Phytochemical investigation, antioxidant and antibacterial activities of the fruit extracts of *Solanum anguivi*

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**ABSTRACT**

*Solanum anguivi* Lam. is an ethnomedicinal plant. Local traditional practitioners believe that it reduces the risk of diabetes and atherosclerosis diseases. The present study was intended to conduct qualitative phytochemical analysis, determine the total flavonoid and phenolic contents, estimate the antioxidant capacity and antibacterial activities of the extracts of the fruits of this plant. The antioxidant activity was determined by analyzing the radical scavenging activity (RSA) using 2,2-diphenyl-1-picrylhydrazyl (DPPH), and ferric reducing antioxidant power (FRAP) assays. The antibacterial activities were determined by the agar well diffusion method. Qualitative phytochemical screening of the crude extracts obtained from the fruits of the plant indicated the presence of alkaloids, flavonoids, phenols, glycosides, steroids, terpenoids, saponins and tannins. The highest total phenolic and total flavonoid content were obtained in the ethanol extract of the fruits, followed by dichloromethane and *n*-hexane extract. The total phenolic content (in gallic acid equivalents, GAE) ranged from 113.3 to 202.72 mg GAE/g. The total flavonoid content (in catechin equivalent, CE) varied from 61.72 to 142.64 mg (CE)/g. All fruit extracts of *S. anguivi* exhibited antioxidant activity as revealed by DPPH and FRAP assays. The DPPH RSA (% inhibition) of the fruit extract varied from 35.11 to 80.13. The total phenolic and Flavonoid contents showed a linear correlation with RSA. Furthermore, all fruit extracts showed antibacterial activity against gram-positive and gram-negative bacteria varying from 12.5 to 16.75 mm. The result showed that the extracts of the plant exerted stronger bactericidal effect on gram-positive bacteria than on gram-negative bacteria.

**Introduction**

Since times immemorial, humans have used ethnobotanical species for medicine, food, shelter, and other purposes [1]. Rural communities in many developing countries still rely on the use of traditional medicinal plants for the treatment of a variety of health problems. This is partly due to the lack of access to modern health care facilities for rural communities.

It has been recognized since ancient times that nature is a potential source of pharmacologically important drugs. This has resulted in the use of a large number of medicinal plants for treating various diseases. In fact, many modern medicaments are based on the traditional use of such drugs. In some Asian and African countries, up to 80% of the population rely on traditional medicine for their primary health care needs [2]. The term *traditional medicine* refers to ‘the sum total of the knowledge, skills and practices based on the theories, beliefs and experiences indigenous to different cultures, whether explicable or not, used in the maintenance of health, as well as in the prevention, diagnosis, improvement or treatment of physical and mental illnesses’ [3].

Plants secrete many organic bioactive compounds, known as secondary metabolites that do not have a direct role in the photosynthesis, growth and development of the plant but are crucial in ensuring survival of the plant by performing many important functions like protection from herbivores. The secondary metabolites are also known to have antioxidant, antifungal, antibiotic and antiviral activity, thus holding a significant position in boosting the plant’s defence system against any kind of pathogens [4].

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Solanum anguivi belongs to the plant family Solanaceae and can be found as a wild plant in many places throughout the non-arid parts of Africa. The fruit of S. anguivi is used in folklore medicine for the treatment of high blood pressure, ulcer, nerve disorder and diabetes [5–7]. The fruits of S. anguivi have also been reported to possess antioxidant activity in addition to bactericidal effects similar to some other species of Solanum genus [8,9]. The present study was aimed at the phytochemical screening of the fruits extracts of S. anguivi and some fractionated compounds, and investigating their antioxidant and antibacterial activities.

Materials and methods

Plant materials

The fresh fruits of S. anguivi were collected from Danigila, 477 km North-West of Addis Ababa, Ethiopia in August 2019. The plant was identified by a botanist at the Department of Biology, Bahir Dar University, Ethiopia.

Instruments

A pH meter (Heidolpunimax, England), electrical shaker, IR spectrometer (Jasco, FT-IR-6600, Japan), UV–Vis spectrophotometer (Cary 60 Agilent technologies China) were the instruments used in this study.

Chemicals and reagents

Solvents and reagents were used as received from the suppliers. N-hexane (Pentokey Organy India LTD); dichloromethane, ethanol, acetone, methanol, aluminum chloride, ethyl acetate (all from Carlo Erba SAS), Wagner's reagent, sodium nitrite, potassium hexacyanoferrate (II), ascorbic acid, trichloroacetic acid, gallic acid, ferric chloride, petroleum ether, Mueller Hinton agar (all from Blulux Laboratories (P) Ltd.-120 001); dimethyl sulfoxide (DMSO) (Sisco Research Laboratory Pvt. Ltd), a standard antibiotic disc (Gentamicine µg/disc); Folin-Ciocalteu reagent, 2,2-Diphenyl-1-picrylhydrazyl (DPPH) (Himedia, India) and catechine (Himedia, India) were among the analytical grade chemicals and reagents used in the study. Distilled water was used throughout the entire research work.

Sample preparation

The collected fruit samples were thoroughly washed with tap water to remove all the dust particles. The cleaned fruits were air-dried in the absence of light, ground into a fine powder and stored at room temperature in a plastic bag prior to use.

Extraction

The air-dried powdered fruit sample was successively extracted with n-hexane, dichloromethane and ethanol using the maceration technique for 48 h in each solvent. The solvent from each extract was removed using a rotary evaporator under reduced pressure. The resulting semi-dried mass of each extract was kept away from light until used for further experiments.

Isolation of compounds

Of the crude S. anguivi fruit extracts obtained using the aforementioned solvents, the dichloromethane extract showed a relatively better antibacterial activity. This extract was impregnated with silica gel and subjected to column chromatography to isolate compounds using acetone-petroleum ether mixtures (1% – 3%) as the eluent. The eluted fractions were analyzed by thin layer chromatography (TLC). The fractions having similar Rf (retention factor) values were pooled together and subjected to further chromatography to obtain the pure compounds as judged by TLC (single spot) and observation under ultraviolet (UV) light. This led to the isolation of three gummy compounds (labelled CM-1, CM-2 and CM-3), each exhibiting strong absorption bands in the infrared spectrum ascribable to carbonyl groups. Full characterization of these compounds, however, awaits the obtainment of additional requisite spectral data.

Qualitative phytochemical analysis

Test for terpenoids (Salkowski’s test)

The phytochemical analysis of n-hexane, dichloromethane and ethanol extracts of the fruit part of S. anguivi was performed as per literature reports [10,11]

Quantitative phytochemical determination

Determination of total phenolic content (TPC)

The total phenolic content of the crude extracts was determined by using the Folin-Ciocalteu method [12]. A series of standard gallic acid solutions (10, 20, 30, 40 and 50 ppm) were prepared from a gallic acid stock solution. The plant extract containing 1 mL of each of these standard solutions was mixed with 5 mL of Folin-Ciocalteu reagent and allowed to stand for 6 min. Following the addition of 4 mL of 10% sodium carbonate solution to each mixture, absorbance was recorded
after 30 min at 765 nm in a UV-visible spectrophotometer. The total phenolic content of the n-hexane, dichloromethane and ethanol extracts was calculated as gallic acid equivalents (mg GAE/g).

**Determination of total flavonoid content (TFC)**

Aluminum chloride complex forming assay was used to determine the total flavonoid content of the extracts. Catechin was used as a standard to make the calibration curve, and the flavonoid content was determined as catechin in equivalents [13]. Standard catechin solutions (2.4, 4.7, 9.4, 18.7 and 37.4 mg/L) were prepared. Distilled water (5 mL) was added to a mixture containing the plant extract and 1 mL of each of the catechin solutions. Finally, 0.3 mL of 5% sodium nitrite solution was added to each mixture. After allowing the mixture to stand for 5 min, 0.3 mL of 10% aluminum chloride solution was added and the mixture was allowed to stand for 6 min at room temperature. Then 2 mL of 1 mol/L sodium hydroxide solution was added followed by the addition of distilled water until the final volume reaches 10 mL. Finally, the absorbance of the reaction mixtures was recorded at 510 nm in a UV-visible spectrophotometer. The total flavonoid content of each extract was calculated as catechin equivalents (mg CE/g).

**Antioxidant capacity assays**

**DPPH radical scavenging assay**

The free-radical scavenging activities of the extracts and isolated compounds were determined by using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging method [14]. A fresh 0.004% solution of DPPH was prepared in ethanol. Standard solutions of 40, 60, 80 and 100 mg/L of ascorbic acid were prepared as a reference. To a separate solution of each extract and isolated compounds containing 4 mL of the ascorbic acid, 1 mL of DPPH solution was added. Each mixture was allowed to stand in darkness for 20 min. A control was prepared by mixing 2 mL of the DPPH solution and 3 mL of ethanol. Finally, the absorbance was measured and the percentage inhibition of DPPH by extracts and isolated compounds were calculated by using the following formula:

\[
\% \text{Inhibition} = \left( \frac{A - B}{A} \right) \times 100
\]

Where \(A\) is the absorbance of pure DPPH in oxidized form and \(B\) is the absorbance of sample taken after 20 min of reaction with DPPH.

**Ferric reducing antioxidant power (FRAP) assay**

The reducing power of the prepared extracts and isolated compounds were determined according to methods reported in the literature [15]. Different concentrations (40, 60, 80 and 100 mg/L) of \(S.\ anguivi\) fruit extracts, isolated compounds and the same concentrations of ascorbic acid were prepared. From each concentration, 2.5 mL was taken and mixed with 2.5 mL phosphate buffer (pH = 6.6) and 2.5 mL of 1% potassium ferricyanide solution. The mixture was incubated at 50°C for 20 min. Then, 2.5 mL of trichloroacetic acid (TCA) solution (10% w/v) was added to terminate the reaction. Then the solution was mixed with 2.5 mL of distilled water and 0.5 mL ferric chloride solution (0.1% w/v). Finally, absorbance was measured by using a UV-vis spectrophotometer against a blank solution.

\[
\text{Percentage (\%) reduction power} = \left( \frac{A_{\text{sample}} - A_{\text{blank}}}{A_{\text{sample}}} \right) \times 100
\]

Where \(A_{\text{sample}}\): Absorbance of sample, and \(A_{\text{blank}}\): Absorbance of blank

**Antimicrobial activity assays**

Two gram-positive (\(Staphylococcus aureus\), \(Streptococcus pyogenes\)) and gram-negative (\(Escherichia coli\), \(Klebsiella pneumonia\)) bacteria with ATCC (American Type Culture Collection) type were used.

**Preparation of test solutions**

Test solutions (1000 mg/L) were prepared by dissolving 1 mg of each crude extract and isolated compounds in 1 mL of dimethyl sulfoxide (DMSO). A 500 and 250 ppm of isolated compounds were prepared by serial dilution method from 1000 ppm solution of isolated compounds.

**Agar diffusion method**

The disk diffusion method with Muller Hinton agar was used for evaluating the antimicrobial activity. Using a sterile cotton swab, the fresh culture of bacteria strains was swabbed on the surface of sterile agar plates. Each plant extract of the test solution was poured on the surface of agar plates inoculated with culture bacteria in Petri dishes by using 5 mm diameter sterile discs (Whatman No 3 paper). The standard antibiotic disc (gentamycin, 30 µg/disc) served as the positive antibacterial control and the DMSO solution was used for the negative control. Then the plates were incubated for 24 h at 37°C. The antibacterial activities
of crude extracts and isolated compounds at different concentrations (1000, 500 and 250 mg/L) were determined. After 24 h, the zone of inhibition was observed and recorded in millimetres. The tests were performed in triplicates for each microorganism evaluated and the final results were presented as arithmetic average with standard deviation (Mean ± Std). Antibacterial activity was recorded if the zone of inhibition was greater than 6 mm [16].

Minimum inhibitory concentration (MIC)
The minimum inhibitory concentration (MIC) values of isolated compounds were determined by using the broth dilution method. Each isolated compound was individually prepared in four test tubes having different concentrations (125, 62.5, 31.25 and 15.625 mg/L) using serial dilution. Test tube 1 was filled with 5 mL of an equal amount of Muller Hinton broth and isolated compounds. Then 2.5 mL of solutions from test tube 1 was transferred to test tube 2 and diluted to 5 mL with Muller Hinton broth. This procedure was repeated for the next two test tubes and each test tube was filled with 1 mL Muller Hinton broth including bacterial suspension. The resulting mixtures were incubated at 37 °C for 24 h. The concentration that exhibited turbidity was taken as an indication of the growth of bacteria, and the lowest concentration at which the medium remained clear (no growth of bacteria) was recorded as the relative minimum inhibitory concentration [17].

Results
Qualitative preliminary phytochemical analysis
In the present study, the phytochemical screening test of fruit extracts of *S. anguivi* revealed the presence of saponins, glycosides, alkaloids, tannins, phenols, flavonoids, steroids and terpenes as shown in Table 1.

| Class of compounds | Test reagent | n-hexane | DCM | Ethanol |
|--------------------|--------------|----------|-----|---------|
| Alkaloids          | Wagner       | −        | ++  | −       |
| Phenols            | ferric chloride test | + | +   | +       |
| Flavonoids         | NH₃          | +        | +   | +       |
| Steroid            | Salkowski’s Test | ++ | ++  | +       |
| Terpenoid          | Salkowski’s Test | ++ | +   | −       |
| Saponins           | Shaking with water | − | −   | +       |
| Tannins            | ferric chloride test | − | +   | ++      |
| Glycosides         | NaOH test    | −        | +   | +       |
| Anthraquinone      |              | −        | −   | −       |

*‘+’ present, ‘++’ highly present, ‘−’ not present.*

Isolation of compounds/fractionation
Three compounds (labelled CM-1, CM-2, and CM-3) were isolated from dichloromethane fruit extracts of *S. anguivi*. There was a single spot on TLC when visualized under UV-Vis light (λ_max 254 and 365 nm) by the different solvent systems.

Compound-1
A light yellow gummy compound (16 mg) was isolated from dichloromethane fruit extracts of *S. anguivi* and eluted by 30% petroleum ether in acetone and labelled as CM-1. Preliminary qualitative phytochemical test of compound-1 gave only a positive result for flavonoids. The UV-visible spectrum of compound-1 showed two absorption maxima at 238 nm and 336 nm. The flavonoids spectrum typically consists of two absorption maxima at the ranges 240–285 nm (band II) and 300–550 nm (band I) in the UV-visible spectrum. Methylation of glycoside groups (especially of 3, 5, 7 and 4 hydroxyls) causes band shifts to a shorter wavelength [18]. The absorption maxima of compound-1 were present in the range of the flavonoid spectrum in the UV-visible range, indicating that compound-1 is a flavonoid. Some important IR results of compound-1 are summarized in Table 2 and compared with the previously IR result of flavonoid C-glycoside.

Compound-2
A greenish gummy compound (12 mg) labelled as CM-2 was isolated and eluted by 70% petroleum ether in mixtures of ethyl acetate-acetone (70:15:15). The TLC profile of compound-2 (CM-2) indicated one single spot in different solvent systems. Preliminary qualitative phytochemical test of compound-2 gave only a positive result for tannins.

The UV-visible spectrum of compound-2 had an absorption maximum (λ_max) at 246 nm in the UV-Vis region spectrum. Tannins have absorption maxima in the range of 205 nm to 280 nm in the Ultraviolet-visible
The IR result of compound-2 is summarized in Table 3 and compared with the previous IR results of tannins.

**Compound-3**

This compound was eluted by 60% petroleum ether in a mixture of acetone and dichloromethane (60:20:20) combinations. It was 15 mg reddish-brown gummy compound and had a single spot on TLC when visualized under UV-Vis light (λ max 254 and 365 nm) by a different solvent system. Qualitative phytochemical screening test of compound-3 gave only a positive result for flavonoid compounds.

The UV-visible spectrum of compound-3 showed two peaks at 251 and 325 nm in the UV-visible spectrum region. The peaks at λ max of 251 nm and another peak at 325 nm were found in the absorption spectrum of flavonoids.

The IR data result of compound-3 showed that a band at 3404 cm⁻¹ implies the presence of hydroxyl (-OH) stretching and at 2925 indicates CH₂ stretching. An intensive and sharp peak at 1612 cm⁻¹ is characteristic of -C=O stretching or aromatic compounds and a sharp peak at 1458 cm⁻¹ is characteristic of aromatic compounds. The peak at 1255 cm⁻¹ also confirms the presence of O-C stretching. The IR results of compound-3 (CM-3) were in agreement with the IR result reported before for characterization of flavonoid compounds [23]. Table 4 shows the IR result for compound 3 compared with previously reported IR results of flavonoids.

**Quantitative analysis for total phenolic and total flavonoid contents**

**Total phenolic content**

Phenolic compounds, especially phenolic acids, play an important role in the overall radical scavenging ability [25]. The total phenolic content of each extract was determined using the Folin-Ciocalteu’s reagent in terms of gallic acid equivalent. The regression equation of the calibration curve of the gallic acid standard for the present study was 

\[ y = 0.00112x - 0.0067 \]

with \( R^2 \) of 0.9994. The absorbance readings and calibration curve of the standard solutions are shown in Appendix 1 (Online Supplemental Material). The total phenolic

| Table 2. IR result of Compound-1 and previous IR result of glycoside flavonoids. |
|------------------|-------------------|-------------------|-------------------|
| IR peaks in cm⁻¹ | Present result | Previous result | Assignment | Reference |
| 3418             | 3418             | 3398             | –OH stretching | [19]      |
| 2926             | 2926             | 2922             | –CH₃ stretching|            |
| 2859             | 2859             | 2847             | –CH₃ stretching|            |
| 1617             | 1618             | 1618             | C=O stretching |            |
| 1450             | 1450             | 1450             | aromatic C=C stretching | |
| 1265             | 1265             | 1256             | C=O stretching |            |
| 1064             | 1060             | 1060             | –O–C=O– stretching | (glycoside linkage) |

| Table 3. IR result of compound-2 and previous IR results of tannin compounds. |
|------------------|-------------------|-------------------|-------------------|
| IR peaks in cm⁻¹ | Present result | Previous result | Assignment | Reference |
| 3424             | 3424             | 3424             | –OH stretching | [21]      |
| 2925             | 2925             | 2925             | –CH₃ stretching|            |
| 2855             | 2855             | 2855             | –CH₃ stretching|            |
| 1725             | 1725             | 1725             | C=O stretching |            |
| 1600             | 1600             | 1600             | Two bands indicates aromatic C=C stretching | [22] |
| 1454             | 1454             | 1454             | aromatic C=C stretching | |
| 1265             | 1265             | 1265             | C=O stretching |            |

| Table 4. IR result of compound-3 and previous IR results of flavonoid compounds. |
|------------------|-------------------|-------------------|-------------------|
| IR peaks in cm⁻¹ | Present result | Previous result | Assignment | Reference |
| 3404             | 3404             | 3410             | –OH stretching | [23]      |
| 2925             | 2925             | 2937             | –CH₃ stretching|            |
| 2856             | 2856             | 2870             | –CH₃ stretching|            |
| 1612             | 1612             | 1619             | C=O stretching |            |
| 1458             | 1458             | 1462             | Two bands indicates aromatic C=C stretching | [23] |
| 1409             | 1409             | 1450             | aromatic C=C stretching | |
| 1255             | 1255             | 1256             | C=O stretching |            |
content of each extract of fruits of *S. anguivi* was determined using this regression equation and the results are depicted in Table 5.

**Total flavonoid content**

Aluminum chloride complex forming assay was used to determine the total flavonoid content of the extracts. Catechin was used as standard and flavonoid content was determined as catechin equivalent (mg CE/g) [26]. The total flavonoid content (TFC) of each fruit extract was determined as catechin equivalent (mg CE/g) dry sample. To perform the calculations of total flavonoid content, a standard curve is needed which is obtained from a series of different catechin concentrations. The calibration curve was constructed by plotting absorbance versus concentration of catechin as shown in Appendix 2 (Online Supplemental Material). A straight line with an equation of $y = 0.0076x + 0.0669$ and a coefficient of determination ($R^2$) of 0.9968 was obtained as shown in Appendix 2 (Online Supplemental Material). Using this regression equation, the total flavonoid content was determined at the given absorbance values and the results obtained are depicted in Table 6.

**Antioxidant capacity assay**

**DPPH radical scavenging activity**

DPPH accepts a hydrogen atom from antioxidants thereby getting reduced. As a result, the absorbance decreases, as the radical changes from DPPH to the DPPH-H form. The degree of discoloration indicates the scavenging potential of the antioxidant compounds or extracts in terms of hydrogen and electron-donating ability [27].

The purple colour of DPPH is changed when mixed with the crude extracts and each of the compounds isolated from the extract (the colour change depends on the antioxidant ability), indicating the scavenging of the radicals by antioxidants. This demonstrates that the antioxidants found in the extracts and the isolated compounds quench the free radicals. In the present study, the percentage of inhibition was determined (Table 7 and Figure 1) to evaluate the antioxidant activity of the extracts and isolated compounds with the ability to inhibit free radicals. The absorbance of each extract and isolated compounds at each concentration is shown in Appendix 3 (Online Supplemental Material).

**Ferric reducing antioxidant power (FRAP) assay**

The reducing power of fruit extracts of *S. anguivi* and isolated compounds were evaluated by the transformation of Fe$^{III}$ to Fe$^{II}$ through electron transfer ability which serves as a significant indicator of its antioxidant capacity. Like the antioxidant activity measured by the DPPH assay, the reducing power increased with increasing concentration of the extract. When potassium ferricyanide reacts with ferric chloride in the presence of antioxidants, potassium ferrocyanide and ferrous chloride are found as a product. The presence of antioxidants causes the conversion of the Fe$^{III}$/ferrocyanide complex to the ferrous form.

| Table 5. Total phenolic content of each extract. |
|-----------------------------------------------|
| Extract           | Total phenolic content (mg GAE/g) |
| n-hexane          | 113.63                             |
| Dichloromethane   | 170.00                             |
| Ethanol           | 202.72                             |

| Table 6. Total flavonoid content of the extract. |
|-----------------------------------------------|
| Extract           | Total flavonoid content (mg CE/g) |
| n-hexane          | 61.72                              |
| Dichloromethane   | 120.8                              |
| Ethanol           | 142.64                             |

| Table 7. Inhibition (%) at each concentration of ascorbic acid, extracts and isolated compounds. |
|---------------------------------------------------------------|
| Concentration (mg/L) | Ascorbic acid | n-Hexane | DCM | Ethanol | CM-1 | CM-2 | CM-3 |
|----------------------|--------------|----------|-----|---------|------|------|------|
| 40                   | 88           | 35.11    | 49.37 | 60.96   | –    | –    | –    |
| 60                   | 91.5         | 43.54    | 54.76 | 62.82   | 20.29| 27.1 | 35.2 |
| 80                   | 94.79        | 49.43    | 55.63 | 68.24   | 26   | 31.34| 40.9 |
| 100                  | 97.87        | 56.26    | 59.85 | 80.13   | 27.25| 36.82| 41.26|
The reducing power of fruit extracts of *S. anguivi* and isolated compounds were expressed as absorbance vs. concentration (40, 60, 80 and 100 mg/L) and the result are shown Table 8 and Figure 2. The absorbance readings at each concentration of the extracts are depicted in Appendix 4 (Online Supplemental Material).

**Antibacterial activity**

**Antibacterial activities of crude extracts of fruits of *S. anguivi***

Antibacterial activities of fruit crude extracts of *S. anguivi* obtained by using *n*-hexane, dichloromethane and ethanol as the extracting solvents were evaluated by using Agar well diffusion method. Two gram-negative bacteria (*Escherichia coli* and *Klebsiella pneumonia*) and two gram-positive bacteria (*Staphylococcus aureus* and *Streptococcus pyogenes*) were used in the Agar well diffusion method.

The dichloromethane crude extracts exhibited better antibacterial activity followed by ethanol and *n*-hexane crude extract (Table 9). The dichloromethane crude extract showed maximum antibacterial activity followed by ethanol and *n*-hexane crude extracts against gram-positive bacteria (*Staphylococcus aureus* and *Streptococcus pyogenes*). The antibacterial activity of crude extracts of fruits of *S. anguivi* on *Staphylococcus aureus* was observed in the range between 12.5 to 16.75 mm inhibition zones. The highest inhibition zone (16.75 mm) was displayed by dichloromethane crude extract, while the least activity was observed with the *n*-hexane extracts (12.5 mm inhibition zone). All the crude extracts exhibited more potent bactericidal effects toward the gram-positive bacteria *Staphylococcus aureus*.

The crude extracts of fruits of *S. anguivi* also showed antibacterial activity against gram-negative bacteria (*Escherichia coli* and *Klebsiella pneumonia*). The ethanol crude extract exhibited better antibacterial activity (14.5 mm) inhibition zone followed by dichloromethane extract (14.25 mm inhibition zone) against *Klebsiella pneumonia*. As shown in Table 9, maximum activity was exhibited by dichloromethane extract (14.5 mm inhibition zone) followed by ethanol extract (13.5 mm inhibition zone) and *n*-hexane crude extract exhibited the least inhibitory activity (11.25 mm) against *Escherichia coli*. Of the gram-negative bacteria, *Escherichia coli* was more susceptible compared to *Klebsiella pneumonia* to *n*-hexane and dichloromethane extracts, and *Klebsiella pneumonia* was more susceptible to the ethanol extract.

**Antibacterial activities of isolated compounds**

Isolated compounds (CM-1, CM-2, and CM-3) of dichloromethane crude extract of fruits of *S. anguivi* exhibited antibacterial activity at different concentrations. All isolated compounds showed antibacterial activity against gram-negative and gram-positive bacteria. CM-2 and CM-3 showed comparable antibacterial activity and CM-1 exhibited less potent antibacterial activity against gram-positive and gram-negative bacteria as shown in Tables 10 and 11. The isolated compounds displayed an inhibition zone against *Staphylococcus aureus* ranging between 10.25 and 13.5 mm as shown in Table 10. The largest inhibition zone was observed with CM-3, followed by CM-2, and CM-1 had the smallest inhibition zone. The isolated compounds also showed antibacterial activity against *Streptococcus pyogenes* and the inhibition zone ranged from 9.5 to 11.5 mm. The larger inhibition

![Figure 1. Inhibition % of DPPH free radical by ascorbic acid (AA), n-hexane extract (HE), DCM extract (DCME), ethanol extract (EE), compound-1 (CM-1), compound-2 (CM-2) and compound-3 (CM-3).](image)

| Concentration (mg/L) | Absorbance | |
|----------------------|------------|---|
|                      | Ascorbic acid | n-Hexane | DCM | Ethanol | CM-1 | CM-2 | CM-3 |
| 40                   | 39.63       | 21.3     | 30.98 | 39.63 | 10.74 | 13.92 | 16.58 |
| 60                   | 63.18       | 24.25    | 38.84 | 50.10 | 13.44 | 17.12 | 19.82 |
| 80                   | 66.11       | 32.66    | 39.88 | 53.16 | 19.94 | 22.03 | 23.73 |
| 100                  | 73.11       | 35.35    | 43.69 | 64.84 | 22.87 | 26.29 | 28.04 |
Table 9. Zones of inhibition of crude extracts of fruits of *S. anguivi* against gram-positive and gram negative-bacteria.

| Test bacteria       | Conc (ppm) | n-Hexane | Dichloromethane | Ethanol | Gentamycin |
|---------------------|------------|----------|-----------------|---------|------------|
| *Staphylococcus aureus* | 1000       | 12.50 ± 0.7 | 16.75 ± 0.35   | 14.25 ± 0.35 | 30.00 ± 0.00 |
| *Streptococcus pyogenes* | 1000       | 11.50 ± 0.71 | 14.75 ± 0.35   | 13.50 ± 0.71 | 29.50 ± 0.35 |
| *Klebsiella pneumonia* | 1000       | 11.00 ± 0.35 | 14.25 ± 0.35   | 14.50 ± 0.71 | 29.50 ± 0.35 |
| *Escherichia coli* | 1000       | 11.25 ± 1.42 | 14.50 ± 0.71   | 13.50 ± 1.06 | 28.00 ± 0.71 |

zone was observed with CM-2 and the smallest one, with CM-1. Compound CM-2 and compound CM-3 showed stronger antibacterial activity against *Streptococcus pyogenes*. The result also showed that the isolated compounds exhibited antibacterial activity against gram-negative bacteria (*Klebsiella pneumonia* and *Escherichia coli*) in different concentrations (Table 11). The isolated compounds produced an inhibition zone ranging from 9.25 to 11.25 mm in diameter against *Klebsiella pneumonia*. The highest activity was displayed by CM-3 and the least potent activity was observed with CM-1. The maximum antibacterial activity was shown by CM-3, which produced an 11.5 mm inhibition zone, followed by CM-2 (11 mm inhibition zone), and the least potent activity was shown by CM-1 (9.55 mm) inhibition zone against *Escherichia coli* bacteria.

### Minimum inhibitory concentration determination (MIC) of isolated compounds

Minimum inhibitory concentration (MIC) refers to the lowest concentration of isolated compounds that will inhibit the visible growth of bacteria after 48 h of incubation. The MIC values of isolated compounds were determined at different concentrations. The concentration that exhibited turbidity was taken as an indication of growth of bacteria and the lowest concentration at which the medium remained clear (no growth of bacteria) was recorded as the relative minimum inhibitory concentration [17]. In this study, the antibacterial activities of isolated compounds of

Table 10. Zones of inhibition of isolated compounds from DCM extracts of fruits of *S. anguivi* against gram-positive bacteria.

| Test bacteria       | Conc (µg/ml) | Compound-1 | Compound-2 | Compound-3 | Gentamycin |
|---------------------|--------------|------------|------------|------------|------------|
| *Staphylococcus aureus* | 250         | 10.25 ± 0.35 | 10.50 ± 0.71 | 11.00 ± 0.71 | 30.00 ± 0.00 |
|                     | 500          | 10.50 ± 0.35 | 11.25 ± 0.35 | 12.5 ± 0.71 | 29.50 ± 0.35 |
|                     | 1000         | 11.75 ± 0.71 | 12.00 ± 0.71 | 13.50 ± 0.71 | 28.00 ± 0.71 |
| *Streptococcus pyogenes* | 250         | 9.50 ± 0.71 | 10.25 ± 0.35 | 10.5 ± 0.71 | 28.00 ± 0.50 |
|                     | 500          | 10.25 ± 0.35 | 10.5 ± 0.71 | 10.75 ± 0.35 | 11.00 ± 0.60 |
|                     | 1000         | 11 ± 0.71 | 11.5 ± 0.71 | 11.25 ± 0.35 | 11.50 ± 0.35 |

Table 11. Zones of inhibition of isolated compounds from DCM extracts of fruits of *S. anguivi* against gram-negative bacteria.

| Test bacteria       | Conc (µg/ml) | Compound-1 | Compound-2 | Compound-3 | Gentamycin |
|---------------------|--------------|------------|------------|------------|------------|
| *Klebsiella pneumonia* | 250         | 9.25 ± 0.35 | 9.75 ± 0.35 | 9.5 ± 0.71 | 29.00 ± 0.50 |
|                     | 500          | 10.00 ± 0.71 | 10.25 ± 0.35 | 11 ± 0.00000 | 28.00 ± 0.50 |
|                     | 1000         | 10.50 ± 0.35 | 11.00 ± 0.71 | 11.25 ± 0.35 | 28.00 ± 0.00 |
| *Escherichia coli* | 250          | 9.55 ± 0.07 | 10.00 ± 1.41 | 10.20 ± 0.35 | 28.00 ± 0.50 |
|                     | 500          | 10.25 ± 0.35 | 10.75 ± 0.35 | 10.50 ± 0.71 | 28.00 ± 0.00 |
|                     | 1000         | 10.75 ± 0.35 | 11.00 ± 0.71 | 11.50 ± 0.00 | 28.00 ± 0.00 |
dichloromethane crude extract of fruits of *S. anguivi* were evaluated at four different concentrations (125, 62.5, 31.25 and, 15.625 ppm) and the results are shown in Table 12. All isolated compounds showed MIC value of 31.25 mg/L against *S. aureus* and *S. pyogenes*. Compound-1 and compound-2 showed MIC value at 31.25 mg/L and compound-1 showed MIC value at 62.5 mg/L against gram-negative bacteria (*E. coli*), whereas *K. pneumonia* showed resistance to the antibiotics at lower concentration and had MIC value at 62.5 mg/L in all isolated compounds.

### Discussion

**Qualitative preliminary phytochemical analysis**

The result showed that the dichloromethane and ethanol extracts contained more bioactive compounds as compared to the *n*-hexane extract. It is due to their greater polar nature than the *n*-hexane extract. A previous study reported that steroids, flavonoids, alkaloids and saponins were present in ethanol and diethyl ether-chloroform extracts of fruits of *S. anguivi* [28].

**Isolation of compounds/fractionation**

Table 2 shows that the present IR result of compound-1 was compatible with the IR result of flavonoid C glycoside reported by [19]. Therefore, by comparing the IR and UV-visible result of compound-1 to previously reported results of glycoside flavonoid and the qualitative phytochemical test in this study, compound-1 is believed to be a class of flavonoids.

Table 3 shows that the present result was in agreement with the previous report about tannin. The bands at 1720 and 1700 cm\(^{-1}\) underline the presence of carbonyl groups that are particularly hydrolysable tannins. The hydrolysable tannins always present the –C=O stretching signal between 1720 and 1700 cm\(^{-1}\) [22]. By comparing the IR result of compound-2 with the previous IR result of tannin and observing the qualitative phytochemical test result, compound-2 may be a class of tannin. Table 4 reveals that the IR data in this study agreed with the previous IR data reports for flavonoid compounds. By comparing the IR and UV-visible spectra of compound-3 with previous IR and UV-visible spectra of flavonoids and by observing the qualitative phytochemical test results in this study, compound-3 might be a class of flavonoid compounds.

**Total phenolic content**

As presented in Table 5, the total phenolics content in the crude extracts of fruit samples of *S. anguivi* ranged from 113.3 to 202.72 mg GAE/g of dried weight sample. The highest total phenolic content was obtained from ethanol extract (202.72 mg GAE/g) followed by dichloromethane extract (170 mg GAE/g) and the lowest value was recorded in the *n*-hexane extract (113.63 mg GAE/g) of dry weight. This is in agreement with the expectation that phenolics, being polar compounds, are more efficiently extracted by polar solvents. A previous study reported that fruits of *S. anguivi* showed total phenolic content of 161 and 45 mg GAE/g of dry weight by ethanol and mixtures of diethyl ether-chloroform extracts of fruits of *S. anguivi* [28].

**Total flavonoid content**

Table 6 shows the total flavonoid content (TFC) of crude extracts of fruits of *S. anguivi* ranged from 61.72 to 142.64 mg CE/g. The highest total flavonoid content was obtained in the ethanol extract (142.64), followed by the medium polarity dichloromethane extract (120.8) and the least total flavonoid content was recorded in the *n*-hexane crude extract (61.72) mg CE (catechin equivalent)/g of dried weight as shown in Table 6. The result revealed that the amount of

### Table 12. MIC of isolated fractions.

| Isolated compounds | Test bacteria | *S. aureus* | *S. pyogenes* | *K. pneumonia* | *E. coli* |
|--------------------|--------------|------------|---------------|----------------|----------|
| Compound-1         | 125 mg/L     | −          | −             | −              | −        |
|                    | 62.5 mg/L    | −          | −             | −              | −        |
|                    | 31.25 mg/L   | −          | −             | +              | +        |
|                    | 15.625 mg/L  | +          | +             | +              | +        |
| Compound-2         | 125 mg/L     | −          | −             | −              | −        |
|                    | 62.5 mg/L    | −          | −             | +              | +        |
|                    | 31.25 mg/L   | −          | +             | −              |        |
|                    | 15.625 mg/L  | +          | +             | +              | +        |
| Compound-3         | 125 mg/L     | −          | −             | −              | −        |
|                    | 62.5 mg/L    | −          | −             | −              | −        |
|                    | 31.25 mg/L   | −          | +             | −              |        |
|                    | 15.625 mg/L  | +          | +             | +              | +        |

− inhibition of bacterial growth, + presence of bacterial growth.
flavonoid extracts from the plant depends on the polarity of the solvent. According to a literature report, the total flavonoid content of extracts of fruits of *S. anguivi* obtained using ethanol and diethyl ether-chloroform mixture as the extracting solvents was, respectively, 58.75 and 15.9 mg QE/g of dried weight, respectively [28].

**DPPH radical scavenging activity**

Apparently, the antioxidants in the extracts were able to quench DPPH free radical, which absorbs at a higher wavelength than the control, a solution with all reagents but not the extracts of *S. anguivi*, and the absorbance decreased. The highest antioxidant activity was obtained for the ethanol extract, and the n-hexane extract showed the least antioxidant activity (Table 7). The activity of scavenging free radicals is based on the hydrogen or electron-donating ability of phytochemicals extracted by each solvent. The higher antioxidant activity of ethanol and dichloromethane crude extract can be ascribed to the higher concentrations of phytochemicals, presumable flavonoids and phenolics, contained therein relative to those found in the n-hexane crude extract. Flavonoids and phenolic compounds are known to quench free radicals via donation of hydrogen atom electron. The quantitative determination of total phenolic content and total flavonoid content of crude extracts of fruits of *S. anguivi* correlated linearly with the antioxidant activity in the present study. The results in Figure 1 also showed that the isolated compounds have good antioxidant activity, with compound CM-3 exhibiting better antioxidant activity. All isolated compounds exhibited less potent antioxidant activity than the crude extracts of fruits of *S. anguivi* suggesting a possible synergy among the various phytochemicals present in the crude extracts. All crude extracts of fruits of *S. anguivi* and isolated compounds showed less antioxidant activity than the standard (ascorbic acid). Inhibition of DPPH radical increases with increasing concentration of plant extracts and isolated compounds as shown in Table 7 and Figure 1. The present results are in close agreement with a literature report in which the antioxidant activity of ethanol and diethyl ether-chloroform extracts of *S. anguivi* fruits, recorded in terms of radical scavenging activity, ranged from 64.00 to 85.50% and 14.10–40.00%, respectively [28]. Likewise, the antioxidant activity of crude extract obtained from a mixture of fruits of *S. aunnum* and *S. anguivi* using hexane-acetone and ethanol as the extracting solvents varied from 37 to 70% and 65–87%, respectively [5].

**Ferric reducing antioxidant power (FRAP) assay**

The ethanol extracts of *S. anguivi* fruit exhibited the highest reducing power and the n-hexane extract showed the least reducing power (Table 8 and Figure 2). Of the isolated compounds, compound CM-3 showed the highest reducing power and compound CM-1 showed the least reducing power, indicating that all isolated compounds showed less reducing power (lower antioxidant activity) than the crude extracts. All crude extracts and isolated compounds exhibited less reducing power than the standard ascorbic acid used in the present study. The antioxidant property of the crude extracts as well as the isolated compounds in the FRAP assay can be traced to electron-donating capability of the constituent phytochemicals [7]. The higher antioxidant activity of ethanol and dichloromethane extracts correlated linearly with their respective phenolics and flavonoids content.

**Antibacterial activity**

The present study showed that all the fruit extracts of *S. anguivi* possessed significant antibacterial activity, which provides possible rationalization to the traditional use of this plant for the treatment of health problems like ulcer. The fruit extracts of *S. anguivi* had better activity toward gram-positive bacteria compared to gram-negative bacteria. Generally, gram-negative bacteria are more resistant to antimicrobial agents compared with gram-positive bacteria because they have a phospholipid membrane carrying the structural lipopolysaccharide impermeable to antibacterial substances [29]. All crude extracts showed a weaker inhibition zone than that of gentamycin (standard antibiotic) used as a positive control in this study. Phytochemical groups (Table 1) extracted in each solvent are responsible for these antibacterial activities. Alkaloids, flavonoids, phenolics and other secondary metabolites have antibacterial activity. Plants with alkaloids have been determined to exhibit antibacterial properties and are used in medicines for reducing headache and fever [30]. The antibacterial activity of *Solanum* species is well known and probably caused by the alkaloids [31]. The maximum antibacterial activity shown by the dichloromethane crude extract in the present study can be due to the alkaloids (Table 1) detected in this extract. As reported elsewhere [32], the dichloromethane leaf extract of *Solanum lycocarpum* was more active than the ethanol extract against eight tested bacteria (including the bacteria used in the present study). Other *Solanum* species extracts also exhibit antibacterial activity. Ethanol extracts of
Solanum torvum were active against Staphylococcus aureus, Escherichia coli and Klebsiella and had an inhibition zone of 15, 12, and 16 mm, respectively [33]. The methanol, acetone and n-hexane extracts of seven Solanum species (S. nigrum, S. villosum, S. torvum, S. surratense, S. sysimbrifolium, S. diphyllum, and S. inca-num) showed significant antibacterial properties against S. aureus, B. subtilis, P. vulgaris, S. typhi and E. coli, and the inhibition zone ranged from 7 to 16.66 mm [34].

Generally, the present study showed that the antibacterial activities of all isolated compounds decreased as the concentration decreased. This result indicates that the isolated compounds were bacteria static at higher concentrations. The least antibacterial activity was found at lower concentration and the highest antibacterial activity was found at higher concentration in all isolated compounds and all bacteria.

Minimum inhibitory concentration (MIC) of isolated compounds

Compound-2 and compound-3 showed inhibition of bacteria at a lower concentration. As per reports in the literature, the ethanol extract from different parts of Solanum nigrum shows MIC values at 12, 11 and 12 mg/L on Staphylococcus aureus, Escherichia coli and Klebsiella pneumonia, respectively [33, 35] and another study also reported that ethanol extracts of Solanum surattense gave the MIC value of 25–100 mg/L against all the tested bacteria (including all the tested bacteria in the present study) [36], which was comparable with the MIC value of the isolated compounds of dichloromethane crude extract of fruits of S. anguivi.

Conclusions

Qualitative phytochemical screening test of n hexane, dichloromethane and ethanol extracts of fruits of S. anguivi revealed the presence of flavonoids, alkaloids, phenols, glycosides, steroids, terpenoids, saponins and tannins. Three gummy compounds were isolated from the dichloromethane extract that have a single spot as checked by TLC. The ethanol crude extract apparently contained most of the flavonoid and phenolic compounds followed by the dichloromethane extract. Alkaloids were detected only in the latter extract. All the crude extracts and isolated compounds possessed antioxidant activity as evidenced by DPPH and FRAP assays. The highest antioxidant activity was exhibited by the ethanol extract followed by the dichloromethane and n-hexane extracts. Compound-3 exhibited better antioxidant activity followed by compound-2. This may be due to the ability of phytochemicals to donate hydrogen atoms or electrons. Antibacterial effects of fruit extracts of S. anguivi showed different degrees of inhibition zone against both gram-positive and gram-negative bacteria. The dichloromethane extract showed better antibacterial activity relative to the ethanol and n-hexane extracts. Compound-3 and compound-2 showed better antibacterial activity than compound-1. Generally, the crude extracts showed higher antioxidant and antibacterial activities than the isolated compounds of the dichloromethane extract, reflecting the likelihood of synergistic effects among the various phytochemicals in the crude extracts. The results from this study support the use of S. anguivi as a medicinal plant in the form of fruit extracts.

Data availability statement

All data that support the findings reported in this study are available from the corresponding author upon reasonable request.

Disclosure statement

The authors declare that there is no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Bahadur S, Khan MS, Shah M, et al. Traditional usage of medicinal plants among the local communities of Peshawar valley, Pakistan. Acta Ecol Sin. 2020;40(1):1–29.
[2] Orbán-Gyapai O, Liktor-Busa E, Küsz n, et al. Antibacterial screening of Rumex species native to the Carpathian Basin and bioactivity-guided isolation of compounds from Rumex aquaticus. Fitoterapia. 2017;118:101–106.
[3] Salmerón-Manzano E, Garrido-Cardenas JA, Manzano-Agugliaro F. Worldwide research trends on medicinal plants. IJERPH. 2020;17(10):3376.
[4] Badyal S, Singh H, Kumar Yadav A, et al. Plant secondary metabolites and their uses. Plant Arch. 2020;20(2):3336–3340.
[5] Daramola B. Preliminary investigation on antioxidant interactions between bioactive components of Solanum
Elekofehinti OO, Kamdem JP, Meinerz DF, et al. Saponin from the fruit of *Solanum anguivi* protects against oxidative damage mediated by Fe^{2+} and sodium nitroprusside in rat brain synaptosome P2 fraction. Arch Pharm Res. 2015;38(7):1–7.

Elekofehinti OO, Kamdem JP, Bolingon AA, et al. African eggplant (*Solanum anguivi* Lam.) fruit with bioactive polyphenolic compounds exerts in vitro antioxidant properties and inhibits Ca^{2+}-induced mitochondrial swelling. Asian Pacif J Tropic Biomed. 2013;3(10):757–766.

Rajalakshmi A, Jayachitra A. Antioxidant, antibacterial effects of solanine isolated from *Solanum nigrum* and its cytotoxic activity on the HEP-2 and AGS cell lines. Int J Pharm Sci Res. 2017;8:2932–2939.

Pasdaran A, Pasdaran A, Mamedov N. Antibacterial and antioxidant activities of the volatile composition of the flower and fruit of *Solanum sisymbriifolium* (Litchi Tomato). Pharm Sci. 2017;23(1):66–71.

Banu KS, Cathrine L. General techniques involved in phytochemical analysis. Int J Adv Res Chem Sci. 2015;2(4):25–32.

Adeyanjnu O, Olutayo OO, Michael A, et al. Preliminary phytochemical and antimicrobial screening of the leaf extract Pilostigma reticulatum (dc) Hochst. Afr J Pure Appl Chem. 2011;5(3):43–46.

Odabasoglu F, Aslan A, Cakir A, et al. Comparison of antioxidant activity and phenolic content of three lichen species. Phytother Res. 2004;18(11):938–941.

Chantiratikul P, Meechai P, nakbanpotec W. Antioxidant activities and phenolic contents of extracts from *Salvia mohlenbergii* and *Eichhornia crassipes*. Res J Biol Sci. 2009;4(10):1113–1117.

Shirazi OU, Khattak MM, Shukri NA, et al. Determination of total phenolic, flavonoid content and free radical scavenging activities of common herbs and spices. J Pharmacogn Phytochem. 2014;3(3):104–108.

Oyaizu M. Studies on products of browning reaction. Jpn J Nutr Diet. 1986;44(6):307–315.

Nascimento GGF, Locatelli J, Freitas PC, et al. Antibacterial activity of plant extracts and phytochemicals on antibiotic-resistant bacteria. Braz J Microbiol. 2000;31(4):247–256.

Pattewar SV, Patil DN, Dahikar S. Antimicrobial potential of extract from leaves of *Kalanchoe pinnata*. Int J Pharm Sci Res. 2013;4(12):4577.

Ewais EA, Abd El-Maboud MM, Elhaw MH, et al. Phytochemical studies on *Lycium schweinfurthii* var. *schweinfurthii* (*Solanaceae*) and isolation of five flavonoids from leaves. J Med Plant Stud. 2016;4:288–300.

Yang D, Xie H, Jia X, et al. Flavonoid C-glycosides from star fruit and their antioxidant activity. J Funct Foods. 2015;16:204–210.

Ukoha P, Ejikeme P, Maju C. Tannins of the testa of *Anacardium occidentale* (cashew) and husk of *Arachis hypogaea* (groundnut): characterization and potential applications. J Am Leather Chem Assoc. 2010;105(7):242–249.

Pantoja-Castro MA, González-Rodriguez H. Study by infrared spectroscopy and thermogravimetric analysis of tannins and tannic acid. Revist Latinoamericana Quimica. 2011;39(3):107–112.

Tondi G, Petutschnigg A. Middle infrared (ATR FT-MIR) characterization of industrial tannin extracts. Ind Crops Prod. 2015;65:422–428.

Yoo HS, Lee JS, Kim CY, et al. Flavonoids of *Crotalaria sessilisfilora*. Arch Pharm Res. 2004;27(5):544–546.

El-Sayed Z, Hassan W. Polymethoxylated flavonones from *Solanum abutiloides*, grown in Egypt (*Solanaceae*). Zagazig. J. Pharm. Sci. 2006;15:53–59.

Zieliński H, Kozłowska H. Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. J Agric Food Chem. 2000;48(6):2008–2016.

C., M., P, Nakbanpotec W. Antioxidant activities and phenolic contents of extracts from *Salvinia molesta* and *eichorniacrassipes*. J Biol Sci. 2009;4:1113–1117.

Arulpriya P, Lalitha P, Hemalatha S. Antioxidant activities of the extracts of the aerial roots of *Pothos aurea* (Linden ex Andre). Der Pharma Chemica. 2010;2(6):84–89.

Daramola B. Effects of extraction solvent, morphological parts and ripening stage on antioxidative activity of *Solanum anguivi* fruit. Int Food Res J. 2015;22(2):644–650.

Patrone JB, Stein DC. Effect of gonococcal lipooligosaccharide variation on human monocyte cytokine profile. BMC Microbiol. 2007;7(1):7–15.

Patra JK, Mohanta YK. Antimicrobial compounds from mangrove plants: a pharmaceutical prospective. Chin J Integr Med. 2014;20(4):311–320.

Al-Fatimi M, Wurster M, Schröder G, et al. Antioxidant, antimicrobial and cytotoxic activities of selected medicinal plants from Yemen. J Ethnopharmacol. 2007;111(3):657–666.

da Costa GAF, Morais MG, Saldanha AA, et al. Antioxidant, antibacterial, cytotoxic, and anti-inflammatory potential of the leaves of *Solanum lyrocarpum* A. St. Hil. (*Solanaceae*). Evid Based Complement Alternat Med. 2015;2015:315987.

Sivapriya M, Dinesha R, Harsha R, et al. Antimicrobial activity of different extracts of sunnakedai (*Solanum torvum*) fruit coat. Int J Biol Chem. 2011;5(1):1–5.

Singh P, Singh P, Singh A, et al. In vitro evaluation of phytochemical and antibacterial activity of wild species of *Solanum L*. IOSR J Biotechnol Biochem. 2019;5(1):81–87.

Gbadamosi I, Afolayan A. In vitro anti-radical activities of extracts of *Solanum nigrum* (L) from South Africa. J App Bioscience. 2016;98:9240–9251.

Sheeba E. Antibacterial activity of *Solanum surattense*. Burm F. Kathmandu Univ J Sci Eng Technol. 2010;6(1):1–4.