

Review

Solanum incanum L.: an updated review of botany, traditional uses, phytochemistry, and pharmacology

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Abstract

Solanum incanum L. (Solanaceae) is a wild perennial shrub that is found throughout South and Southeast Asia including Afghanistan, India, Iran, Pakistan as well as the Middle East and Northern Africa. Traditionally, it has been used to treat various ailments like sore throat, helminth, skin problems, liver pain, painful menstruation, malaria, snake bite, stomach problems, asthma, hypertension, diabetes, etc. The current review has deeply explored with emphasis on botanical information, traditional uses, and phytochemistry of *S. incanum* L. along with reported biological activities. Major phytoconstituents and biological attributes of *S. incanum* have been thoroughly cited to justify use in traditional practices, providing scientists and researchers with comprehensive information for further research on this plant. Major bioactive constituents reported in this plant include Quercetin, Solasodine, β -Sitosterol, Stigmasterol, Solamargine, Yamogenin. Based on reports, the plant exhibits numerous biological activities such as antipyretic, antidiabetic, antinociceptive, anti-inflammatory, anticancer, antimalarial, antihepatotoxic, antioxidant, antimicrobial, antihyperlipidemic, antiulcer, analgesic, nematocidal and spasmolytic activities in order to justify traditional claims. Though the pharmacological investigations have been done, the mechanism of action or biochemical pathways of several compounds need to be elucidated in depth in order to correlate the activity of a particular phytoconstituent with a desired target. Furthermore, the toxicity and safety profile of this plant and its reported bioactive constituents need to be explored further before clinical studies on humans. It is anticipated that the information compiled in this review will provide a detailed overview of the botany, taxonomy, traditional use, phytochemistry and pharmacological insights of this plant for future researchers and it will help to find the new targets and the drug moieties.

Ankita Rani and Jiten Singh have contributed equally to this work.

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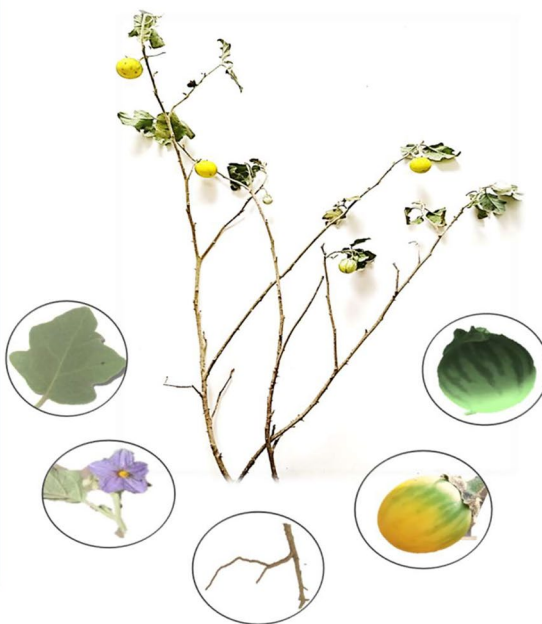
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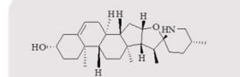
Graphical abstract

Pharmacological activities

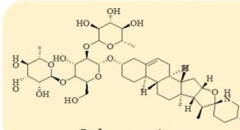
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- Antiulcerogenic
- Analgesic
- Nematocidal

***Solanum incanum* L.**

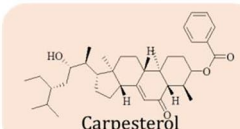
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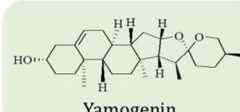
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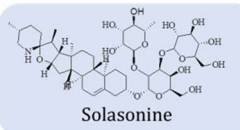
Solamargine



Carpesterol



Yamogenin



Solasonine

Highlights

- *S. incanum* L. contains Solasodine, β -sitosterol, Kaempferol, Chlorogenic acid, and Vitamins (B2 & C) as major phytochemicals.
- *S. incanum* has been traditionally used to treat various ailments, including headaches, stomachaches, malaria, and diabetes.
- The plant exhibits anti-pyretic, anti-microbial, anti-nociceptive, anti-inflammatory, and antioxidant potential.

Keywords *Solanum incanum* L.; · Traditional use; · Phytochemistry; · Pharmacology.

Abbreviations

DPPH	2,2-Diphenyl-1-picrylhydrazyl
TS	Transverse section
IC ₅₀	Half-maximal inhibitory concentration
EC ₅₀	Half maximal effective concentration
MIC	Minimum inhibitory concentration
<i>p.o.</i>	Per orally

1 Introduction

Plants with medicinal properties have a vital function in the management and cure of many ailments. The World Health Organization estimates that almost 80% of the world's population utilizes some sort of herbal medicine to treat illness and disease, and natural products are favored over manufactured ones. The secondary metabolites in medicinal plants are of

great importance in human care in terms of acting as antioxidants, anti-inflammatories, and antimicrobials, and playing a role in regulating enzyme detoxification [1]. *Solanum* is an important genera out of 96 genera in the family Solanaceae. Species of this genus is globally distributed. And this genus is largest one among the angiosperms. There are about 2500 species of this genus present in the world. This genus is known for having wide range of bioactive compounds which are beneficial for human health [2]. The genus *Solanum* is characterized by the presence of an important group i.e. steroidal glycoalkaloids [3]. Over the past 30 years, genus *Solanum* has become an attractive model for chemical and biological studies. Atropine, hyoscyne, solasodine and withanolide are the examples of biomedically relevant compounds for food and medicine. While containing alkaloids with medicinal importance, Solanaceae plants also contain alkaloids that may be toxic to humans and animals ranging from mild irritation to lethal, *S. nigrum*, *S. xanthocarpum*, *S. tuberosum* and *S. lycopersicum* are some of the economically important species of the genus *Solanum*.

S. incanum is one of the nearly 2500 species of *Solanum* genus observed globally [4]. *Solanum incanum* Linn. having synonyms *Solanum melongena* var. *incanum* belongs to the family Solanaceae [3]. It is used in Sub-Saharan Africa, the Middle East, and even further east to India as a folklore remedy [5].

It is a perennial, wild shrub and its species has wide traditional applications. The leaves and fruits of certain cultivars in West Africa are eaten. The fruit consists of small berries in diameter of 2–3 cm and when they are ripe are changed into yellow to brown color [6]. *S. incanum* has rough leaves, prickles on the stem, stalk, calyx, and velvety hairs on the leaves [7]. It grows widely as a weed around buildings, overgrazed grassland, and roadsides, as well as along forest borders, bushland, and grasslands [8]. Several phytochemicals such as terpenes, xanthenes, flavonoids, bioflavonoids, and various metabolites like saponins, tannins, anthraquinones, and cyanates, as well as oxalate have been reported in *S. incanum*. Among steroid glycosides, glycoalkaloids namely solanine and solasonine are present [9].

Fruit and leaves are a good source of minerals like K^+ and Ca^{2+} [7]. Consuming root sap, as well as drinking decoctions made from leaves, fruits, and roots are used to treat a variety of health conditions. This plant is also a conventional cure for injuries, colic, angina, sore throat, stomachache, and headache [9]. It is also used to relieve painful menstruation, liver problems, and pain caused by onchocerciasis, pleurisy, pneumonia, and rheumatism [10] squamous cell carcinoma of the skin shows some pathological changes like actinic keratosis SR-T100 is the extract of *S. incanum* which was recently patented, its activity against actinic keratosis was reported in the third phase of clinical trials [11]. Nowadays SR-T100 is available in the market as cutaneous gel formulation for the antineoplastic activity [12].

2 Methodology

Science Direct, PubMed, Google Scholar, and PubChem are the different databases that are used for gathering the information. The Keywords or search terms used for the search include *Solanum incanum* alone or combined with other keywords like; botanical description, taxonomy, ethnopharmacological uses, geographical distribution, biologically active constituents, phytochemicals, and pharmacological activities. The biologically active constituents are identified by PubChem and drawn by ChemDraw (version 16.0). The drug-likeness and bioavailability along with Lipinski's rule of five will either be followed or rejected was evaluated using freely available online software and databases such as Swiss-ADMET. In this review, we select only preclinical (in-vitro and in-vivo), clinical, and computational studies that are accessible. Some studies are not available and are excluded.

3 Botany

3.1 Distribution and habitat

Solanum incanum is a perennial, wild shrub found in South and Southeast Asia, as well as Afghanistan, Iran, and western Pakistan, in addition to Northern Africa and the Middle East. It can also be found in the Philippines, in the islands of Mauritius and Madagascar in the Indian Ocean [13]. The geographical distribution of this plant is tropical and equatorial Africa, Subtropical southern Africa, Subtropical N Africa and SW Africa [14].

In India, it is found in Maharashtra, Pune, Karnataka, and Mysore [15]. *S. incanum* is mainly grown in open fields or where the impacted areas of humans [13]. This plant is a weed that can be commonly found in overgrazed grasslands and the vicinity of buildings, as well as by roadside. It is also found along forest boundaries, bushland, and grassland [9].

3.2 Taxonomy

The Solanaceae family belongs to the plant kingdom and the order of this family is *Solanales* in the division *Magnoliophyta*, the angiosperms or flowering plant division [16]. This family consists of 100 genera and nearly about 2500 species with high extent in habit, structure, and ecology [2]. The information about the taxonomic classification of *S. incanum* has been mentioned in Table 1 [17].

3.3 Macroscopic characteristics

Solanum incanum is densely covered by soft stellate hairs and branched thorny shrubs with stout prickles. The leaves are lobed or sinuate, measuring 4.5–11 × 4–7.5 cm, ovate-elliptic, having a midrib, and the lateral nerves with scattered prickles. The blossom color is pale purple or blue, and the petioles have a maximum length of 6 mm. The size of the berry is 2 cm in diameter and subglobose, yellow at maturity [9]. The young stem of *S. incanum* is tapering or cylindrical. The color of the stem is brownish and is angular in shape. The mature stems are glabrate to densely stellate-pubescent. Often a deep taproot is present. The shape of the fruit is spherical ovoid and sub-globose berry measuring 2–2.5 cm long. The size of the seed is 2–2.5 cm and has a smooth surface and dull yellow to orange-brown. The shape of the seed is flattened-renform in shape [15]. The flowering of *S. incanum* starts in 28 weeks [18] as shown in Fig. 1.

3.4 Histological characteristics

Stem: The epidermis of the plant *S. incanum* is layered with a thick cuticle. The hypodermis is absent in this plant. The cortex of *S. incanum* is composed of collenchymatous cells, thin-walled parenchyma, some cells filled with calcium oxalate crystals (microsphenoidal), and an inconsistent put-together of pericyclic fibers below it. The endodermis layer is absent in this plant. Pericycle *i.e.*, primary tissue located at the periphery of the root vascular cylinder. Medullary rays are uniseriate, arranged in a single row, layer, and series (parts, cell, etc.). The pith of *S. incanum* is parenchymatous with micro-sphenoidal crystals [19].

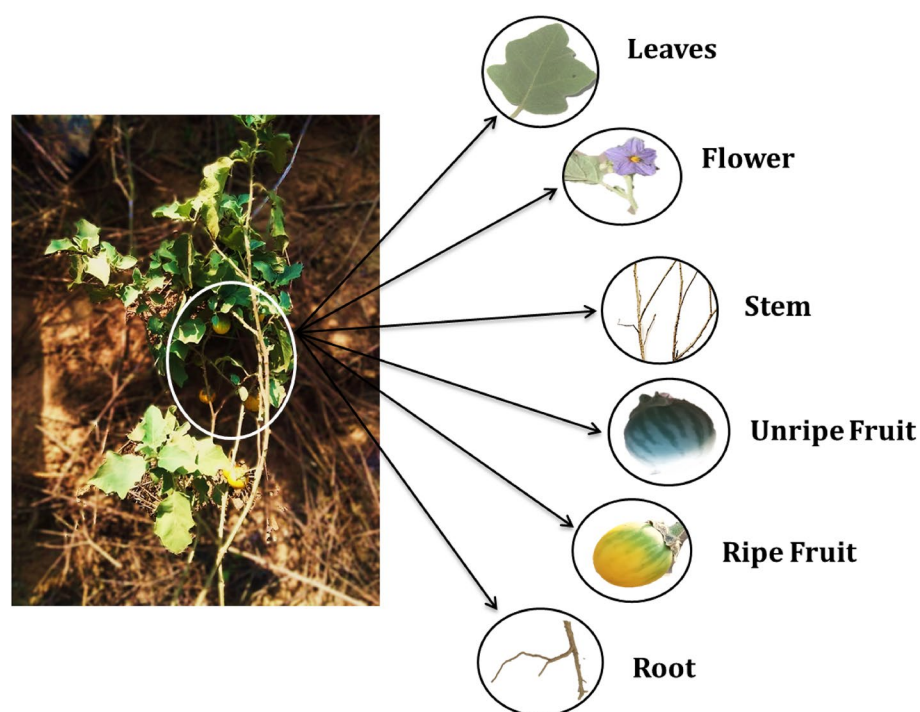
Leaf: The leaf of *S. incanum* consists of three parts- petiole, lamina, and midrib. The shape of the petiole is irregularly circular. In lamina a few stellate trichomes are present and there are 2–3 layers of spongy parenchyma. The T.S. of the petiole is unevenly circular, having just one layer of epidermis. Under the epidermal and parenchymatous ground tissue, a leaf’s microscopic examination reveals collenchymatous tissue [19].

Fruit: Tenacious calyx is shown in the longitudinal section of the fruit of *S. incanum* and long pedicle with few thorns. Outer dark yellowish layers of epicarp are present in the T.S. of this fruit, and a mesocarp formed of mucilaginous pulp. A numerous seed interposes in a centrally located bi-carpellary placenta [19].

Table 1 Taxonomic classification of *Solanum incanum* L

Scientific name	<i>Solanum incanum</i> Linn
Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Asteridae
Order	Solanales
Family	Solanaceae
Genus	<i>Solanum</i>
Species	<i>Incanum</i>

Fig. 1 Image of *Solanum incanum* L.



4 Traditional uses

S. incanum is a traditional medication used for the treatment of human and animal illnesses. In Ethiopia, more than 800 plant species are used for the treatment of around 300 diseases, including both physical and mental, such as anxiety disorders, birth abnormalities, cerebral palsy, melancholy, and schizophrenia [20]. The leaves, berries, and roots of *S. incanum* plant are utilized traditionally to aid in relieving hemorrhoids, dyspepsia, ear pain, and bruised fingers [21]. In Africa, it is used to treat a variety of ailments including sore throats, skin conditions, fever, liver discomfort, angina, colic, indigestion, general infections, dandruff, headaches, and stomachaches [9]. This plant is also used in wound treatment as a folklore remedy in Africa [22]. In Taiwan, it is utilized as a conventional medical treatment for the cure of hepatitis [23]. The seeds and fruits of this plant are widely used to curdle milk to produce cheese in Africa and Asia [24]. In animals, this plant is used to control cattle ticks and make compost [9]. Leaf paste and pounded fruits are used for scarifications. Various parts of this plant are reported to be used in warts, rashes, and carbuncles [25]. The main medicinal plant used in Oromia (Ethiopia) to treat skin lesions caused by dermatophilosis, foot rot, coudriosis, and pasteurellosis is *S. incanum* fruit. The infusion prepared from plant roots is utilized for treating fasciolosis, snake bites, and black legs [26]. The plant is also used as an antimicrobial, antipyretic, spasmolytic, analgesic, antinociceptive, hypoglycemic, anorexic, antihyperlipidemic, antiprotozoal, and insect-repellent agent [19]. Other applications of this plant include the alleviation of discomfort brought on by rheumatism, pneumonia, pleurisy, onchocerciasis, and painful menstruation [6].

5 Biological activities

Various biological and pharmacological activities associated with *S. incanum* are discussed below.

5.1 Antipyretic effect

In a previous study it was reported that root extract of the *S. incanum* in dichloromethane methanol (ratio 1:1) at the dose of 50 and 100 mg/ kg shows antipyretic and antinociceptive effect when compared with standard (100 mg/ kg of Acetyl salicylic acid (ASA)) and control (10% Dimethylsulfoxide in saline as vehicle) and significantly reduced the body

temperature and it was reported that the interval of temperature monitoring were 120, 150 and 180 min. In this study the body temperature was monitored via rectal method and to induced fever, rats were treated with 50 µg of Lipopolysaccharide intraperitoneal injection. Antinociceptive effect was performed using the tail flick and hot plate method. The mean response time in hot plate method for the standard drug ASA and morphine were 8.5 and 17.67 respectively while, selected extract shows 3.5, 8.5 and 9.0 at the doses of 50, 100 and 200 mg/kg of the extract. The antipyretic effect of *S. incanum* root extract may be due to the presence of bioactives which have antipyretic effects and may have the ability to cross the blood–brain barrier to inhibit the activity of cyclo-oxygenase [27]. The antinociceptive effect of this root extract is via a central integrated mechanism [27].

5.2 Antimalarial effect

Chiamah and group outlined the antimalarial effects of leaf ethyl acetate extract of *S. incanum* by down-regulating delta aminolevulinate dehydratase when given a dose of 250 mg/kg to Plasmodium berghei-infected mice. The presence of significant concentrations of eicosane, tetratracotane, and 2-methyloctacosane may be the reason for the extract's antimalarial action. [3].

5.3 Anti-inflammatory effect

In a recent study to inquire about the anti-inflammatory activity possessed by *S. incanum*, Swiss Albino mice were injected with 6.5 mg/kg, 12.5 mg/kg, and 25 mg/kg dose of flavonoids-rich fraction of *S. incanum* roots extract, standard (diclofenac), and vehicle (normal saline) half an hour before pain and inflammation were induced. The 0.05 ml of 5% formaldehyde solution is used to induce inflammation. *S. incanum* may have impeded phosphodiesterases involved in cell activation, influenced the work of enzyme systems that are involved in the inflammation process, or blocked the biosynthesis of mediators of inflammation, that serve as strong signaling molecules regulating leukocyte movements and therefore restricting chemotaxis. Thus shows potent anti-inflammatory effects [28].

5.4 Anticancer activity

To evaluate the anticancer activity of *S. incanum* Yu et al. prepared its extract (SR-T100) by using different ratios of ethanol/water exhibited anticancer activity by inducing DNA damage, apoptosis, and G0/G1 cell cycle arrest in murine B16 melanoma cells in vitro [29]. Further, intraperitoneal injection of this extract (5 mg/mL) decreased the size and the number of existing melanoma metastases in the lungs in mice. SR-T100 has an active ingredient, solamargine, which has the ability to induce apoptosis of cancer cells. Another mechanism involved is the down-regulation of aldehyde dehydrogenase-1 (a marker of cancer stem-like cells). This study concludes that the said extract can be developed as a promising and new drug for treating existing tumors associated with regional and metastatic melanoma [30].

5.5 Antihepatotoxic activity

In a study by Lin and team in 1988 many compounds (solasodine (3 mg/kg), solasonine (0.1 mg/kg), solamargine (1 mg/kg), campesterol (10 mg/kg), and ursolic acid (10 mg/kg)) isolated from *S. incanum* fruit were screened for antihepatotoxic effects using a carbon tetrachloride-induced cytotoxicity model in ICR male mice (20–25 g). All the compounds showed strong hepatoprotective activity in the mice by demonstrating the significant decrease in liver damage markers (SGOT and SGPT) which is seen after their dosing [31].

5.6 Antioxidant activity

Almoulah et al. performed an antioxidant study on *S. incanum* fruits in a DPPH and ABTS assay and reported that the aqueous fruit extract of this plant possesses better antioxidant activity (IC₅₀: 177.9 µg/ml) in DPPH assay and in ATS assay (IC₅₀ value 616.4 µg/ml). The outcomes revealed that the aqueous extract of *S. incanum* may include greater possibilities for antioxidant components than the ethanol extract [32].

5.7 Antidiabetic activity

Andargie et al. performed a study on the antidiabetic activity of *S. incanum* and reported that its methanolic root extract (80%) shows marked antidiabetic action in Streptozotocin-induced diabetic mice. Where the extract at a dose (400 mg/kg) resulted in the maximum reduction in blood glucose level on day 14. A percentage reduction of 19.7% was observed compared to the normal medication (33.7%). It exhibits antidiabetic activity by reducing triglycerol levels, and plasma glucose levels and also helps in increasing the body weight of the animal. A decrease in lipogenesis, enhanced lipolytic activity by inhibition of hormone-sensitive lipase or lipidemic enzymes, or activation of certain serum lipases might all contribute to a lower triglycerol level [29].

5.8 Antimicrobial activity

Sbhatu and Abraha screened different extracts of *S. incanum* fruit, stem, and leaf for antimicrobial potential using Gram-positive and Gram-negative bacterial strains. They reported that the ethanol extracts showed significant inhibition (> 16.0 mm) against *E. coli* and *S. aureus*. Ethanolic leaf extracts exhibited maximum inhibition (MIC:1.56 mg/mL). Higher activity of ethanol extract is may be due to the extraction of bioactive compounds with wide polarity ranges of 80% v/v ethanol, while water can only extract polar compounds [9].

Musyimi assessed the antimicrobial screening of aqueous and ethanol extracts of *S. incanum* leaves, roots, and seeds by employing the agar-well diffusion method and reported that both the extracts possess dose-dependent significant ($p < 0.05$) antibacterial activity against *E. coli* and *S. aureus* at 25, 50, 75 and 100 mg/ml and compared with amoxicillin (25 mg/ml) taken as standard. In conclusion, ethanolic extracts of different parts demonstrated a higher effect as compared to aqueous extracts. The antibacterial effects of all extracts are due to the presence of secondary metabolites and the variations in the effect produced are due to different factors like the organism, solvent used in extraction, and plant parts [33].

5.9 Antihyperlipidemic activity

In the antihyperlipidemic investigation, the researchers evaluated the impact of *S. incanum* aqueous fruit extract on the lipid profile in the alloxan induced diabetic Wistar albino rats. The fruit extract at a dose of 500 mg/kg given *p.o.* displayed significant antihyperlipidemic effect. A lowering of triglycerol may be result from either ↓ lipogenesis ↑ lipolytic activity through inhibition of hormone sensitive lipase or lipidemic enzymes or stimulation of some serum lipase as have been suggested for some anti-diabetic plants [34].

5.9.1 Antiulcerogenic effect

A study was performed by Belayneh et al. to assess the antiulcer activity of extracts (hydromethanol) from *S. incanum* roots and leaves in antiulcerogenic effects including Pylorus ligation and ethanol-induced gastric ulcers in fasted mice. Both the extracts at dose (400 mg/kg) dramatically reduced the ulcerogenic effect. Investigations offer evidences that the anti-ulcer activity of medicinal plants is primarily attributed to the presence of phenolic compounds, flavonoids, and saponins [35].

5.9.2 Analgesic effect

S. incanum methanol leaf extract was administered to mice at different doses i.e. 100, 200, and 400 mg/kg *p.o.* in hot plate test and acetic acid induced writhing test and compared with negative control (Tween 80, 2%) and standards (Morphine, 5 mg/kg; Aspirin, 150 mg/kg) respectively. In the hot plate test, the prolonged reaction time was observed at the highest dose of the extract when compared with the standard (Morphine, 5 mg/kg). In Acetic acid induced writhing method, the extract displayed a remarkable analgesic effect i.e. 55.6, 38.2 and 44.8% inhibition

of the number of writhing at 100, 200 and 400 mg/kg doses, respectively. Hence, it can be inferred that *S. incanum* methanol leaf extract possesses central and peripheral analgesic activity [36].

5.9.3 Anti-tick effect

Anti-tick effect of *S. incanum* fruit extracts was studied by Obed in 2023 on *Rhipicephalus appendiculatus* ticks at 100, 50, and 25 mg/ml concentrations. Results obtained using the larval packet test, revealed remarkable larval mortality. The results might be explained by how easily the active ingredients in the extract entered the larvae's cell membrane. The alkaloid present in the fruit interferes with the membranes of the cells and disrupts the integrity of cells so that they cannot withstand the osmotic forces, as their membranes are destroyed finally leading to apoptosis [37].

5.9.4 Nematicidal activity

Fruit extract of *S. incanum* L. showed nematicidal activity and the main phytochemicals responsible by solanine by inhibiting the nematode (*Meloidogyne* spp.) responsible for causing root-knot disease in *Capsicum annum* L. under both glasshouse and field conditions in a study performed at Nakuru County, Kenya. The study reveals a considerable reduction in the number of galls and an improvement in plant growth metrics like height and leaf number in the treated plant. The reduction in the population of nematode associated with the increased in the concentration of various phytochemical like ammonia, phenol-formaldehyde, organic acids, tannins, hydrogen sulfide and volatile fatty acids decreased the gall formation and nematodal multiplication [38].

5.9.5 Spasmolytic effect

S. incanum aqueous root extract was assessed for spasmolytic activity using acetylcholine-induced contractions in the isolated guinea pig ileum, and compared with standard (Atropine). The extract demonstrated a dose dependent significant spasmolytic effect (EC_{50} : 0.215 mg/ml) when administered at doses 50, 100, 200 and 400 mg/kg, respectively. The charcoal travel time in the intestine of the mice were significantly reduced after administration of the different dose (as mentioned) by 36.28, 51.45, 52.93 and 38.53%. The antispasmodic effect of the extract is due to the presence of alkaloid, saponins and flavonoids [39].

6 Major phytoconstituents of *S. incanum*

Though *S. incanum* contains enormous phytoconstituents, only major phytochemicals with potential therapeutic effects have been mentioned in Fig. 2 and discussed below:

6.1 Solasodine

One of the primary active ingredients found in *S. incanum* is solasodine having IUPAC name (22*R*,25*R*)-Spirosol-5*α*-en-3*β*-ol and molecular formula: $C_{27}H_{43}NO_2$, which can be used in promoting neurogenesis, acting as an antioxidant, and reducing infections [40]. Previously, it was reported that the mixture of solasodine glycosides have potential to treat human skin carcinoma in keratosis, squamous cell carcinoma and basal cell carcinoma at the conc. of 0.005% and 10% of standard mixture of solasodine glycoside [41]. It was reported that solasodine having the cytotoxic activity that's why it selectively kills the cancer cells [42].

6.2 Carpesterol

Carpesterol [(22*R*)-22-hydroxy-6-oxo-4-methyl-5-stigmast-7-en-3*β*-yl benzoate] is a steroidal compound with the chemical formula $C_{37}H_{54}O_4$ [43]. It is mainly found in seed oils. The decoction and the extract of leaves and roots of *S. incanum* is effective in wounds and cancerous sores. It also acts as antidote to the poisoning by opium [44].

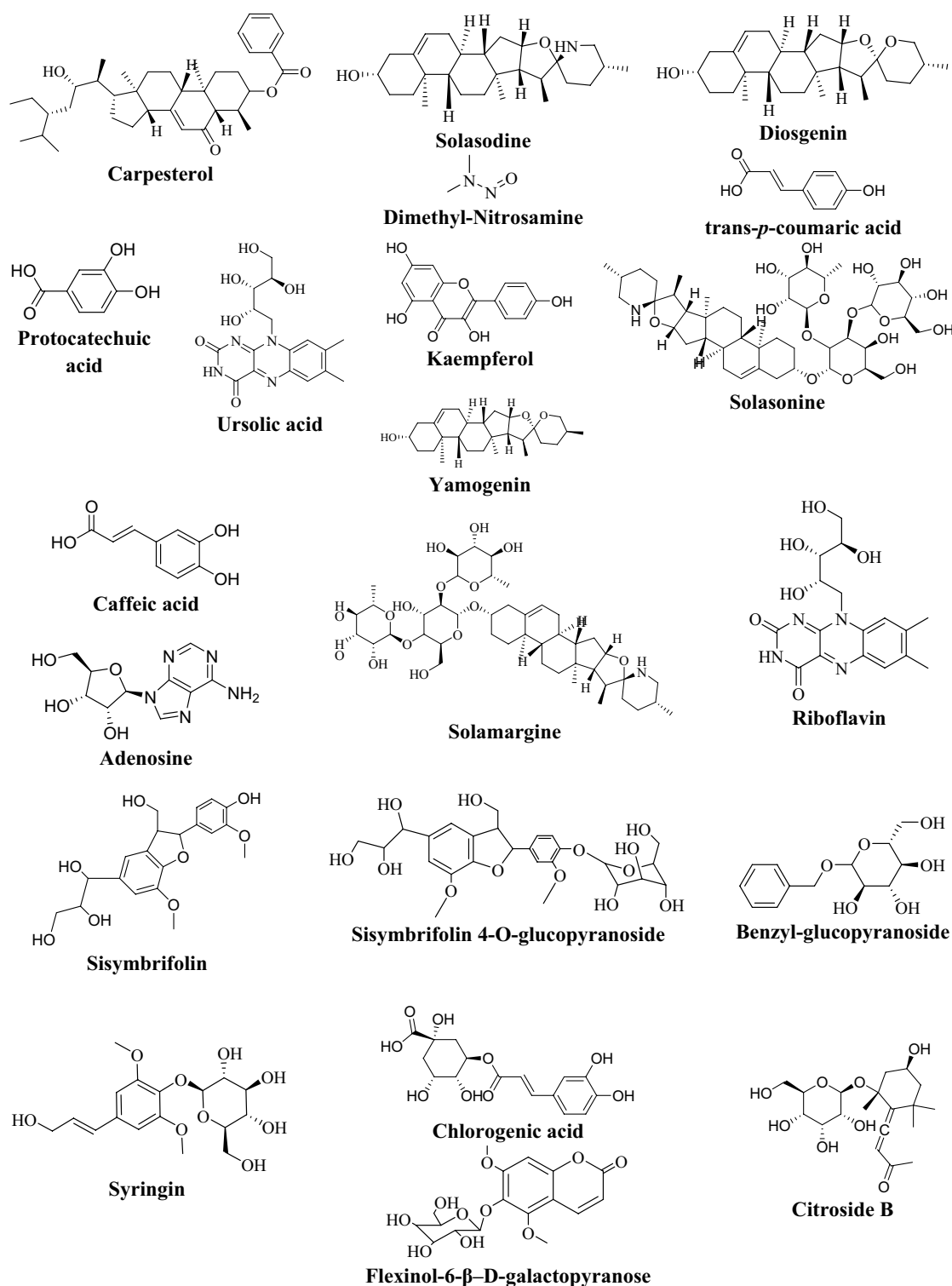


Fig. 2 Chemical structure of phytochemicals reported in the *S. incanum* species

6.3 β-sitosterol

B-sitosterol (Stigmast-5-en-3β-ol) (Molecular formula $C_{29}H_{50}O$), a bioactive phytosterol found in plant cell membranes. It was reported that β-sitosterol increase the insulin in the animal model of 21 days compared to control group. In a

study it was reported that β -sitosterol shows the protective effect in the diabetes induced oxidative damage [45, 46].

6.4 Stigmasterol

Stigmasterol ($C_{29}H_{48}O$), is also called the Wulzen anti-stiffness factor or Stigmasterinm [47]. It was reported that the galactose as a sugar moieties and 2 phenolic substances, such as methyl caffeate and caffeic acids [48].

6.5 Solamargine

Solamargine ($C_{45}H_{73}NO_{15}$), is a type of steroidal alkaloid glycoside. The content of solamargine was found to be half in the leaves of *S. incanum* when compared to its another species *S. xanthocarpus*, whereas the content in the leaves is 6 times higher than the aerial parts [18]. It shows the cytotoxic effect in BEAS-2B, HK-2, L-02 and MCF-10A. Along with this at the conc. of more than 14.2 g/ml showed the cytotoxicity in V79 cells. It also demonstrate the healthy primary bovine aortic endothelial cells, epithelial cells and rat fibroblasts [49].

6.6 Ursolic acid

Ursolic acid (3 β -hydroxyurs-12-en-28-oic acid) having molecular formula $C_{30}H_{48}O_3$, a natural triterpene compound is present in a variety of vegetables and fruits. It was reported that ursolic acid inhibits the KB cells and esterification of ursolic acid with aliphatic acids were increased the cytotoxic effect against the hepatoma PLC/PRF/5 cells of human [50].

6.7 Benzyl-glucopyranoside

Benzyl-glucopyranoside or Benzyl β -D-glucopyranoside ($C_{13}H_{18}O_6$) is found in plants like *Camellia sinensis* and *Cotoneaster simonsii* and it is also found in *S. incanum* [50].

6.8 Kaempferol

Kaempferol (3,4',5,7-Tetrahydroxyflavone) is a natural flavonoid present in many fruits such as tomatoes, beans, strawberries, and grapes [51]. Pure kaempferol ($C_{15}H_{10}O_6$) may be obtained from diverse plant species in the divisions Pteridophyta, Coniferophyta, and Angiosperms of the Kingdom Plantae [52].

6.9 Chlorogenic acid

Chlorogenic acid ($C_{16}H_{18}O_9$) is a group of phenolic acids that is present in many human diets with coffee, apples, pears, berries, artichokes, burdock and aubergines [53, 54].

6.10 Quercetin

Quercetin (3,5,7,3',4'-pentahydroxyflavone) frequently occurs in flowers, stems, bark, roots, fruits (e.g. apples, dill, berries), vegetables, etc. [55]. Its molecular formula is $C_{15}H_{10}O_7$.

6.11 Protocatechuic acid

Protocatechuic acid (3,4-dihydroxybenzoic acid), is indeed one of the naturally occurring phenolic acid present in numerous fruits and edible plants, including plums, gooseberries, and nuts [56].

6.12 6.12. Trans-p-coumaric acid

Trans-*p*-coumaric acid ($C_9H_8O_3$) is found in Bamboo plants [57].

6.13 Caffeic acid

Caffeic acid ($C_9H_8O_4$), a polyphenol compound, is present in coffee beans, some fruits, and vegetables such as propolis, potatoes, carrots, and olives [58].

6.14 Diosgenin

Diosgenin (3 β -Hydroxy-5-spirostene) is a steroidal sapogenin naturally occurring in plants of families namely agavaceae, amaryllidaceae, dioscoreaceae, leguminosae, liliaceae, rhamnaceae, scrophulariaceae, solanaceae [59].

Diosgenin ($C_{27}H_{42}O_3$, 414.6 g/mol) is employed in cancer, cardiovascular diseases, diabetes, hepatoprotective, hyperlipidemia, and neurological disorders [60, 61].

6.15 Yamogenin

Yamogenin ((25S)-spirost-5-en-3 β -ol), a diastereomer of diosgenin, is responsible for the antihyperlipidemic effect. Its molecular formula of yamogenin is $C_{27}H_{42}O_3$ and its molecular weight is 414.6 g/mol [62]. This compound is used as an antitumor, fungicidal, insecticidal, and antifeedant agent, and possesses molluscicidal activity [63].

6.16 Dimethylnitrosamine

Dimethylnitrosamine ($C_2H_6N_2O$) is a nitrosamine class of compound that is known for its potent hepatotoxin, carcinogen, and mutagen [64].

6.17 Riboflavin (Vitamin B2)

Riboflavin, also called lactoflavin or Vitamin G, is a water-soluble Vitamin. Molecular formula of riboflavin is $C_{17}H_{20}N_4O_6$ [65].

6.18 Vitamin C

Vitamin C, also known as L-ascorbic acid ($C_6H_8O_6$, 176.12 g/mol), naturally occurs in citrus, vegetables, and potatoes [66].

Several other phytoconstituents reported in *S. incanum* include Solasonine, Sisymbirifolin, Sisymbirifolin 4-O-glucopyranoside, Syringin, Flexinol-6- β -D-galactopyranose, Adenosine, etc. (Chemical structure shown in Fig. 2) have low bioavailability (Table 2). Numerous essential minerals such as Na^+ , K^+ , and Mg^{2+} are reported in *S. incanum* fruit which are necessary for plant growth as described below [67].

Chromatographic studies

1. HPLC

Determination of solasodine

- Mobile phase: Ethyl acetate–Methanol–Water (10: 1.35: 1)
- Spray reagent: Dragendorff's reagent followed by 10% Ethanolic sulphuric acid reagent.
- R_f value: 0.87 (Standard)
- Detection: Brownish blue, Yellow coloured zone at Visible light mode were present in the tracks, which shows the presence of Alkaloid in the given standard and may be in the sample.

Table 2 Phytochemistry of the *S. incanum* and pharmacokinetic details such as Lipinski Rule of 5, GI Absorption and Bioavailability Score

S. No	Phytoconstituents	Pubchem ID	Lipinski Rule of 5	GI Absorption	Bioavailability Score	References
1	Solasodine	442,985	Yes, 1 violation	High	0.55	[41]
2	Stigmasterol	5,280,794	Yes, 1 violation	Low	0.55	
3	Solasonine	119,247	No	Low	0.17	[42]
4	Solamargine	73,611	Yes	High	0.55	
5	Carpesterol	21,155,918	No	Low	0.17	
6	Ursolic Acid	64,945	Yes, 1 violation	Low	0.85	
7	Sisymbirifolin	274,361,028	Yes	High	0.55	
8	Benzyl-glucopyranoside	11,076,492	Yes	High	0.55	
9	Syringin	5,316,860	Yes	Low	0.55	
10	Citroside B	14,312,562	Yes	Low	0.55	
11	Adenosine	60,961	Yes	Low	0.55	[12]
12	Kaempferol	5,280,863	Yes	High	0.55	
13	Chlorogenic acid	1,794,427	Yes, 1 violation	Low	0.11	
14	Quercetin	5,280,343	Yes	High	0.55	
15	Protocatechuic acid	72	Yes	High	0.56	
16	trans- <i>p</i> -coumaric acid	637,542	Yes	High	0.85	
17	Caffeic acid	689,043	Yes	High	0.56	
18	Diosgenin	99,474	Yes, 1 violation	High	0.55	
19	Yamogenin	441,900	Yes, 1 violation	High	0.55	[43]
20	Dimethyl-nitrosamine	6124	Yes	High	0.55	
21	Riboflavin	493,570	Yes	Low	0.55	[44]
22	Vitamin C	54,670,067	Yes	Low	0.55	

Determination of quercetin

- Mobile phase: Toluene–Acetone–Formic acid (4.5: 4.5: 1)
- Spray reagent: 1% Ethanolic Aluminium chloride reagent.
- R_f value: 0.60 (Standard)

Detection: Yellow, Blue, Yellowish blue coloured fluorescent zone at UV 366 nm mode were present in the tracks, which shows the presence of Flavonoid in the given standard and may be in the sample [68].

7 Nutritional composition of *S. incanum*

- **Moisture content:** *S. incanum* has a high moisture content of $91.4 \pm 0.56\%$, indicating that it is primarily composed of water, which is common for many vegetables.

Proximate composition of raw and processed *S. incanum* plant (concentration % of DW):

- Crude protein: $8.31 \pm 0.63\%$
- Available carbohydrates: 51.74%
- Ash content: $21.2 \pm 0.42\%$
- Crude lipid: $12.53 \pm 0.74\%$
- Crude fiber: $6.22 \pm 0.36\%$
- Caloric value: 308.9 kcal/100 g

Bioactive constituents: The study identifies several bioactive compounds:

- Saponin: 14.4%
- Alkaloid: 0.6%
- Flavonoid: 26.7%
- Oxalate: 2295 mg/100 g
- Cyanogenic glycoside: 5.71 mg/100 g [69].

Antinutritional factors composition of *S. incanum* fruits: composition in mg per 100 g includes.

- Cyanides: 0.95 ± 0.03
- Nitrates: 96.14 ± 5.16
- Oxalates: 54.08 ± 1.00
- Phytates: 55.05 ± 4.48
- Tannins: 75.36 ± 0.17 [70].

Vitamins and minerals: The plant contains essential vitamins such as riboflavin, ascorbic acid, and tocopherol. The mineral composition per 100 g (dry weight) includes:

- Phosphorus (P): 1085.00 mg
- Magnesium (Mg): 39.14 mg
- Potassium (K): 216.89 mg
- Manganese (Mn): 147.78 mg
- Copper (Cu): 256.17 mg
- Sodium (Na): 149.34 mg
- Iron (Fe): 326.50 mg
- Calcium (Ca): 15.29 mg

These minerals are crucial for various body functions and overall health [69].

Fruit parts

The phytochemicals present in *S. incanum* fruit include alkaloids, cyanogenic, cardiac glycosides, flavonoids, saponins, steroids and tannins. Alkaloids being one of the largest groups of phytochemicals in *S. incanum*, are responsible for the painkiller effect. Diseases such as wounds, varicose ulcers, hemorrhoids, frostbite, and burns are treated by plants with tannin. It is reported that plants containing flavonoids are useful in the treatment of allergies, inflammation, platelet aggregation, microbes, ulcers, and tumors. The phenolic contents of the fruit show antimicrobial properties. Saponins can be used to treat hyperglycemia [67]. Strong bioactive phenolics reported in *S. incanum* are chlorogenic acid (5-O-caffeoylquinic acid), 3-O-malonyl-5-O-(E)-caffeoylquinic acid, 5-O-malonyl-4-O-(E)-caffeoylquinic acid, and N-(E)-caffeoylputrescine [71].

8 Conclusion

Natural substances, particularly those derived from plants, have undergone extensive testing to ensure their safety and efficacy and have attracted a lot of curiosity. Different parts of the *S. incanum* such as fruit, root and leaves has been ethnomedicinally used to cure headaches, stomachaches, liver pain, painful menstruation, sore throats, malaria, stomach disorders, asthma, hypertension, diabetes, common cold, and pain induced by pneumonia, rheumatism, and onchocerciasis. From published reports, it is concluded that *S. incanum* L. possesses significant antipyretic, antinociceptive, antimalarial, anti-inflammatory, anticancer, antihepatotoxic, antioxidant, antidiabetic, antimicrobial, antihyperlipidemic, antiulcer, analgesic, nematocidal and spasmolytic activities which in turn might be due to the presence of one or more of the phytoconstituents/mineral/vitamins reported in this plant. In this review paper we concluded that *S. incanum* contains a number of the phytoconstituents such as solasodine, carpesterol, β -sitosterol, stigmaterol, solamargin, ursolic acid, benzyl-glucopyranoside, kaempferol, chlorogenic acid, quercetin, protocatechuic acid, trans-*p*-coumaric acid, caffeic acid, diosgenin, yamogenin, dimethylnitrosamine, vitamin B2 and vitamin C. This review provide the complete

details of the plants morphology, phytochemistry, proximal composition, nutritional composition and their pharmacological activities. The phytochemical information reported in this review will be helpful for determination of the target site of pathological conditions and also helpful in the structure activity relationship elucidation. Being a rich source of phytoconstituents, minerals and vitamins, *S. incanum* L. might be nutritionally valuable and can be further explored for its potential as a nutraceutical.

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Author contributions DK conceived and designed the manuscript. AR and SP carried out the literature collection of the data and wrote the manuscript including tables and figures. JS assisted in the compilation of data. AJ carried out grammatical correction of the manuscript. All the authors read and approved the final manuscript.

Availability of data and materials No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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