GC–MS profiling and antibacterial activity of Solanum khasianum leaf and root extracts

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Abstract

Background: Solanum khasianum is an important medicinal herb of the Solanaceae family. The present study was focused to determine the bioactive compounds in S. khasianum leaf and root extract by GC–MS analysis and their antibacterial activity by agar well diffusion method.

Results: Sixteen bioactive compounds were detected in leaf extract and thirty-two compounds in root methanolic extract by GC–MS. The major potent compounds identified in leaf and root extracts were heptadecane 9-hexyl (43.65%) and stigmasterol (23.18%). The root extract showed increased antibacterial activity than leaf extract.

Conclusion: These extracts possessed significant antibacterial activity against the tested bacterial isolates in dose-dependent manner. This study provides the phytoconstituents, antibacterial property and scientific evidence for the traditional claim and use of S. khasianum.

Keywords: Solanum khasianum, GC–MS analysis, Antibacterial activity, Phytochemicals, Biological activity

Background

Nature is the richest source of several natural therapeutic compounds. Solanaceae, one of the largest plant families with huge and varied secondary metabolites, used in the management of several ailments. The medicinal value of plants can be correlated to different phytochemicals, as they offer a wide diversity of pharmacological activities. Due to these pharmacological properties, a great attention has been derived toward the medicinal plants.

Solanum khasianum is a traditional medicinal plant belonging to Solanaceae family. The plant was known to possess potential alkaloids (solasodine, solasonine, solanine, solamargine and khasianine) that represent an alternative source of medicine (Kaunda and Zhang 2019; Chirumamilla et al. 2021). The berries of S. khasianum was reported to possess anticancer (Rosangkima and Jagetia 2015), antibacterial (Pavani and Shasthree 2021), anti-inflammatory (Chirumamilla et al. 2022), antioxidant, anti-diabetic and anti-cholinesterase properties (Gogoi et al. 2021). Besides these, the plant is used traditionally to treat several other diseases like filaria, smallpox, whooping cough, rheumatism, trachoma, bronchitis, snake bites, skin and tooth infections (Chirumamilla et al. 2021).

To the best of our knowledge there is no information on the chromatographic analysis of S. khasianum leaf and root extracts. Hence, the current study was focused to determine several bioactive compounds in S. khasianum leaf and root extracts by GC–MS analysis. The antibacterial property against gram positive and gram negative bacteria isolates was also revealed by agar well diffusion method.

Methods

Collection and preparation of plant material

Fresh leaves and roots of S. khasianum were collected during the months of April–May from the department greenhouse (18.0264138, 79.5589066). The plant material was washed thoroughly under running tap water, drained and shade dried at room temperature. These samples were ground to fine powder using homogenizer.
The powdered plant material was mixed with methanol (1:10 w/v) and incubated at 22 °C in an orbital shaker at 120 rpm for 48 h. The samples were filtered using Whatman no.1 filter paper, evaporated and the crude methanolic extracts were subjected to GC–MS profiling and antibacterial activity.

**Gas chromatography and mass spectroscopy (GC–MS) analysis**

Gas chromatography and mass spectrometry were performed to analyze the qualitative and quantitative identification of organic compounds in the given sample. The potential biological compounds of *S. khasianum* leaf and root extracts were analyzed using GC–MS (Agilent: 7890-Jeol: AccuTOF GCV) system coupled with Elite 1 column. Helium gas was used as a carrier gas at 1 ml/min rate of flow, with an injector volume of 2 µl and 280 °C temperature. The oven temperature was raised from 40 to 280 °C with an isothermal for 5 min. The bioactive compounds were identified based on retention time, MS fragment ions generated and the percentage of these bioactive compounds was evaluated from the total peak area. The phytochemicals have been identified by comparing their MS spectrum patterns to the standard mass spectra available at the National Institute of Standards and Technology (NIST) Mass Spectra Database.

**Antibacterial activity**

The leaf and root methanolic extract of *S. khasianum* were tested for their antibacterial activity by agar well diffusion method. Luria Bertani (LB) medium was prepared, poured at 20 ml/petri dish and allowed to solidify. 24-h-old bacterial cultures (*Bacillus sphaericus*, *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*) were spread uniformly onto solidified medium. Different concentrations (20, 40, 60 and 80 µg/ml) of *S. khasianum* leaf and root extracts reconstituted in DMSO (dimethyl sulfoxide 10%) and streptomycin standard (10 µg/ml) were loaded into wells and incubated at 37 °C for 24 h. The antibacterial efficacy of *S. khasianum* extracts were observed by measuring the diameter of inhibition zones emerging around the wells. The results of triplicate mean were taken and data was presented as mean ± SD of the respective triplicate.

**Results**

GC–MS profiling detected potential phytochemicals in *S. khasianum* leaf and root methanolic extracts by their molecular formula and retention time. Sixteen phytoconstituents were detected from leaf extract and thirty-two compounds from root extract by GC–MS (Tables 1 and 2). The compounds identified with high concentration in leaf extract include Heptadecane 9-hexyl (43.65%) and Myoinositol hexaacetate (15.05%), whereas the highest compounds identified in root extract include Stigmasterol (23.18%) and cis-Vaccenic acid (9.07%) and presented in Figs. 1 and 2. The diversification of these phytoconstituents was recorded using sunburst graph (Figs. 3 and 4).

Table 3 shows the antibacterial activity of *S. khasianum* leaf and root extracts. The root methanol extract showed the highest inhibition zone at 80 µg/ml of 16 ± 0.15 mm for *B. sphaericus*, 21 ± 0.18 mm for *Escherichia coli*, 17 ± 0.02 mm for *Staphylococcus aureus* and 19 ± 0.18 mm for *Pseudomonas aeruginosa*. Leaf extract at 80 µg/ml concentration showed 15 ± 0.14 mm for *B. sphaericus*, 16 ± 0.16 mm for *Escherichia coli*, 15 ± 0.01 mm for *Staphylococcus aureus* and 17 ± 0.11 mm for *Pseudomonas aeruginosa*.

**Discussion**

Accurate certification and studies of phytoconstituents are increasing periodically, as they are repositories of several potent drugs. Gas chromatography and mass spectroscopy (GC–MS) has been validated to be a significant tool for bioprospecting of plant bioactive compounds. However, diethyl phthalate and *n*-hexadecanoic acid were identified to be common in leaf and root extract of *S. khasianum*. Other organic compounds in leaf extract that are accountable for their wide use in medicinal aid include: Dodecanal, reported to possess highest antibacterial activity (Faridha Begum et al. 2016). Benzene propanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-octadecyl ester shows strong antifungal and antioxidant activities in *Azadirachta* and *Thesium humile* (Akpuaka et al. 2013; Belakhdar et al. 2015).

The remaining bioactive compounds analyzed were as follows: Diethyl phthalate, a phytoconstituent well known for its antimicrobial, antioxidant, plasticizer and estrogenic activities in *Ceropogia bulbosa* Roxb (Arora and Meena 2017). E-9-Tetradecenoic acid is reported to have analgesic, anti-inflammatory and antioxidant properties in *Cassia angustifolia* (Al-Marzoqi et al. 2016). The bioactive compound, Myristoleic acid reported in Sesame Seeds was known to prevent cancer (Bhatnagar and Gopala Krishna 2009).

The bioactive molecule *n*-Hexadecanoic acid has reported to have multiple biological properties in *Vitex negundo* (Kumar et al. 2019; Enerijiofi et al. 2021). The phytol, a bioactive compound reported earlier in several species like *Hydrilla verticillate*, *Gracilaria edulis* and *Carissa carandas* with diversified medicinal uses (Prabha et al. 2019; Rao et al. 2019). The compound 9,12,15-Octadecatrienoic acid was known to possess several biological properties like analgesic, anesthetic, anticonvulsant, anti-inflammatory, antioxidant, anti-pyretic, antibacterial
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(Kalaivani et al. 2012); anticancer, antihistaminic, hepatoprotective, hypcholesterolemic, nematicide (Rao et al. 2019) in Andrographis paniculata and Carissa carandas and also known to reduce complications in Covid-19 patients (Weill et al. 2020). α-d-Glucopyranoside, O-α-d-glucopyranosyl-β-D-fructofuranosyl, a phytochemical compound also found in Cyperus alternifolius have cardioprotective, neuroprotective, antidiabetic, antiosteoporotic, anti-inflammatory, antistress properties (Al-Gara et al. 2019).

The 1,2-Propanediol, 3-(tetradecyloxy), a phytoconstituent reported to have antifungal activity (Sundberg and Faergemann, 2008), whereas the compound tert-Hexadecanethiol was known for its anti-tumor activity in Malaxis acuminta (Raval et al. 2016); antioxidant, antifungal and insecticidal activities in Capsicum annuum (Sathya et al. 2016). Another bioactive molecule Heptadecane, 9-hexyl (Fig. 2), the major bioactive compound of S. khasianum leaf extract, known to possess strong antifungal activity in Senecio colhuapiensis (Arancibia et al. 2016). The compound Myoinositol, hexaacetate acts as a precursor of several metabolic pathways, co-factors of enzymes, messenger molecule in signal transduction, reduce liver and myocardial lipid content, alternative of metformin

The chemical profiling of root methanolic extracts of S. khasianum identified different bioactive compounds. Among them, more predominant compound identified was stigmasterol, known to possess anti-inflammatory, antioxidant, antimicrobial and sedative activities (Al-Rubay et al. 2017). The initial compound eluted was 2-Pyrrolidinone, 1-methyl with anticancer, antioxidant,

| Table 1 | Phytochemical constituents identified in leaf methanolic extracts of Solanum khasianum by GC–MS analysis and mass spectra of NIST database |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------|
| RT             | Name of compound                                                                                                                  | Kovats relative index | Molecular formula | Mwt   | Area (%) | Recorded pharmacological activity                                                                 |
| 13.63          | Dodecanal                                                                         | 1387                  | C₁₂H₂₄O           | 184   | 0.85     | Antibacterial, in pharmaceuticals                                                                  |
| 17.47          | Diethyl phthalate                                                                                                                 | 1603                  | C₁₂H₁₄O₄          | 222   | 0.87     | Antimicrobial, antioxidant, plasticizer, estrogenic                                                 |
| 20.71          | E-9-Tetracenoic acid                                                              | 2537                  | C₁₈H₂₆O₂          | 226   | 1.45     | Analgesic, anti-inflammatory, antioxidant                                                          |
| 21.45          | Z-8-Methyl-9-Tetracenoic acid                                                    | 1676                  | C₁₃H₁₆O₂          | 240   | 2.97     | No activity reported                                                                               |
| 21.4           | Myristoleic acid                                                                  | 1783                  | C₁₄H₂₆O₂          | 226   | 2.97     | Cancer preventive                                                                                 |
| 24.03          | n-Hexadecanoic acid                                                               | 1972                  | C₁₆H₃₂O₂          | 256   | 3.36     | Anti-inflammatory, antioxidant, anti-androgenic, hypcholesterolemic, hemolytic nematicide, pesticide, S-α reductase inhibitor, potent mosquito larvicide, treat rheumatic symptoms |
| 26.20          | Phytol                                                                             | 2105                  | C₂₀H₄₀O           | 296   | 2.43     | Antinociceptive, antioxidant, anti-inflammatory, antiallergic, hypolipidemic, anticancer, antimicrobial, cytotoxic, anti-teratogenic, antidiabetic, antispasmodic, anticonvulsant, disinfectant, antidiuretic |
| 26.70          | 9,12,15-Octadecatrienoic acid                                                     | 2125                  | C₁₅H₃₀O₂          | 278   | 2.96     | Analgesic, anesthetic, anticonvulsant, anti-inflammatory, antioxidant, anti-pyretic, antibiotic, cancer preventive, hypcholesterolemic, hepatoprotective, nematicide, antihistaminic and reduce complications in Covid-19 patients |
| 28.68          | α-D-Glucopyranoside, O-α-D-glucopyranosyl-β-D-fructofuranosyl                    | 1926                  | C₁₈H₃₂O₁₆         | 504   | 3.56     | Cardioprotective, neuroprotective, antidiabetic, anti-osteoporotic, anti-inflammatory, antistress |
| 29.89          | 1,2-Propanediol, 3-(tetradecyloxy)                                               | 1603                  | C₁₇H₃₈O₃          | 288   | 1.60     | Antifungal activity                                                                               |
| 30.34          | tert-Hexadecanethiol                                                               | 1522                  | C₁₆H₃₄S           | 258   | 2.76     | Antitumor, antioxidant, antifungal, insecticidal                                                  |
| 30.70          | Ethanol, 2-(tetradecyloxy)                                                        | 1930                  | C₁₆H₃₄O₂          | 258   | 11.3     | No activity reported                                                                               |
| 31.56          | Heptadecane, 9-hexyl                                                              | 2243                  | C₁₇H₃₆            | 324   | 43.65    | Antifungal agent                                                                                  |
| 32.40          | Myoinositol, Hexaacetate                                                          | 2084                  | C₁₈H₄₂O₁₂         | 432   | 15.05    | Precursor of several metabolic pathways, co-factors of enzymes, messenger molecule in signal transduction, reduce liver and myocardial lipid content, alternative of metformin |
| 32.77          | Valeric acid, 4-pentadecyl ester                                                  | 2112                  | C₂₀H₄₀O₂          | 312   | 5.77     | No activity reported                                                                               |
| 34.80          | Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-octadecyl ester       | 1943                  | C₁₈H₃₂O₁₁         | 530   | 1.37     | Antifungal and antioxidant                                                                       |
| RT  | Compound                                                                 | Kovats relative index | Molecular formula | Mwt | Area | Biological activity                                                                 |
|-----|--------------------------------------------------------------------------|-----------------------|-------------------|-----|------|-------------------------------------------------------------------------------------|
| 4.84| 2-Pyrrolidinone, 1-methyl                                              | 1646                  | C₅H₉NO            | 99  | 0.87 | Anticancer, antioxidant, antibacterial, antifungal, anticonvulsant, surfactant        |
| 5.34| 2-Alanine, N-propargyloxycarbonyl-isoheksyl ester                       | 1725                  | C₁₁H₁₄NO₂          | 255 | 0.87 | No activity reported                                                                 |
| 5.46| Pyrrolidine, 2-butyl-1-methyl                                          | 1072                  | C₅H₈N             | 141 | 2.06 | No activity reported                                                                 |
| 6.41| 4H-Pyrano-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl                     | 1134                  | C₃H₆O₄            | 144 | 1.0  | Anti-diabetic, antioxidant, antibacterial, melanin production inhibitor              |
| 9.54| 2-Methoxy-4-vinylphenol                                                | 1315                  | C₈H₁₀O₂            | 150 | 2.52 | Antioxidant, antimicrobial, anti-inflammatory                                        |
| 10.35| Eugenol                                                                | 1356                  | C₁₀H₁₂O₂           | 164 | 1.23 | Antioxidant, antimicrobial, anti-proliferative, anti-inflammatory                    |
| 11.20| Methyl (3,4-dimethoxyphenyl)(hydroxy) acetate                           | 1700                  | C₁₁H₁₆O₃           | 226 | 0.19 | No activity reported                                                                 |
| 11.33| Benzaldehyde, 3-hydroxy-4-methoxy                                      | 1401                  | C₇H₆O₂             | 152 | 0.87 | Antimicrobial activity                                                              |
| 12.50| 1,3-Propanediol, 2-ethyl-2-(hydroxymethyl)-                            | 1261                  | C₄H₈O₂             | 134 | 5.86 | Antioxidant, Antimicrobial                                                         |
| 13.05| Ethanone, 1-(4-hydroxy-3-methoxyphenyl)                                 | 1447                  | C₃H₆O₄            | 166 | 4.92 | Anti-inflammatory, antioxidant, non-steroidal, enzyme inhibitor, food additive       |
| 14.95| Diethyl phthalate                                                       | 1603                  | C₁₂H₁₄O₄           | 222 | 5.53 | Antimicrobial, antioxidant, plasticizer, estrogenic                                   |
| 16.25| 1,2,3,5-Cyclohexanetetrol, (1α,2β,3α,5β)                               | 1472                  | C₁₀H₁₂O₄           | 148 | 6.39 | No activity reported                                                                 |
| 17.76| α-Amino-3-hydroxy-4-methoxyacetophenone                                 | 2819                  | C₁₀H₁₄NO₃         | 181 | 0.9  | No activity reported                                                                 |
| 17.67| Ethanone, 1-(4-hydroxy-3,5-dimethoxyphenyl)                             | 1741                  | C₁₀H₁₄O₄           | 196 | 0.98 | Anti-inflammatory, antioxidant, non-steroidal, enzyme inhibitors, food additive       |
| 17.87| 4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol                           | 1688                  | C₁₀H₁₄O₃           | 180 | 0.31 | Antimicrobial, antioxidant, anti-inflammatory                                        |
| 17.98| Tetradecanoic acid                                                     | 1761                  | C₁₄H₂₈O₂           | 228 | 1.85 | Cancer preventive, antioxidant, nematicide, lubricant, hypcholesterolemic            |
| 19.85| Solavetivone                                                            | 1779                  | C₁₅H₂₂O₂           | 218 | 0.78 | Antibacterial, fungitoxic, antimicrobial, weak cytotoxic activity                   |
| 19.47| Cyclopropeneindene-1a,2(1H)-dicarboxaldehyde-3,4,5,6,6a,6b-hexahydro-5,5,6b-trimethyl-1a,3α,6a,6b-[6ba]-[+]| 1734                  | C₁₃H₂₀O₂           | 232 | 0.33 | No activity reported                                                                |
| 19.81| Phthalic acid, isobutyl nonyl ester                                    | 2470                  | C₁₂H₁₆O₄           | 348 | 1.13 | Efficient in curing chronic cardiovascular, cerebrovascular diseases, anti-tumor, anti-inflammatory, antibacterial |
| 20.35| 4,7-Methano-1H-indene, octahydro-2-(1-methylethylidene)                 | 1078                  | C₁₁H₁₈O₂           | 176 | 0.88 | No activity reported                                                                |
| 20.69| Bicyclo[4.3.0]nonane, 7-methylene-2,4,4-trimethyl-2-vinyl               | 1085                  | C₁₀H₁₄O₂           | 204 | 0.54 | No activity reported                                                                |
| 21.36| n-Hexadecanoic acid                                                    | 1975                  | C₁₆H₃₂O₂           | 256 | 4.68 | Anti-inflammatory, antioxidant, antiandrogenic, hypcholesterolemic, nematicide, pesticide, hemolytic, 5-α reductase inhibitor, mosquito larvicide |
| 23.45| Ergosta-7,22-dien-3-ol, [3β,22E]                                        | 3202                  | C₂₈H₄₆O            | 398 | 2.47 | No activity reported                                                                |
| 23.91| 9,12-Octadeцидиендиев оцид(2,2)                                       | 2134                  | C₁₈H₃₂O₂           | 280 | 2.9  | Anticarcinogenic, antioxidant, anti-inflammatory, antiatherogenic                    |
| 24.02| cis-Vaccenic acid                                                      | 2162                  | C₁₈H₃₂O₂           | 282 | 9.07 | Anticarcinogenic effect                                                             |
| 25.52| Geranylgeraniol                                                        | 2201                  | C₂₀H₃₄O₂           | 290 | 3.28 | Anti-tumorogenic, anti-inflammatory, neuro-protective                               |
| 28.39| Stigmasterol                                                           | 3170                  | C₂₀H₄₆O₂           | 412 | 23.18| Anti-inflammatory, antioxidant, antimicrobial, sedative activity                    |
| 29.05| Methyl triacontanoate                                                  | 3317                  | C₂₁H₃₄O₂           | 466 | 3.0  | No activity reported                                                                |
Table 2 (continued)

| RT   | Compound                                                                 | Kovats relative index | Molecular formula   | Mwt | Area | Biological activity                                                                 |
|------|--------------------------------------------------------------------------|-----------------------|---------------------|-----|------|-------------------------------------------------------------------------------------|
| 29.25| Vitamin E                                                                | 3111                  | C₂₀H₃₂O₂             | 430 | 3.4  | Anticancer, anti-diabetic, antioxidant, anti-inflammatory, anti-aging, analgesic, antioxidant, anti-inflammatory, anti-leukemia, anti-dermatitic, anti-keratinocyte, anti-bacteriocin, anti-coronary, vaso-dilator, hepatoprotective, hypcholesterolemic, anti-ulcerogenic, anti-spasmonic |
| 29.44| Octacosanoic acid, methyl ester                                          | 3112                  | C₂₀H₃₂O₂             | 438 | 5.81 | No activity reported                                                                  |
| 30.66| 9,10-Secocholesta-5,7,10(19)-triene-3,24,25-triol, (3β,5Z,7E)            | 2642                  | C₁₇H₂₄O₃             | 416 | 2.17 | Biocide, anti-corrosion agents                                                        |
| 30.66| Spirost-8-en-11-one, 3-hydroxy, -(3β,5α,14β,20β,22β,25R)                  | 3044                  | C₂₇H₄₀O₄             | 428 | 2.17 | Anticancer, Estrogenic, progesterogenic, anti-inflammatory                            |

The bioactive compound Benzaldehyde, 3-hydroxy-4-methoxy, which is known for its antimicrobial activity and inhibits enzymes like 17-β-hydroxysteroid dehydrogenase, testosterone hydroxylase and arylamine-N-acetyltransferase (Prabhu et al. 2020). 1,3-Propanediol, 2-ethyl-2-(hydroxymethyl), is one such bioactive molecule with antioxidant and antimicrobial activity in *Erythrina variegata* (Umarani and Nethaji 2021). Ethanone, 1-(4-hydroxy-3-methoxyphenyl) and Ethaneone, 1-(4-hydroxy-3,5-dimethoxyphenyl) were the two identified non-steroidal bioactive compounds reported to have anti-inflammatory, antioxidant, enzyme inhibitor antibacterial, antifungal, anticonvulsant and surfactant properties (Hosseinzadeh et al. 2017). The other bioactive compounds identified were as follows: 4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl, a ketone reported earlier in *Malva sylvestris*, known to possess several biological properties (Al-Rubaye et al. 2017; Ashwathnararayana and Naika, 2017). 2-Methoxy-4-vinylphenol, a phytocovergent with antioxidant, antimicrobial, anti-inflammatory properties in *Cassia angustifolia* (Alghamdi et al. 2018). The compound, Eugenol, has several biological properties like antioxidant, antimicrobial (Hamed et al. 2012), anti-proliferative and anti-inflammatory activities (Fujisawa and Murakami 2016).
properties and also employed as food additive (Ashwathanarayana and Naika 2017). The compound 4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol, has been reported to have diverse biological activities like anti-microbial, antioxidant, anti-inflammatory and analgesic (Mostafa et al. 2020). Tetradecanoic acid was identified as a cancer preventive, antioxidant, nematicide, lubricant and hypocholesterolemic in Ceropedia bulbosa (Arora and Meena 2017). Solavetivone, a phytoconstituent of tobacco and Solanum erianthum, has fungitoxic, antimicrobial and weak cytotoxic activities (Chen et al. 2013). Similarly, a compound phthalic acid, isobutyl nonyl ester was observed to be efficient in curing persistent cardiac and cerebrovascular problems, cancer, inflammation and bacterial infections (Ma et al. 2015). The compound 9,12-Octadecadienoic acid (Z,Z) was known to possess ant carcino genic, antioxidant, anti-inflammatory and antiatherogenic properties (Arora and Meena 2017).

The second highest compound, cis-vaccenic acid, was well known for its anti-carcinogenic effect in Origanum vulgare (Al-Tameme et al. 2015). Similarly, geranylgeraniol (Ho et al. 2018) and vitamin E (Arora et al. 2017) were reported to have several biological properties. The compound 9,10-Secocholesta-5,7,10(19)-triene-3,24,25-triol, (3β,5Z,7E), acts as biocide and anti-corrosion agent in Piper nigrum (Mohammed et al. 2016). Spirost-8-en-11-one, 3-hydroxy, -(3β,5α,14β,20β,22β,25R) was found to possess anticancer (Rajendran et al. 2017), estrogenic, progestogen and anti-inflammatory effects (Gopu et al. 2021). Among the bioactive compounds identified in the root methanolic extracts of S. khasianum, the biological activity of some compounds was not yet identified and reported (Table 2).

The S. khasianum leaf methanolic extracts showed high antibacterial activity against P. aeruginosa in concentration-dependent manner, followed by E. coli, B. sphaericus and S. aureus (Fig. 3), whereas the root methanolic extract exhibited high antibacterial activity against E. coli, followed by P. aeruginosa, S. aureus and B. sphaericus. The result indicates that the S. khasianum root extract exhibited remarkable antibacterial property against P. aeruginosa and E. coli. Therefore, root methanolic extract of S. khasianum was considered as the most effective extract than leaf extract with regard to high anti-bacterial activity (Pavani and Shasthree 2021). This indicates that the root extract had more antibacterial compounds than leaf extract. Our results were in accordance with the reports on Momordica cymbalaria (Chaitanya and Pavani 2021). This study confirms that the S. khasianum extracts have significant antibacterial activity against tested bacteria.
Conclusions

The GC–MS analysis revealed the presence of 16 bioactive compounds in leaf methanolic extract and 32 bioactive compounds in root methanolic extract of *S. khasianum* based on their retention time, molecular weight, peak area and MS fragment ions generated. Heptadecane, 9-hexyl and stigmasterol were the predominant potential bioactive compounds identified in leaf and root extract. These extracts have shown high antibacterial activity against gram-positive and gram-negative bacteria. This study confirmed the presence of various biomolecules with significant biological properties, thereby confirming the medicinal claim and use of *Solanum khasianum* and making it a potential source of medicines.
Fig. 4 Sunburst chart representing variation in phytoconstituents in *Solanum khasianum* root extract

Table 3  Antibacterial activity of *Solanum khasianum* extracts on tested bacteria

| Test organism | Leaf extract concentration (µg/ml) | Root extract concentration (µg/ml) |
|---------------|-----------------------------------|-----------------------------------|
|               | 80  | 60  | 40  | 20  | Std | 80  | 60  | 40  | 20  | Std |
| *B. sphaericus* | 15 ± 0.14 | 13 ± 0.19 | 12 ± 0.07 | 10 ± 0.14 | 24 ± 0.12 | 16 ± 0.15 | 15 ± 0.14 | 13 ± 0.16 | 12 ± 0.12 | 28 ± 0.11 |
| *E. coli*      | 16 ± 0.16 | 15 ± 0.22 | 13 ± 0.13 | 12 ± 0.19 | 27 ± 0.15 | 21 ± 0.18 | 18 ± 0.20 | 16 ± 0.24 | 13 ± 0.16 | 24 ± 0.09 |
| *S. aureus*    | 15 ± 0.01 | 13 ± 0.14 | 12 ± 0.17 | 11 ± 0.02 | 25 ± 0.08 | 17 ± 0.02 | 14 ± 0.12 | 13 ± 0.11 | 11 ± 0.15 | 24 ± 0.16 |
| *P. aeruginosa*| 17 ± 0.11 | 15 ± 0.12 | 14 ± 0.23 | 13 ± 0.15 | 20 ± 0.19 | 19 ± 0.18 | 16 ± 0.19 | 15 ± 0.21 | 13 ± 0.22 | 27 ± 0.13 |
Abbreviations
GC–MS. Gas chromatography and mass spectroscopy; W/V: Weight/volume; rpm: Rotation per minute; µl: Microliter; ml: Milliliter; LB: Luria Bertani; µg/ml: Microgram per milliliter; DMSO: Dimethyl sulfoxide; Hrs: Hours; SD: Standard deviation; mm: Millimeter.

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Author contributions
PC conceived the research, analyzed the data and designed the manuscript. SBD helped in designing the manuscript, tables and figures. ST extended overall guidance and finalized the manuscript. All authors have read and approved the manuscript.

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Availability of data and materials
The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations
Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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