380792
7-3	2.000000e+00	-0.8913024	4.8913024	0.3496987
8-3	1.100000e+01	8.1086976	13.8913024	0.0000000
9-3	-2.000000e+00	-4.8913024	0.8913024	0.3496987
10-3	2.000000e+01	17.1086976	22.8913024	0.0000000
5-4	5.000000e+00	2.1086976	7.8913024	0.0001918
6-4	-7.000000e+00	-9.8913024	-4.1086976	0.0000015
7-4	-8.000000e+00	-10.8913024	-5.1086976	0.0000002
8-4	1.000000e+00	-1.8913024	3.8913024	0.9591847
9-4	-1.200000e+01	-14.8913024	-9.1086976	0.0000000
10-4	1.000000e+01	7.1086976	12.8913024	0.0000000
6-5	-1.200000e+01	-14.8913024	-9.1086976	0.0000000
7-5	-1.300000e+01	-15.8913024	-10.1086976	0.0000000
8-5	-4.000000e+00	-6.8913024	-1.1086976	0.0027251
9-5	-1.700000e+01	-19.8913024	-14.1086976	0.0000000
10-5	5.000000e+00	2.1086976	7.8913024	0.0001918
7-6	-1.000000e+00	-3.8913024	1.8913024	0.0000000
8-6	8.000000e+00	5.1086976	10.8913024	0.0000000
9-6	-5.000000e+00	-7.8913024	-2.1086976	0.0027251
10-6	1.700000e+00	14.1086976	19.8913024	0.0000000
8-7	9.000000e+00	6.1086976	11.8913024	0.0000000
9-7	-4000000e+00	-6.8913024	-1.1086976	0.0000000
10-7	1.800000e+01	15.1086976	20.8913024	0.0000000

9-8	-1.300000e+01	-15.8913024	-10.1086976	0.0027251
10-8	9.000000e+00	6.1086976	11.8913024	0.0000000
10-9	2.200000e+00	19.1086976	24.8913024	0.0000000

Treatments codes and their description

Aloe vera methanol-1

Aloe vera acetone-2

Aloe vera water-3

Turmeric methanol- 4

Turmeric acetone-5

Turmeric water-6

Banana peels methanol-7

Banana peels acetone- 8

Banana peels water- 9

Gentamycin-10

Plant Extract	***Pseudomonas aeruginosa* (mm)**	***Staphylococcus aureus* (mm)**	***Escherichia coli* (mm)**
Aloe vera methanol-1	13	20	15
Aloe vera methanol-1	14	21	16
Aloe vera methanol-1	15	19	17
Aloe vera acetone-2	20	23	20
Aloe vera acetone-2	19	22	19
Aloe vera aceton2	18	21	21
Aloe vera water -3	7	13	9
Aloe vera water-3	8	12	10
Aloe vera water 3	9	11	11
Turmeric methanol-4	17	24	19
Turmeric methanol-4	18	25	20
Turmeric methanol-4	19	26	21
Turmeric acetone-5	22	28	23
Turmeric acetone-5	23	29	25

Turmeric acetone-5	24	30	24
Turmeric water-6	12	17	15
Turmeric water-6	11	18	14
Turmeric water-6	10	19	16
Banana peels methanol-7	10	14	11
Banana peels methanol-7	9	16	12
Banana peels methanol-7	11	15	13
Banana peels acetone-8	19	18	14
Banana peels acetone-8	18	17	15
Banana peels acetone 8	20	19	16
Banana peels water-9	6	7	8
Banana peels water-9	5	8	9
Banana peels water-9	7	6	7
Gentamycin-10	28	30	25
Gentamycin-10	27	29	24
Gentamycin-10	29	31	26

Table 4.3: MIC of plant extracts against control strains

Plant Extract	***Pseudomonas aeruginosa* ATCC....(mg/mL)**	***Staphylococcus aureus* ATCC….(mg/mL)**	***Escherichia coli* ATCC….(mg/mL)**
Aloe vera methanol	0.625	0.3125	1.25
Aloe vera acetone	0.3125	0.3125	0.625
Aloe vera water	2.5	1.25	5
Turmeric *(Curcuma longa*) methanol	0.3125	0.3125	0.625
Turmeric acetone	0.3125	0.15625	0.3125
Turmeric water	2.5	2.5	2.5
Banana peel methanol	2.5	2.5	5
Banana peel acetone	2.5	2.5	2.5
Banana peel water	5	5	5



Figure 2 phytochemical analysis (testing for the presence of flavonoids)

Figure 2: Showing phytochemical analysis (testing for the presence of flavonoids)

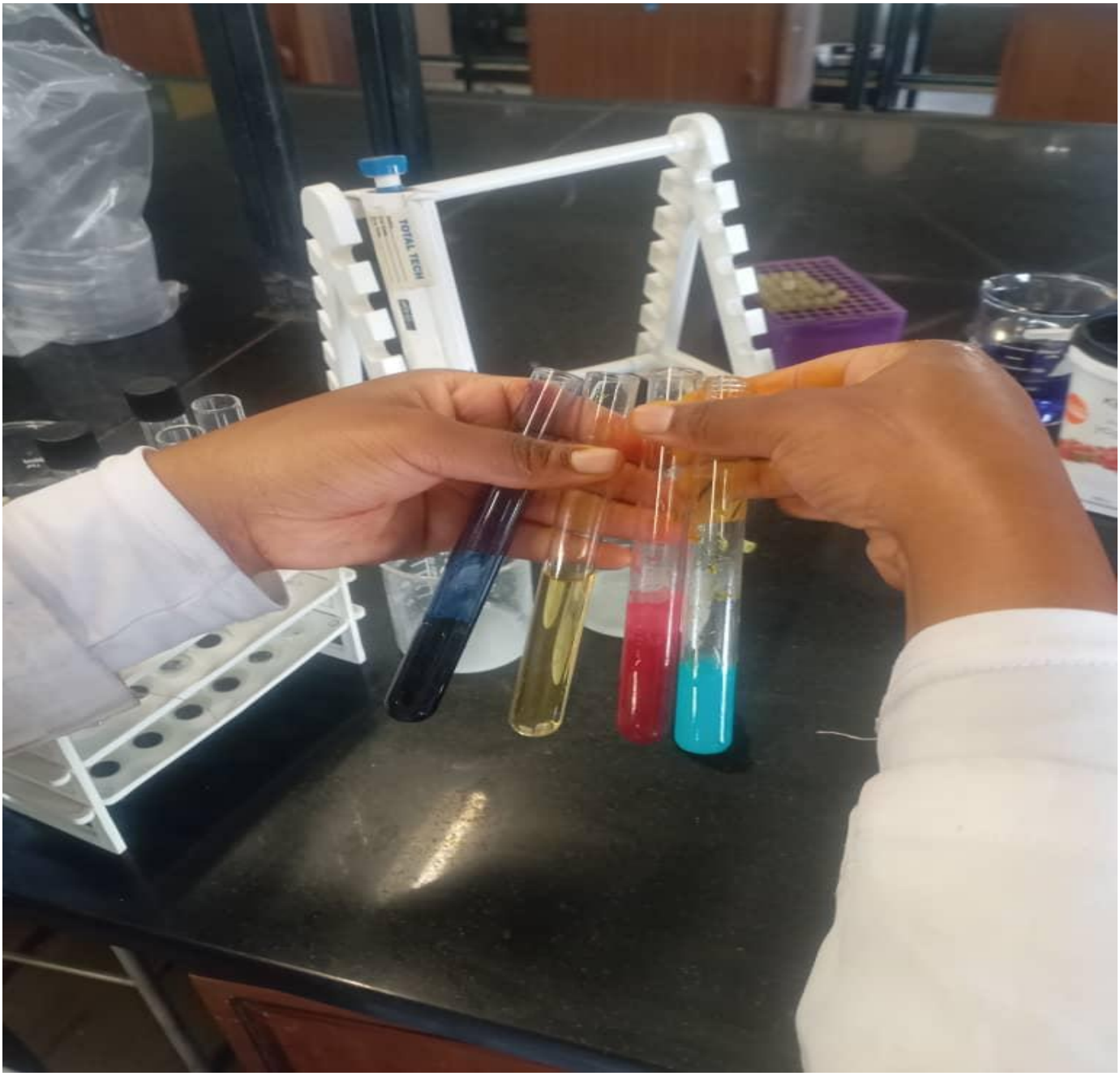


Figure 3 Phytochemical analysis

Figure 3: Phytochemical analysis

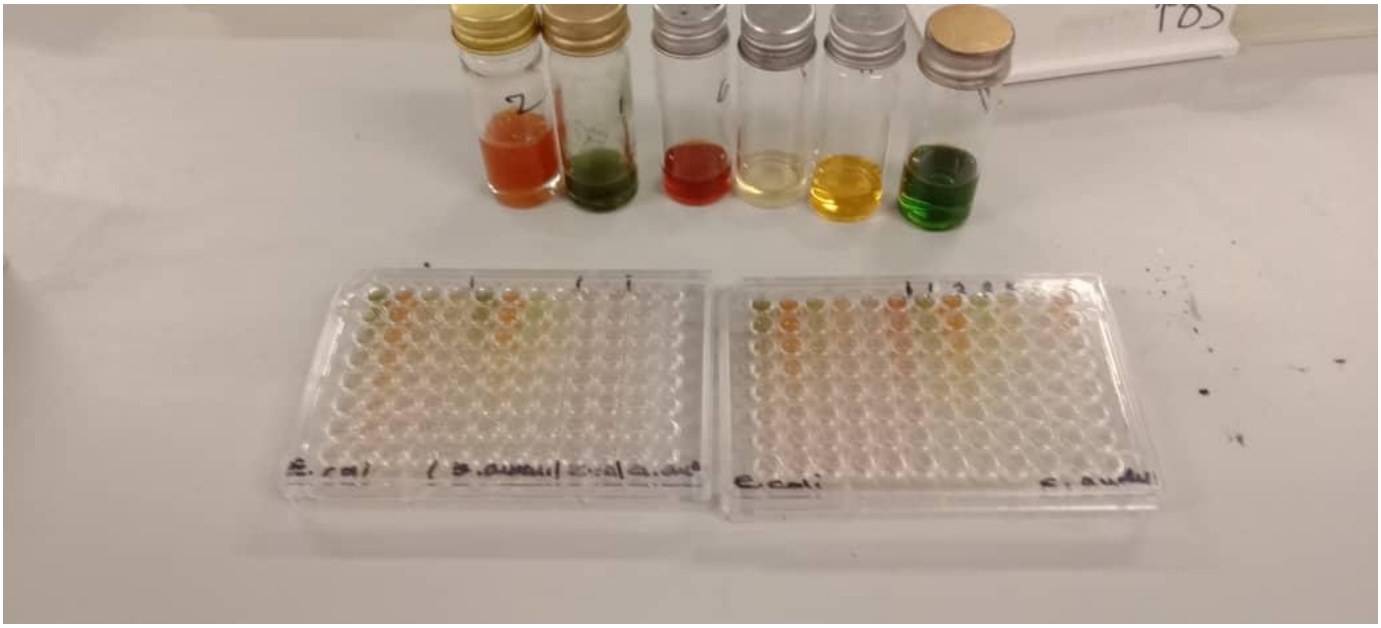


Figure 4: A representative 96-well microtiter plate was used to dertemine the Minimum Inhibitory Concentration (MIC) using broth microdilution technique and INT viability indicator. The presence of clear wells indicated that bacterial growth is inhibited