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Antimicrobial Activities of *Solanum aculeastrum* Fruit Extract against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*: Significance of African Traditional Medicine in Combating Infections and Attaining Universal Health Coverage

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Abstract

Solanum aculeastrum, a member of the Solanum genus, has a rich history of traditional use in various populations throughout tropical and southern Africa for treating different ailments. This study investigated the antimicrobial activities of *S. aculeastrum* fruit extracts grown in Zambia against *Escherichia coli* (*E. coli*) (ATCC 25922), *Staphylococcus aureus* (*S. aureus*) (ATCC 25923), and *Candida albicans (C. albicans)*. After being dried in an oven at 50˚C for eight days, the fruits of *S. aculeastrum* were pulverised and subjected to extraction using methanol and distilled water as solvents. The resulting crude extract was then filtered, concentrated using a water bath, and packed into airtight containers separately. The disc diffusion method was employed to evaluate the antimicrobial activity of the extracts. The results showed that both the methanolic and aqueous extracts demonstrated antimicrobial activity against *S. aureus* and *C. albicans*, but not against *E. coli*. The zone of inhibition was greater in *S. aureus* than in *C. albicans*. This study highlights the importance of researching plants for their medicinal properties, which can pave the way for discovering natural product-based drugs with potential antimicrobial properties. These findings recommend further studies on plants used in African traditional medicine.

Keywords

African Traditional Medicine, *Solanum aculeastrum*, Phytochemicals, *Solanum* Berries, Antimicrobial Activity

1. Introduction

African traditional medicines continue to play a vital role in the management of numerous conditions including those that may be unresponsive to conventional medicines [1]. This form of medical practice mainly uses natural products as sources of medicine and is usually linked to cultural practices [2] [3] [4]. Herbal and other forms of traditional medicines have maintained their popularity and are frequently included in various therapeutic regimens across the continent and other continents [5] [6] [7]. According to the WHO, a greater number of people (approximately 80%) depend on and use traditional medicines [8]. This makes African traditional medicine very important. It is therefore important that research and dissemination of new findings on the health benefits of these agents be constantly undertaken [9]. This is especially important given that Africa bears the highest burden of communicable diseases globally. Furthermore, the increasing prevalence of non-communicable diseases on the continent calls for concerted efforts to maximize the benefit of African traditional medicines in disease management [10]. The evidence above shows the importance of African traditional medicine and how it can be useful in attaining universal health coverage [1] [11] [12].

The common hedge plant *Solanum aculeastrum* occurs as a shrub or small tree with lobed discoloured leaves [13]. The plant belongs to the Solanaceae family and bears sharp prickles on its stem, and poisonous fruits which are yellow when ripe. The *Solanum* genus is one of the largest in this family, comprising economically important species including tomato, potato, and eggplant. *S. aculeastrum* has a long history of use among different populations in tropical and southern Africa for the treatment of various ailments [14]. The decoction of fruits and leaves of the plant is used orally for the treatment of cancer as well as indigestion and stomach upsets [15]. Fresh or boiled berries, or their juice extract, are used as a cure for jigger wounds, and treatment of gonorrhoea and acne [16] [17]. Previous studies have also unravelled molluscicidal, anti-inflammatory [18] [19] and anti-leishmanial activity attributable to aqueous and methanolic leaf and berry extracts of *S. aculeastrum* [20] [21] [22]. These studies illustrate the potential use of plant extracts of *S. aculeastrum* in managing inflammatory disorders as well as parasitic infestations, in addition to its known antimicrobial activity.

Antimicrobial properties of *S. aculeastrum* extracts have previously been demonstrated against various strains of gram-positive and gram-negative bacteria including *Staphylococcus epidermidis* (*S. epidermidis*), *Streptococcus pyo-*

genes, *Escherichia coli* (*E. coli*), *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* [15]. The acetone and methanol plant extracts demonstrated minimum inhibitory concentration (MIC) values comparable to chloramphenicol and streptomycin against various bacterial strains in these studies, underlining their benefit and historical use in treating bacterial infections. Recent studies have also indicated activity against *Mycoplasma* and other bacterial species known to be highly resistant to most conventional antibiotics in routine clinical use [23] [24]. The antifungal properties of *S. aculeastrum* extracts have also been previously demonstrated [25]. In these studies, the extracts demonstrated *in vitro* activity against cultures of *Aspergillus flavus*, *Aspergillus ochraceous* and *Fusarium verticilloides*. Additionally, extracts of *S. aculeastrum* have been shown to inhibit propagation and prevent the release, of aflatoxins by various strains of *A. flavus* [26]. This is a critical observation owing to the high incidence of aflatoxin poisoning occurring due to the contamination of cereal foods by the fungus.

Phytochemical analysis of *S. aculeastrum* leaf and root bark methanolic extracts previously identified the glycoalkaloids solasonine and solasodine to be among the dominant bioactive constituents [27] [28]. Solasodine possesses diuretic, anticancer, antifungal, antiandrogenic, immunomodulatory and antipyretic properties in various animal models [29]. Bioassay-guided fractionation studies have also identified solamargine, an additional steroidal alkaloid obtained from *S. aculeastrum* fruit extracts, to possess cytotoxic and P-glycoprotein inhibition activity [30]. The cytotoxic effects of this alkaloid were, however, found to be non-selective but it is nonetheless thought to be partly responsible for the anticancer properties of *S. aculeastrum* [30]. Other investigations have uncovered the sesquiterpenoid Solyraterpenoid A from *S. lyratum* extracts, which possesses antibacterial activity [31]. Various other steroidal glycoalkaloids from a range of *Solanum* species have been identified and are believed to possess different bioactive properties attributable to plants in this genus [32].

E. coli causes various infections including urinary tract infections, bacteremia, diarrhoea, pelvic and abdominal infections, meningitis, pneumonia, cholangitis, and sepsis, among others [33] [34] [35] [36]. *S. aureus* causes infections like wound infections, cellulitis, abscesses, bloodstream infections, pneumonia, and bone and joint infections [37] [38] [39] [40]. Infections that are caused by *E. coli* are treated using β-lactams, aminoglycosides, fluoroquinolones, and trimethoprim-sulfamethoxazole [41], while those that are caused by *S. aureus* are treated using cefazolin, cloxacillin, oxacillin, nafcillin, daptomycin, vancomycin, and linezolid [42]. However, the emergence of antimicrobial resistance (AMR) to these antibiotics has negatively affected treatment outcomes, with many infections becoming difficult to treat leading to increased morbidity and mortality [33] [43] [44]. To reduce AMR, there is a need to use antibiotics appropriately, promote rational prescribing by adhering to the treatment guidelines [45] [46] [47] and strengthened antimicrobial stewardship programs [48] [49].

The use of herbal and traditional medicines is very common in Zambia [50] [51] [52] [53] [54]. However, there is still a paucity of information on plants that

have antimicrobial activities against common microorganisms such as *E. coli* and *S. aureus*. Therefore, this study investigated the antimicrobial activities of *S. aculeastrum* fruit extracts grown in Zambia against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*.

2. Materials and Methods

2.1. Study Design, Period, and Site

This was a laboratory-based experimental study that was conducted between August 2021 and September 2022 in the Food and Drugs Control Laboratory and microbiology laboratory at the University Teaching Hospitals in Lusaka, Zambia.

2.2. Plant Materials

The mature fruits of *S. aculeastrum* were collected from the Nyama area in Kabwe, Central Province of Zambia, and a voucher herbarium specimen was prepared and presented to the Department of Plant Sciences, University of Zambia for identification and authentication. The plant species was identified positively as *Solanum aculeastrum dunal*.

2.3. Extract Preparation

The *S. aculeastrum* fruits were oven-dried (Grandly, 2000, Germany), at 50˚C for 8 days and then pounded into a powder using a pestle and motor. This was done to increase the surface area for subsequent solvent-based extraction. Methanol and distilled water were employed as solvents for the extraction of the crude material. To achieve this, 20 g of the dried fruit powder was weighed and stirred in 300 mL of either methanol or distilled water for 24 hours. Afterwards, the crude extract was filtered through Whatman® filter paper number one to obtain the respective filtrates which were then concentrated to dryness using a water bath at 45˚C and packed into separate airtight containers for further use. All chemicals and reagents used in this study were of analytical grade which were acquired from commercial sources.

2.4. Phytochemical Analysis

Phytochemical analysis of the filtrates to determine the presence of flavonoids, tannins, alkaloids, saponins, phenols and terpenoids was conducted according to the procedures adapted from Kabuka *et al.*, (2022) [52] and Hikaambo *et al.* (2022) [54].

2.5. Determination of Antimicrobial Activity

We used *E. coli* (ATCC 25922), *S. aureus* (ATCC 25923) *and C. albicans* to test for the antimicrobial activity of plant extracts. These microbes were obtained from the Department of Pathology and Microbiology at the University Teaching Hospital (UTH), Zambia.

The antimicrobial activity tests of *S. aculeastrum* fruit extracts were performed using the disc diffusion method as reported previously by Masaiti *et al.* (2019) [51]. The Mueller-Hinton agar (Oxoid) plates were inoculated with a standard inoculum of *E. coli*, *S. aureus and C. albicans.* Then, the filter paper discs (6 mm in diameter), containing the different concentrations of the extracts were placed on the agar surface and incubated at 37˚C for 24 hours. Thereafter, the zones of inhibition of microbial growth produced by extracts were measured using a ruler (in millimetres) and compared to those of standard discs of ciprofloxacin 5 µg and amphotericin B 20 µg as positive controls.

2.6. Ethical Considerations

Ethical approval to conduct the study was obtained from the University of Zambia Health Science and Research Ethics Committee (UNZAHSREC) through the Department of Pharmacy (Protocol ID number 202211231189). Additionally, approval to carry out the study from UTH was sought from the Senior Superintendent, University Teaching Hospitals (UTH) and the Head of Department in the Department of Microbiology Laboratory.

3. Results

Findings from the phytochemical screening of *S. aculeastrum* aqueous and methanolic extracts are presented in **Table 1**. While the aqueous extract did not have any flavonoids and phenols, the methanolic extract had these phytochemicals in only low concentrations. In addition, tannins and terpenoids were observed to be in low concentration in the aqueous extract but in moderate concentrations in the methanolic extract. Of the two extracts, alkaloids and saponins were in higher concentrations in the aqueous as compared to the methanolic extract.

The extracts were tested for antimicrobial activity against *S. aureus*, *C. albicans* and *E. coli* species. In both the methanolic (**Figure 1**) and aqueous (**Figure 2**) extracts, the zone of inhibition was greater in *S. aureus* than that observed for *C. albicans*. Moreover, none of the fractions elicited any antimicrobial activity against *E. coli* as there was zero zone of growth inhibition for this bacterium. A superimposition of the observed antimicrobial activities from both fractions (**Figure 3**) reveals *S. aureus* to be more susceptible to inhibition of the growth by the extracts than *C. albicans*.

4. Discussion

This study investigated the antimicrobial activities of *S. aculeastrum* fruit extracts against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*. Phytochemicals including flavonoids, tannins, alkaloids, saponins, phenols, and terpenoids were all present in the methanolic extract while the aqueous extract only had flavonoids, alkaloids, saponins, and terpenoids. Additionally, this study found that *S. aculeastrum* fruit extracts have antimicrobial activities against *S. aureus* and *C. albicans*.

Table 1. Phytochemical composition of *S. aculeastrum* aqueous and methanolic extracts.

Phytochemicals	Aqueous extract	Methanolic (95%) extract
Flavonoids	–	+
Tannins	+	++
Alkaloids	++	+
Saponins	+++	++
Phenols	–	+
Terpenoids	+	++

Key: +++ High concentration; ++ Moderate concentration; + Low concentration and (–) Absent.

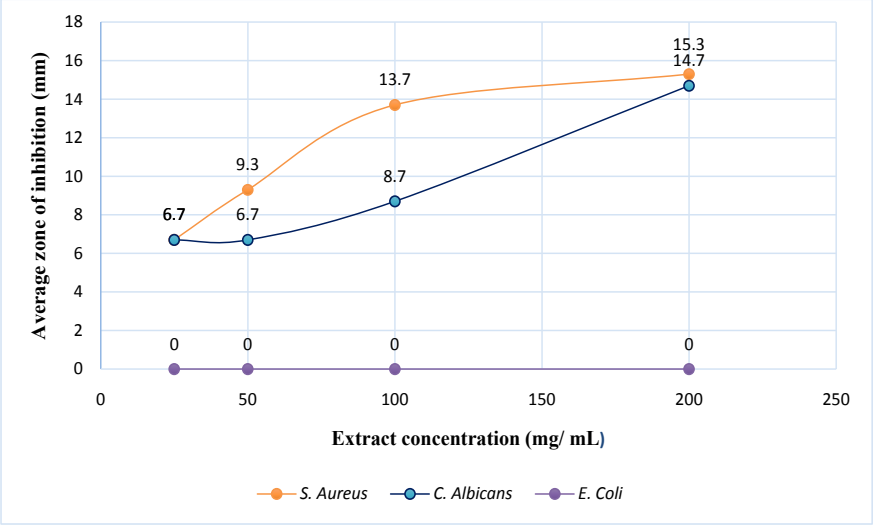

Figure 1. Antimicrobial activity of *S. aculeastrum* methanolic.

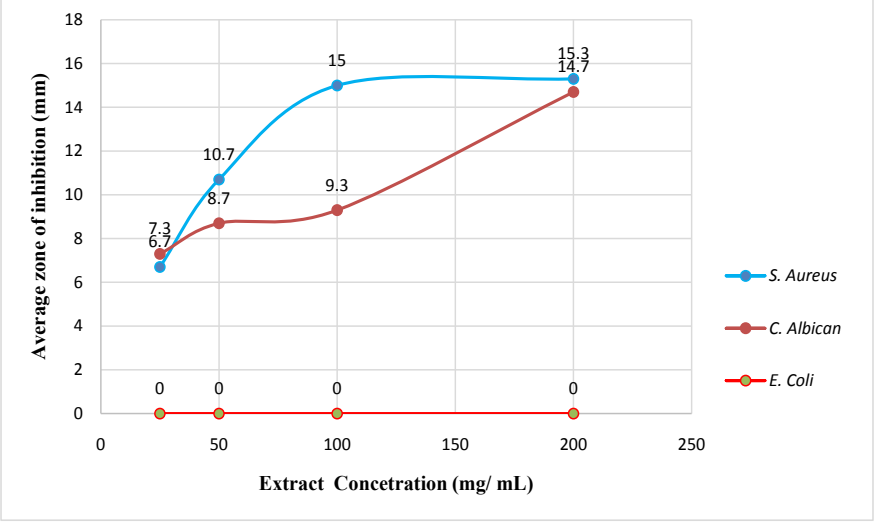

Figure 2. Antimicrobial activity of *S. aculeastrum* aqueous extract.

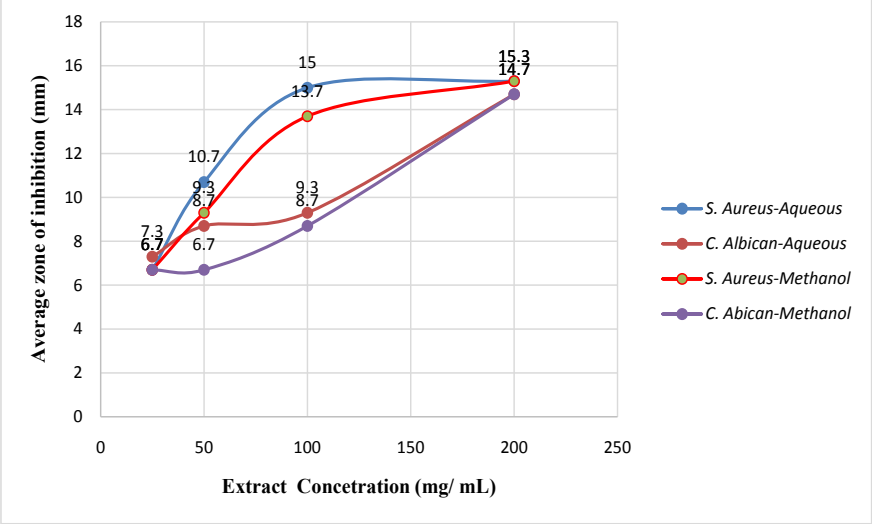

Figure 3. Superimposition of the antimicrobial activity of the methanolic and aqueous extracts.

The phytochemicals found in our study are consistent with those found in *S. aculeastrum* fruits grown in the Eastern Cape province of South Africa which also found the presence of alkaloids, saponins, phenolics, and flavonoids [55]. Additionally, *β*-Solamarine and Solamargine, a class of steroidal saponins were also observed in methanolic extracts of the *S. aculeastrum* fruits grown in Kenya [56].

Despite their differences in overall phytochemical composition, both the aqueous and methanolic extracts of *S. aculeastrum* fruit in this study displayed significant inhibition of *S. aureus* growth. In an earlier study, methanolic extracts of *S. aculeastrum* root bark from the Mpigi region in Uganda were shown to display potent inhibition of the quorum-sensing system in the *S. aureus* reporter strain AH-1677 [24]. The mentioned pathway plays a vital role in enabling the species to invade hosts and cause abscess formation. Thus, inhibition of processes mediated by the pathway is associated with a significant reduction in strain virulence [57]. Similar activity was reported with the ethyl acetate and hexane extracts of *S. aculeastrum* root bark. Low sub-IC_{50} concentrations of the *S. aculeastrum* plant extract were used in the quorum sensing inhibition study to avoid potential growth-inhibition activity. Nevertheless, this was an important finding and can be related to the outstanding growth inhibition of *S. aureus* demonstrated in our study. In the same study, the ethyl acetate extract of *S. aculeastrum* root inhibited the production of *δ*-toxin by AH1263 and NRS243 strains of *S. aureus*. The peptide *δ*-toxin (alternatively referred to as *δ*-hemolysin) plays an important role in the growth and pathogenicity of the bacterium by promoting bacterial cell propagation and evasion of host defence mechanisms [58] [59]. These findings are relatable to those obtained in this study whereby potent inhibition of *S. aureus* growth was observed with the plant fruit extract and no inhibition was demonstrated against *E. coli*.

In a separate study focusing on the anti-inflammatory and antibacterial activity of plant extracts, *S. aculeastrum* extracts from Uganda were also shown to have potent growth-inhibiting effects on *S. aureus* compared to *E. coli* [21]. By employing the antibacterial Resazurin bioassay, the aqueous and methanolic Soxhlet extracts of *S. aculeastrum* root showed the highest growth inhibitory activity (MIC 11.71 μg/ml) against the ATCC 25923 strain of *S. aureus*. Little to no inhibition of growth was observed against *E. coli* at the highest concentration of plant extract used in this study [60]. This finding is also in tandem with the outcome of our study. The absence of activity against *E. coli* in our study may be due to poor penetration of the outer membrane with a lipopolysaccharide layer [54]. Ciprofloxacin, the standard used in our investigation, produced potent inhibition of *S. aureus* and moderate inhibition of *E. coli* growth, as anticipated.

The results obtained for *C. albicans* are consistent with studies done by Steenkamp (2007) which showed inhibition of *C. albicans* strains by methanol extracts of *S. aculeastrum* fruit [61]. These results suggest that the extracts contain phytochemical compounds with therapeutic potential against *C. albicans* [61]. In another study, methanolic and aqueous extracts from the fruits and leaves of *S. aculeastrum* did not show any activity against *C. albicans* but were, however, found to be active against *Aspergillus flavus* and *Pencillium chrysogenum* [15]. The above findings demonstrate that extracts of *S. aculeastrum* fruit has some antimicrobial activities against some microorganisms.

5. Conclusions

The results of this study provide compelling evidence that the extract of *S. aculeastrum* fruit possesses potent antimicrobial activity against two commonly encountered pathogens, namely *S. aureus* and *C. albicans*. The observed effects are likely attributable to the presence of phytochemicals with well-established medicinal properties, suggesting that these compounds may represent promising candidates for further exploration and characterization.

Given the ever-increasing threat of antimicrobial resistance (AMR), there is an urgent need for the development of novel therapeutics that can effectively combat bacterial and fungal infections. Natural product-based drug discovery has emerged as a promising avenue for addressing this challenge, as plants have long been recognized as a rich source of bioactive compounds with diverse and potent pharmacological properties.

The present findings underscore the importance of continued investigation into the medicinal properties of plant-derived compounds, particularly those with demonstrated antimicrobial activity. By identifying and characterizing these compounds, we can potentially develop novel therapeutic agents that are both effective against infections and less prone to the development of resistance. As such, this study represents a valuable contribution to the ongoing effort to identify new sources of antimicrobial agents and combat the growing threat of AMR.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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