Indian Journal of Natural Products and Resources
Vol. 17(3), September 2026, pp. 502-510
DOI: 10.56042/ijnpr.v17i3.21558

# Formulation and antimicrobial evaluation of a *Solanum torvum*-based herbal foot crack cream for the management of heel fissures

Lavanya Elumalai, Sakthi Priyadarsini Sethuraman* and Raju Kamaraj

Department of Pharmacognosy, SRM College of Pharmacy, Faculty of Medicine and Health Science, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu District, Tamil Nadu 603203, India

*Received 12 July 2025; revised received 08 July 2026; accepted 15 July 2026*

The study aimed to assess the antibacterial and antifungal properties of an herbal foot crack cream formulated from the hydroalcoholic leaf extract of *Solanum torvum*, a plant long used in ethnomedicine. The hydroalcoholic extract was prepared using hydroalcoholic extraction and incorporated into a topical cream base. Phytochemical analysis revealed that the cream contained flavonoids, alkaloids, tannins, and saponins, which are known to confer antimicrobial activity. The effectiveness of the cream was assessed using agar well diffusion against *Staphylococcus aureus* (Gram-positive), *Escherichia coli* (Gram-negative), and *Candida albicans* (fungus), with gentamicin as the standard for antibacterial activity and amphotericin B as the standard for antifungal activity. The results of our study revealed that among the three formulations. Formulation F2 showed the highest antibacterial potential, with clear zones of inhibition of 18.05±1.20 mm and 16.1±0.28 mm against *E. coli* and *S. aureus,* respectively, at 500 µg/mL. Further, the formulation F2 demonstrated significant antifungal activity, with a zone of inhibition of 15.5±0.56mm compared to the standard Amphotericin B (25.65±2.19 mm) against *Candida albicans*. The findings suggest that an herbal formulation based on *S. torvum* could be a promising, natural, and cost-effective candidate for an efficacy study of heel fissures and associated skin infections.

**Keywords:** Antimicrobial activity, Cracked heels, Herbal foot cream, Natural remedy, Skin infections, *Solanum torvum*

**IPC code; Int. cl. (2021.01)**– A61K 9/06, A61K 36/00, A61K 36/81, A61K 127/00, A61P 17/00, A61P 31/00

## Introduction

Cracked heels and fissures are common dermatological conditions associated with xerosis, psoriasis, diabetes, and prolonged exposure to dry environmental conditions. Excessive moisture loss from the skin reduces elasticity, resulting in thickened callused skin that eventually develops painful fissures. These conditions may worsen in diabetic patients due to impaired circulation and peripheral neuropathy, increasing the risk of secondary microbial infections[1-3]. Conventional treatment mainly involves keratolytic and moisturising agents such as salicylic acid and urea creams; however, prolonged use may lead to excessive dryness, irritation, allergic reactions, and poor patient compliance. Therefore, there is growing interest in herbal alternatives possessing moisturising, antimicrobial, and wound-healing properties.

Natural products continue to play a vital role in modern drug discovery, with nearly 25% of currently used drugs originating from higher plants, including taxol, morphine, quinine, caffeine, atropine, and reserpine[4,5]. Advances in phytochemical screening, spectroscopic techniques, and bioassays have further accelerated the exploration of medicinal plants as potential therapeutic agents. Among these, *Solanum torvum* Swartz (Solanaceae), commonly known as turkey berry, is widely distributed in tropical regions and has long been used in traditional medicine as a sedative, diuretic, digestive aid, antitussive, and in the treatment of liver and spleen enlargement[6,7]. The leaves of the plant have also been traditionally applied as poultices for skin lesions associated with diabetes and other skin-related disorders, suggesting its possible usefulness in managing cracked heel-associated skin damage[8-10].

Phytochemical investigations of *S. torvum* have revealed the presence of steroidal glycosides such as torvosides A–M and sitosterol β-D-glucopyranoside, along with flavonoids, alkaloids, saponins, and phenolic compounds[11]. These phytoconstituents are associated with antimicrobial, antioxidant, anti-inflammatory, and wound-healing activities. Previous reports have demonstrated antibacterial and antifungal activities of the plant against clinically important microorganisms[12]. Since cracked heels are often complicated by microbial infections, particularly by

*Correspondent author
Email: sakthips1@srmist.edu.in

*Candida* spp., *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, the antimicrobial potential of *S. torvum* may offer more promising therapeutic benefits.

With the increasing prevalence of antibiotic resistance, there is an urgent need for effective alternative therapeutic approaches, particularly for immuno compromised individuals. *Candida* spp., a major cause of nosocomial fungal infections, has shown concerning resistance toward commonly used antifungal agents[13-15]. Similarly, multidrug-resistant microorganisms such as *Escherichia coli*, *P. aeruginosa*, and *S. aureus* continue to pose serious therapeutic challenges. Based on its traditional usage in skin-related disorders and its reported pharmacological properties, the present study aimed to formulate and assess a herbal foot crack cream containing *S. torvum* extract and to investigate its antibacterial and antifungal potential against microorganisms commonly associated with cracked heel infections.

## Materials and Methods

### Plant material

The leaves of *S.torvum* were collected from the Botanical Herbal Garden at SRM College of Pharmacy and authenticated at the Siddha Central Research Institute (Authentication code: S25012503T, Forma No. PCOG002-ACF). The collected plant material was washed, shade-dried for two weeks, and coarsely powdered. Extraction was carried out by maceration using a hydroalcoholic solvent system (water: ethanol, 7:3) as previously reported[16].

### Fluorescence analysis

Fluorescence analysis of the powdered leaf material was performed using various chemical reagents and solvents, and the resulting fluorescence characteristics were observed under visible and UV light at 254 and 365 nm[17].

### Phytochemical screening of *S. torvum* leaf extract

Preliminary phytochemical screening of the *S. torvum* leaf extract was carried out using standard procedures[18,19]. The presence of flavonoids, carbohydrates, proteins, alkaloids, saponins, and steroids was evaluated using Shinoda, Molisch's, Biuret, Dragendorff's/Mayer's, foaming, spot, and Liebermann–Burchard tests, respectively.

### Formulation and evaluation of *S. torvum* crack cream

#### *Preparation of herbal crack cream base*

A herbal cream base was prepared by separately heating the oil and aqueous phases at 60–65°C, then mixing them with continuous stirring to obtain a homogeneous formulation. Three formulations with varying excipient compositions were prepared and evaluated for physicochemical properties, among which Formula 2 was selected as the optimised base for the preparation of *S. torvum* foot crack cream. *S. torvum* foot crack cream was formulated by incorporating the hydroalcoholic extract into the optimised Base Formula 2 at concentrations of 1, 2, and 3%, followed by the addition of lavender oil as a fragrance.

### Evaluation of herbal crack cream

The formulated creams were evaluated for their colour, odour, appearance, homogeneity, smear type, and greasiness[20]. Skin irritancy studies were performed to assess the irritation[21]. Physicochemical parameters, including pH, viscosity, spreadability, and loss on drying, were determined using standard procedures[22]. Stability studies such as freeze–thaw cycling, phase separation, and centrifugation tests were also performed to confirm the physical stability of the formulations[23].

### Determination of emulsion type

The type of formulated emulsion was studied using a dye solubility test with amaranth dye and microscopic observation[21].

### FT-IR analysis

FT-IR spectroscopy was carried out using a Perkin Elmer/Shimadzu IRTracer-100 spectrophotometer to evaluate the compatibility between *S. torvum* extract and formulation excipients[24].

### *In vitro* antimicrobial studies

The antimicrobial activities of the developed herbal cream formulations were evaluated using the agar well diffusion method against *S. aureus*, *E. coli*, and *C. albicans*. Sterile nutrient agar and potato dextrose agar media were inoculated with the respective microbial strains, and wells were prepared using a sterile borer. The diluted cream formulations were added to the wells and incubated under suitable conditions. Antimicrobial activity was determined by measuring the zones of inhibition produced around the wells[25,26].

### Accelerated stability studies

The formulations were exposed to standard conditions (25°C±2°C/ 60%±5% RH) as well as accelerated conditions (40°C±2°C with 75%±5% relative humidity) to assess the energy input required for their degradation, as per the ICH guidelines for 60 days[27].

Table 1 — Composition of *S. torvum* cream base and formulations

| S No | Composition (Unit) | Role | Cream base formula | | | Herbal foot Crack cream formulations from Base 2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | Base 1 | Base 2 | Base 3 | F1 (1%) | F2 (2%) | F3 (3%) |
| 1 | *S. torvum* leaf extract | Active extract | - | - | - | 0.1 | 0.2 | 0.3 |
| 2 | Stearic acid (g) | Thickener, Stabilizer | 3 | 2 | 2 | 2 | 2 | 2 |
| 3 | Lanolin (g) | Emollient | 2 | 2 | 2 | 2 | 2 | 2 |
| 4 | Almond oil (mL) | Thickener | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | Cetyl alcohol (g) | Emollient | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| 6 | Bees wax (g) | Moisturizer | 0.4 | 0.31 | 0.25 | 0.31 | 0.3 | 0.31 |
| 7 | Sodium benzoate (g) | Preservative (oil phase) | 0.1 | 0.1 | 0.1 | 0.1 | 0. | 0.1 |
| 8 | Methyl paraben (g) | Preservative (aqueous phase) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0. |
| 9 | Propylene glycol (mL) | Humectant and solvent | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 10 | Triethylamine (mL) | pH balancer, emulsifying agent | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0. |
| 11 | Glycerine (mL) | Humectant | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | Lavender oil (mL) | Fragrance | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 13 | Menthol (mL) | Cooling effect | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 14 | Distilled water | Solvent | Q.S. | Q.S. | Q.S. | Q.S. | Q.S. | Q.S. |

Q.S.- Quantity Sufficient

**Statistical analysis**

The results are expressed as the mean±SEM using GraphPad Prism 6.0 (USA) with a significance level of $P < 0.05$.

## Results and Discussion

Scientific investigations have identified more than 30,000 antimicrobial compounds from plants, with over 1,340 plant species reported to possess significant antibacterial properties. However, the increasing emergence of drug-resistant microorganisms has reduced the effectiveness of existing antimicrobial agents, highlighting the urgent need to explore natural products as alternative therapeutic sources[28,29].

In the present study, *S. torvum* extract-based foot crack creams were developed (Table 1) and evaluated for antimicrobial activity (Fig. 1). The percentage yield of the hydroalcoholic extract of *S. torvum* leaves was found to be 27.6% w/w. Fluorescence analysis of the powdered leaf material treated with various chemical reagents revealed characteristic colour changes under daylight and UV light (254 and 365 nm), indicating the presence of specific phytochemical constituents. The green fluorescence observed under short-wave UV light suggested the presence of phenolic compounds and flavonoids (Table 2 and Fig. 2). Further preliminary phytochemical screening of the powdered drug and hydroalcoholic extract confirmed the presence of tannins, alkaloids, amino acids, and carbohydrates.

Fig. 1 — *Solanum torvum* leaves.

**Formulation and evaluation of herbal foot crack cream**

The cream bases as given in Table 1 were evaluated for organoleptic and physicochemical parameters, including homogeneity, pH, consistency, smear type, and greasiness. Among these, the base formula 2 exhibited acceptable physicochemical properties and was selected for the preparation of *S. torvum* herbal foot crack cream formulations F1, F2, and F3 at concentrations, 1, 2, and 3%, respectively (Fig. 3).

All formulations exhibited satisfactory physicochemical characteristics with pH values ranging from 6.0 to 6.3, indicating good compatibility with normal skin pH. The formulations showed smooth texture, good homogeneity, and acceptable spreadability

Table 2 — Fluorescence study of *S. torvum* leaf powder in daylight and ultraviolet light

| Treatment | Visible light | Short UV (254 nm) | Long UV (366 nm) |
|---|---|---|---|
| Powder | Brown | Dark green | Greenish brown |
| Powder + water | Light brown | Light green | Dark brown |
| Powder + 1N HCl | Light brown | Light green | Light brown |
| Powder + 1N $H_2SO_4$ | Brown | Dark green | Light brown |
| Powder + nitric acid | Dark brown | Green | Light brown |
| Powder +acetic acid | Brown | Light greenish brown | Dark brown |
| Powder +alc. NaOH | Yellowish brown | Green fluorescence | Dark brown |
| Powder + alc. KOH | Yellowish brown | Green fluorescence | Brown |
| Powder + ammonia | Brown | Green fluorescence | Brown |
| Powder + iodine | Golden brown | Green fluorescence | Brown |
| Powder + $FeCl_3$ | Light brown | Green fluorescence | Light brown |

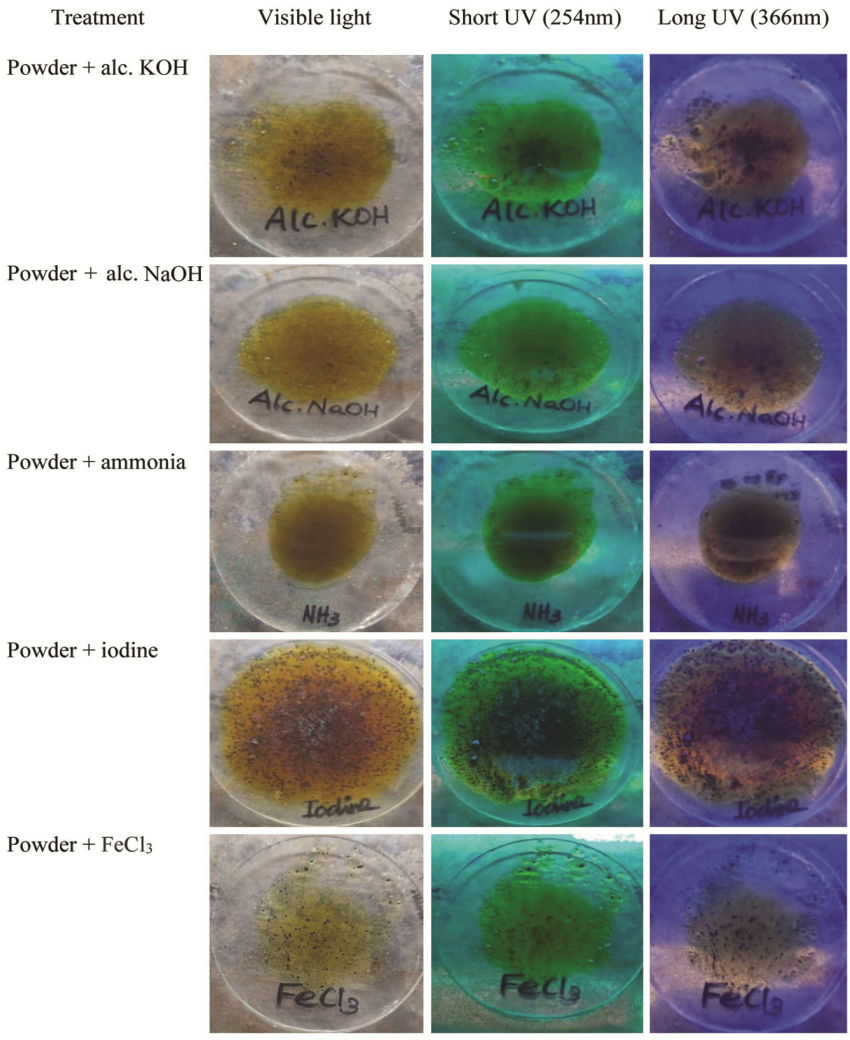


Fig. 2 — Fluorescence analysis of powdered drug of *S. torvum*.

without any noticeable irritation or colour change during storage. Viscosity increased proportionally with extract concentration, thereby improving consistency and application properties. Among the developed formulations, F2 demonstrated optimum spreadability and loss on drying (1.64% w/w), suggesting enhanced moisture-retaining capacity (Table 3). The dye solubility test confirmed that all formulations were water-in-oil

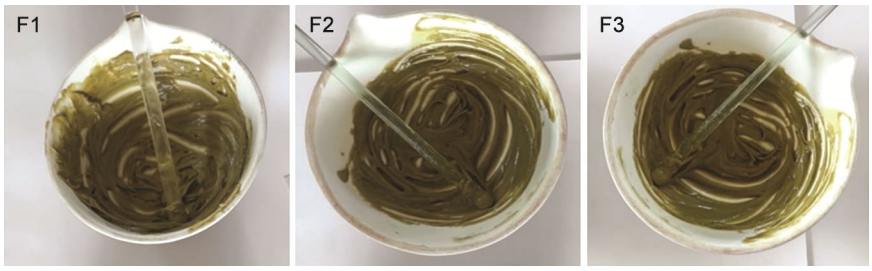


Fig. 3 — Foot crack cream formulation (F1, F2 & F3) from *S. torvum* leaf extract.

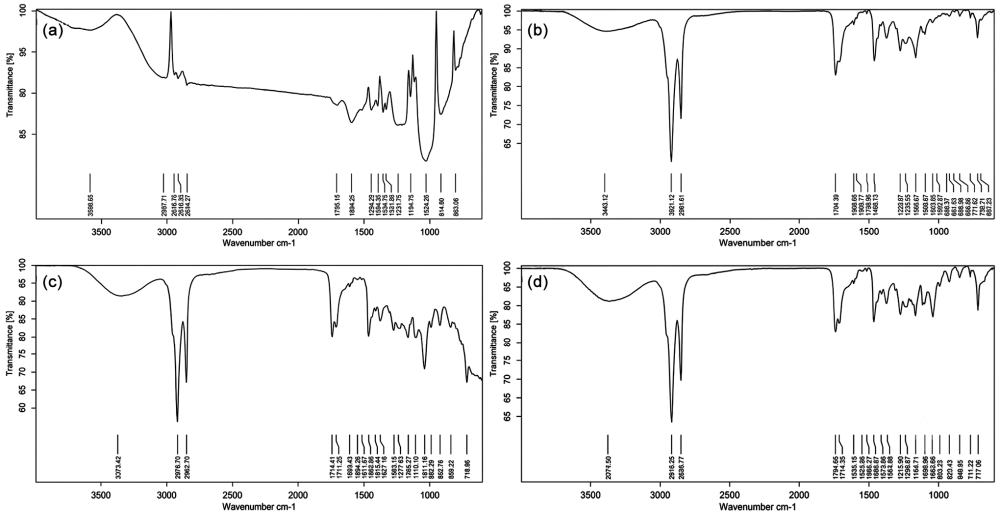


Fig. 4 — Comparative FT-IR spectral analysis of (a) *S. torvum* extract and the developed formulations: (b) F1, (c) F2 (c), and (d) F3.

Table 3 — Evaluation of physical parameters of formulations F1, F2 and F3 of herbal foot crack cream

| S No | Physical parameters | F1 | F2 | F3 |
|---|---|---|---|---|
| 1 | Appearance | Dark green | Dark green | Dark green |
| 2 | Odour | Pleasant | Pleasant | Pleasant |
| 3 | Texture | Smooth | Smooth | Smooth |
| 4 | Consistency | Semisolid | Semisolid | Semisolid |
| 5 | Greasiness | No greasiness | No greasiness | No greasiness |
| 6 | Type of smear | Washable | Washable | Washable |
| 7 | pH (Mean ± SD) | 6.006±0.047 | 6.173±0.015 | 6.300±0.060 |
| 8 | Viscosity (cps) | 120 | 180 | 210 |
| 9 | Spreadability (g·cm/sec) | 25.00 | 28.88 | 31.76 |
| 10 | Loss on Drying (% w/w ± SD) | 2.10±0.08 | 1.64±0.05 | 3.92±0.06 |
| 11 | Freeze-thaw test | No changes | No changes | No changes |
| 12 | Phase separation test | No phase separation | No phase separation | No phase separation |
| 13 | Centrifugation test | No changes | No changes | No changes |

(W/O) emulsions. Furthermore, the absence of phase separation or instability during centrifugation and freeze–thaw studies indicated that the developed formulations possessed good physical stability.

**FT-IR analysis**

The FT-IR spectra of *S. torvum* extract and the formulations (F1, F2, and F3) showed that the main functional groups are consistent, indicating that the presence of bioactive compounds have successfully been retained in all the three formulations as displayed in Fig. 4. Our findings revealed the presence of similar functional groups, indicating compatibility of the excipients in the cream base to the *S. torvum* extract as given in Table 4.

**Antibacterial and antifungal effects of *S. torvum* crack cream formulations**

The antibacterial activity of *S. torvum* hydroalcoholic extract-based foot crack cream formulations (F1–F3) was evaluated against *E. coli* and *S. aureus*. All formulations exhibited concentration-dependent antibacterial activity, with maximum inhibition observed at 500 µg/mL. Against *E. coli*, formulation F2 showed the highest activity with an inhibition zone of 18.05±1.20 mm, followed by F1 (16.95±0.35 mm) and F3 (13.5±0.56 mm), as shown in Fig. 5. Similarly, against *S. aureus*, F2 and F3 demonstrated higher antibacterial activity with inhibition zones of 16.1±0.28 mm at 500 µg/mL (Table 5).

The antifungal activity of *S. torvum* hydroalcoholic extract-based foot crack cream formulations (F1–F3) was evaluated against *Candida albicans* at concentrations ranging from 50–500 µg/mL (Table 6 and Fig. 6). All formulations exhibited concentration-

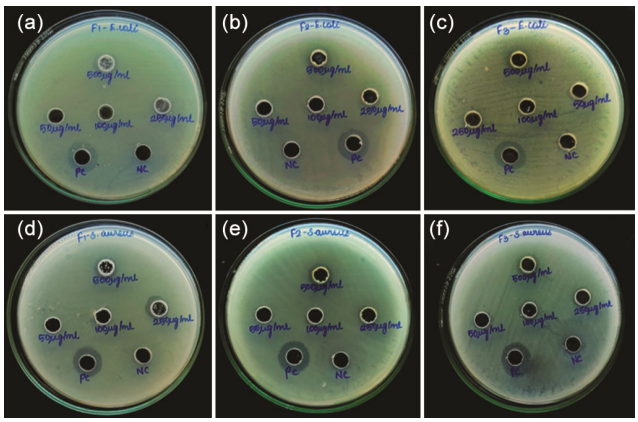


Fig. 5 — Antibacterial activity of *Solanum torvum* herbal foot crack cream formulations F1, F2, and F3 against (a–c) *Escherichia coli*, and (d–f) *Staphylococcus aureus*, respectively.

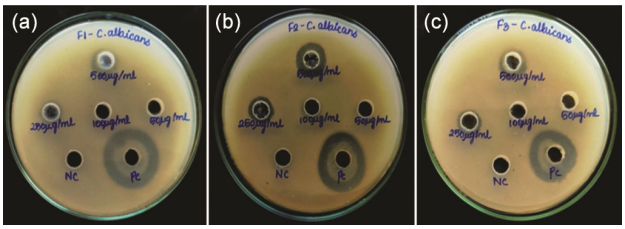


Fig. 6 — Antifungal activity of *Solanum torvum* herbal foot crack cream formulations (a) F1, (b) F2, and (c) F3 against *Candida albicans*.

Table 4 — FT-IR interpretation of the *S.torvum* extract and its formulations

| FT-IR Interpretation | Wavenumber ($cm^{-1}$) | Functional Group | Possible Bond/Compound |
|---|---|---|---|
| Plant extract | 3027.71, 2946.72, 1594.25, 1237.75, 1144.78, 1026.56, 914.64 | =C-H Stretching, C-H Stretching, C=C Stretching, C-O Stretching, =C-H Bending | Alkenes, Alkanes, Aromatic Compounds, Esters, Ethers, Carboxylic Acids, Alcohols, Primary and Secondary Alcohols |
| Formulation F1 | 2921.12, 2851.61, 1741.38, 1609.84, 1464.13, 1275.37, 1236.95, 1164.67, 771.82, 720.21 | C-H Stretch, C-H Bending, C=O Stretch, C=C Stretch, C-O Stretch, C-H Out-of-plane Bending, C-H Rocking | Alkanes, Carbonyl (Aldehydes, Ketones, Esters, Carboxylic Acids), Aromatic Compounds, Ethers |
| Formulation F2 | 2918.79, 2850.70, 1741.41, 1711.28, 1609.43,1549.28, 1515.07, 1464.00, 1311.16, 1275.22, 1237.63, 1110.63, 1041.19, 902.43, 848.38, 717.46 | C-H Stretch, C-H Bending, C=O Stretch, C=C Stretch, C-O Stretch, C-H Out-of-plane Bending, C-H Rocking | Alkanes, Carbonyl (Aldehydes, Ketones, Esters, Carboxylic Acids), Aromatic Compounds, Ethers |
| Formulation F3 | 3374.50, 2918.35, 2850.77, 1741.05, 1714.10, 1699.78, 1551.59, 1516.21, 1466.97, 1413.46, 1367.90, 1274.93, 1164.71, 1042.66, 923.43, 849.98, 717.46 | C-H Stretch, C-H Bending, C=O Stretch, C=C Stretch, C-O Stretch, C-H Out-of-plane Bending, C-H Rocking | Alkanes, Carbonyl (Aldehydes, Ketones, Esters, Carboxylic Acids), Aromatic Compounds, Ethers |

Table 5 — Antibacterial activity of herbal crack cream formulations containing hydroalcoholic extract of *S. torvum*

| S No | Formulation | Test organisms | Zone of inhibition (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 500 µg/mL | 250 µg/mL | 100 µg/mL | 50 µg/mL | Gentamycin |
| 1 | F1 | *E. coli* | 16.95±0.35 | - | - | - | 21.4±0.98 |
| | | *S. aureus* | 14.6±0.70 | 14.1±1.69 | - | - | 19±0.98 |
| 2 | F2 | *E. coli* | 18.05±1.20 | 13.15±0.35 | 11.3±0.84 | - | 22.3±0.56 |
| | | *S. aureus* | 16.1±0.28 | 11.6±0.70 | - | - | 22.2±0.42 |
| 3 | F3 | *E. coli* | 17.32±2.86 | 13.13±0.19 | - | - | 18±0.14 |
| | | *S. aureus* | 16.1±0.28 | 14±0.14 | 11.6±0.70 | - | 21.05±0.21 |

*Values represented as Mean* ± SD of triplicates.

Table 6 — Antifungal activity of herbal crack cream formulations containing hydroalcoholic extract of *S. torvum*

| S No | Formulation | Test organism | Zone of inhibition (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 500 µg/mL | 250 µg/mL | 100 µg/mL | 50 µg/mL | Amphotericin B Standard |
| 1 | F1 | *Candida albicans* | 14.85±0.35 | 12.2±0.42 | - | - | 28.5±0.56 |
| 2 | F2 | | 15.5±0.56 | 12.5±0.56 | 10.6±0.70 | - | 25.65±2.19 |
| 3 | F3 | | 13.9±0.28 | 12.9±1.13 | - | - | 24.75±0.35 |

*Values represented as Mean* ± SD of triplicates

Table 7 — Physical parameters of *S. tarvum* foot crack cream formulations at standard and accelerated conditions

| Day | Formulation | Conditions | pH | Homogeneity | Appearance | Spreadability | After feel | Type of smear G/NG | Removal |
|---|---|---|---|---|---|---|---|---|---|
| 0th | F1 | Standard | 5.9 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 5.9 | Good | NCC | Good | Emollient | NG | Easy |
| | F2 | Standard | 6.0 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.0 | Good | NCC | Good | Emollient | NG | Easy |
| | F3 | Standard | 6.0 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.1 | Good | NCC | Good | Emollient | NG | Easy |
| 15th | F1 | Standard | 6.2 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.3 | Satisfactory | NCC | Good | Emollient | NG | Easy |
| | F2 | Standard | 6.2 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.3 | Good | NCC | Good | Emollient | NG | Easy |
| | F3 | Standard | 6.3 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.3 | Good | NCC | Good | Emollient | NG | Easy |
| 30th | F1 | Standard | 6.3 | Satisfactory | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.3 | Satisfactory | NCC | Good | Emollient | NG | Easy |
| | F2 | Standard | 6.3 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.4 | Good | NCC | Good | Emollient | NG | Easy |
| | F3 | Standard | 6.3 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.4 | Good | NCC | Good | Emollient | NG | Easy |
| 60th | F1 | Standard | 6.4 | Satisfactory | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.5 | Satisfactory | NCC | Good | Emollient | NG | Easy |
| | F2 | Standard | 6.4 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.5 | Good | NCC | Good | Emollient | NG | Easy |
| | F3 | Standard | 6.6 | Good | NCC | Good | Emollient | NG | Easy |
| | | Accelerated | 6.6 | Good | NCC | Good | Emollient | NG | Easy |

Standard conditions (25°C **± 2°C / 60% ± 5% RH); A**ccelerated conditions (**40°C ± 2°C/ 75% ± 5% relative humidity)**; NCC-No colour change; G/NG-Greasy/Non-greasy

dependent antifungal potential, with the highest inhibition at 500 µg/mL. Among the tested formulations, F2 showed the greatest antifungal effect with a zone of inhibition of 15.5±0.56 mm, followed by F1 (14.85±0.35 mm) and F3 (13.9±0.28 mm).

Several medicinal plants have been reported to possess significant antibacterial and antifungal activities[30–39]. Previous studies have also reported the antimicrobial potential of herbal extracts against various pathogenic microorganisms, supporting their application as natural therapeutic agents. In agreement with these findings, the present study demonstrated that *S. torvum* hydroalcoholic leaf extract-based herbal foot crack cream exhibited notable antibacterial and antifungal activity against the tested pathogens. Overall, the results suggest that *S. torvum* could be a promising natural alternative for treating cracked heels and their associated microbial infections, warranting further investigation for the development of novel antimicrobial formulations.

**Accelerated stability testing**

Accelerated stability studies were performed in a stability chamber maintained at 40±2°C and 75±5% relative humidity in accordance with ICH guidelines. All formulations remained stable without phase

separation or colour change, and maintained acceptable pH values (5.9–6.6). The creams retained good homogeneity, spreadability, washability, and non-greasy emollient properties throughout the study period, although F1 showed a slight reduction in homogeneity after 30 days. Among the formulations, F2 exhibited the best overall physical stability, suggesting its suitability for long-term topical applications. The observed results showed no significant variation in the evaluated parameters, indicating the stability of the developed formulations under accelerated storage conditions (Table 7).

## Conclusion

The present study successfully developed and evaluated *S. torvum* hydroalcoholic extract-based herbal foot crack cream formulations with satisfactory physicochemical properties, good stability, and significant antimicrobial activity. Among the developed formulations, F2 exhibited optimum characteristics, including suitable pH, viscosity, spreadability, moisture retention, and enhanced antibacterial and antifungal activity against *E. coli*, *S. aureus*, and *C. albicans.* The findings support the traditional medicinal potential of *S. torvum* and suggest that the developed herbal formulation could serve as a promising natural alternative for managing cracked heels and associated microbial infections. Further preclinical and clinical studies are required to validate its therapeutic efficacy and safety for long-term topical use.

## Conflict of interest

The authors declare no conflict of interest.

## AI use disclosure

We declare no AI-generated content has been included in the manuscript.

## References


1 Antinori S, Milazzo L, Sollima S, Galli M and Corbellino M, Candidemia and invasive candidiasis in adults: A narrative review, *Eur J Intern Med*, 2016, **34**, 21-28.

2 Kullberg B J and Arendrup M C, Invasive candidiasis, *N Engl J Med*, 2015, **373**(15), 1445-1456,doi: 10.1056/ NEJMra1315399.

3 Aimon N, Pongchairerk U and Suebkhampet A, Phytochemical analysis and antibacterial activity of ethanolic leaf extract of *Solanum torvum* Sw. against pathogenic bacteria, *Kasetsart J Nat Sci*, 2015, **49**, 516-523.

4 Newman D J and Cragg G M, Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019, *J Nat Prod*, 2020, **83**(3), 770-803, doi: 10.1021/acs.jnatprod.9b01285.

5 Harvey A L, Edrada-Ebel R and Quinn R J, The re-emergence of natural products for drug discovery in the genomics era, *Nat Rev Drug Discov*, 2015, **14**(2), 111-129.

6 Useful Plants of India, Publications and Information Directorate, CSIR, New Delhi, 1986, 582.

7 Chatterjee A and Pakrashi S C, *The Treatise on Indian Medicinal Plants*, Vol. 4, Publications and Information Directorate, New Delhi, 1995, 204.

8 Karmakar K, Islam M A, Chhanda S A, Tuhin T I, Muslim T, *et al.*, Secondary metabolites from the fruits of *Solanum torvum* Sw., *J Pharmacogn Phytochem*, 2015, **4**(1), 123-126.

9 Nguta J M, Opong R A, Nyarko A K, Manu D Y and Addo P G, Medicinal plants used to treat TB in Ghana, *Int J Mycobacteriol*, 2015, **4**(2), 116–123, doi: 10.1016/ j.ijmyco.2015.02.003.

10 Komlaga G, Agyare C, Dickson R A, Mensah M L K, Annan K, *et al.*, Medicinal plants and marketed herbal products used in the treatment of malaria in the Ashanti region, Ghana, *J Ethnopharmacol*, 2015, **172**, 333–346, doi: 10.1016/ j.jep.2015.06.041.

11 Cuong L C V, Lien L T, Phuong N T M, Thu V T K, Ha T P, *et al.*, Cytotoxic activity of steroidal glycosides from aerial parts of *Solanum torvum*, *Nat Prod Res*, 2020, doi: 10.1080/14786419.2020.1788022.

12 Yousaf Z, Wang Y and Baydoun E, Phytochemistry and pharmacological studies on *Solanum torvum* Swartz, *J Appl Pharm Sci*, 2013, **3**(4), 152–160, doi: 10.7324/ JAPS.2013.3428.

13 World Health Organization, Antimicrobial resistance, WHO, Geneva, 2023.

14 Pappas P G, Lionakis M S, Arendrup M C, Ostrosky-Zeichner L and Kullberg B J, Invasive candidiasis, *J Fungi*, 2018, **4**(3), 125, doi: 10.3390/jof4030125.

15 Murray C J L, Ikuta K S, Sharara F, Swetschinski L, Aguilar G R, *et al.*, Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis, *Lancet*, 2022, **399**(10325), 629–655, doi: 10.1016/S0140-6736(21)02724-0.

16 Mishra B, Kar D M, Maharana L and Mishra G P, Physicochemical and phytochemical investigation of different fractions from hydroalcoholic extract of *Solanum torvum* (Swartz) fruits, *Int J Pharm Pharm Sci*, 2016, **8**, 408–413.

17 Kokoski C J, Kokoski R J and Slama F J, Fluorescence of powdered vegetable drugs under ultraviolet radiation, *J Am Pharm Assoc*, 1958, **47**(10), 715–717, doi: 10.1002/ jps.3030471010.

18 María R, Shirley M, Xavier C, Jaime S, David V, *et al.*, Preliminary phytochemical screening, total phenolic content and antibacterial activity of thirteen native species from Guayas Province, Ecuador, *J King Saud Univ Sci*, 2018, **30**, 500-506, doi: 10.1016/j.jksus.2017.03.009.

19 Harborne J B, *Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis*, (London: Chapman and Hall), 1973.

20 Aulton M E and Taylor K M G, Aulton's Pharmaceutics: The Design and Manufacture of Medicines, 5th Edn, (Elsevier, London), 2018, 503-515.

21 Alam S, Algahtani M S, Ahmad M Z and Ahmad J, Investigation utilizing the HLB concept for the development of moisturizing cream and lotion: *In-vitro* characterization and stability evaluation, *Cosmetics*, 2020, **7**(2), 43, doi: 10.3390/cosmetics7020043.

22 Annysaellycornia S, Rahayu E, Warti L and Asih D, Formulation and stability tests of cream from *Averrhoa bilimbi* juice, *J Res Pharm Pharm Sci*, 2022, **1**(2), 61–63, doi: 10.33533/jrpps.v1i2.6309.

23 Marissa Z, Mita S R, Kusumawulan C K and Sriwidodo S, Antioxidant and photoprotective activity of bromelain cream: viscosity and spreadability tests, *Cosmetics*, 2024, **12**(2), 41, doi: 10.3390/cosmetics12020041.

24 Reddy M S, Tanzeem S K and Haq S M F U, Formulation and evaluation of celecoxib emulgel, *Int J Pharm Biol Sci*, 2020, **10**(1), 82-89, doi: 10.21276/ ijpbs.2020.10.1.12.

25 Sharma S, Sharma A and Mehta A, Phytochemical screening and FTIR analysis of methanolic extract of *Solanum xanthocarpum*, *Indian J Nat Prod Resour*, 2021, **12**(1), 89–95.

26 Balouiri M, Sadiki M and Ibnsouda S K, Methods for *in vitro* evaluating antimicrobial activity: A review, *J Pharm Anal*, 2016, **6**(2), 71–79, doi: 10.1016/j.jpha.2015.11.005.

27 Clinical and Laboratory Standards Institute (CLSI), *Performance Standards for Antimicrobial Susceptibility Testing*, 34th edn, CLSI Supplement M100, Wayne, PA, USA, 2024.

28 Payghan S A, Kate V K, Purohit S and Bhandari A, Effect of aging on emulsion stability, *Invent Rapid Pharm Tech*, 2013, **505**, 1–7.

29 Franco C M and Vázquez B I, Natural compounds as antimicrobial agents, *Antibiotics*, 2020, **9**(5), 217, doi: 10.3390/antibiotics9050217.

30 Sevindik M, Antioxidant and antimicrobial capacity of *Lactifluusrugatus*, *Indian J Tradit Knowl*, 2020, **19**(2), 423–427, doi: 10.56042/ijtk.v19i2.35356.

31 Sakkas H and Papadopoulou C, Antimicrobial activity of basil, oregano, and thyme essential oils, *J Microbiol Biotechnol*, 2017, **27**(3), 429–438, doi: 10.4014/ jmb.1608.08024.

32 Paudel P N, Satyal P, Satyal R, Setzer W N, Gyawali R, Composition and antimicrobial activity of *Origanum majorana* essential oil, *Molecules*, 2022, **27**(18), 6136, doi: 10.3390/molecules27186136.

33 Okla M K, Alatar A A, Al-Amri S S, Soufan W H, Ahmad A, *et al.*, Antibacterial and antifungal activity of *Avicennia marina* extracts, *Plants (Basel)*, 2021, **10**(2), 252, doi: 10.3390/plants10020252.

34 Mwangi W C, Waudo W, Shigwenya M E and Gichuki J, Antimicrobial and antioxidant activities of *Terminalia catappa*, *BMC Complement Med Ther*, 2024, **24**(1), 137, doi: 10.1186/s12906-024-04449-7.

35 Harley B K, Quagraine A M, Neglo D, Aggrey M O, Orman E, *et al.*, Antifungal and antibiofilm activity of *Erythrina senegalensis* against *Candida albicans*, *PLoS One*, 2022, **17**(11), e0278096, doi: 10.1371/journal.pone.0278096.

36 El-Zahar K M, Al-Jamaan M E, Al-Mutairi F R, Al-Hudiab A M, Al-Einzi M S, *et al.*, Antioxidant, antibacterial and antifungal activities of *Berberis vulgaris* extract, *Molecules*, 2022, **27**(18), 6114, doi: 10.3390/molecules27186114.

37 Suurbaar J, Mosobil R and Donkor A M, Antibacterial and antifungal activity of *Ricinus communis* leaf extract, *BMC Res Notes*, 2017, **10**(1), 660, doi: 10.1186/s13104-017-3001-2.

38 Olawuwo O S, Famuyide I M and McGaw L J, Antibacterial activity of medicinal plants against poultry pathogens, *Front Vet Sci*, 2022, **9**, 820304, doi: 10.3389/fvets.2022.820304.

39 Soliman S S M, Semreen M H, El-Keblawy A A, Abdullah A, Uppuluri P, *et al.*, Assessment of herbal drugs for anti-*Candida* activity, *BMC Complement Altern Med*, 2017, **17**(1), 257, doi: 10.1186/s12906-017-1760-x