



MINI REVIEW ARTICLE

A comprehensive review on traditional therapeutic uses, bioactive principles and pharmacological activities of Kantakari (*Solanum virginianum* L.): An important Ayurvedic herb

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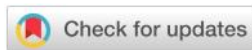
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Abstract

Solanum virginianum L., a perennial wild plant, belongs to the 'Dashamoola' group in Ayurveda. 'Kantkari Ghrita' in Charaka Samhita is used for cough, cold, fever, asthma, and cardiac diseases. 'Dasmul Asava' and 'Dashmularishta' are tonics for lactating mothers. Inflammatory disorders, rheumatism, and diabetes are traditionally treated using leaf juice and fruits. Various plant parts contain bioactive compounds like solamargine, solasonine, campesterol, β -sitosterol, cycloartenol, chlorogenic acid, vanillic acid, etc. Roots, flowers, stems, and fruits are used for their medicinal properties such as carminative, febrifuge, expectorant, diuretic, and bitter tonic effects. They are employed to treat cough, asthma, fever, toothache, tuberculosis, rheumatism, sore throat, kidney disorders, gonorrhoea, vesicular eruptions, and burning sensation in the feet. Different extracts from various plant parts exhibit significant anti-inflammatory, nephroprotective, anti-asthmatic, hepatoprotective, immunomodulatory, antimicrobial, larvicidal, antinociceptive, antispermatogetic, antioxidant, and antidiabetic activities. This study reviews 37 relevant research articles to comprehensively explore the plant's traditional uses, bioactive compounds, and pharmacological properties in both *in-vitro* and *in-vivo* settings, along with their mechanisms of action.

Keywords

Ethnobotany; pharmacology; bioactives; Solanaceae; Kantakari; *Solanum xanthocarpum*

Introduction

Solanum virginianum L. is an erect or creeping herb that belongs to the family Solanaceae. *S. xanthocarpum* Schrad, *S. surattense* Burm.f., *S. arabicum* Dunal, *S. armatum* Forssk., *S. ferox* Burm.f., *S. gula* Buch.-Ham., *S. jacquinii* Willd., *S. jacquinii* Miq., *S. macannii* Santapau, *S. mairei* H.Lev., *S. melongena* Wall., and *S. virginicum* L., are the synonyms of this species (1, 2, 3). The plant has different vernacular names throughout India and elsewhere (Table 1). It is one among the 'Dashamoola' group in Ayurveda. In Ayurvedic Pharmacopoeia of India, it has been mentioned that the formulations viz. 'Dasmul Asava' and 'Dashmularishta' containing roots of the plant are used as a tonic for lactating mothers (4). In ancient Ayurvedic treatises such as Charaka Samhita and Sushruta Samhita, the curative properties of fruits and the whole plant were mentioned in the treatment of mis-peristalsis,

Table 1. Vernacular names of *S. virginianum*

S. No.	Vernacular Name	Language	Reference
1	Thai egg plant, Yellow berried nightshade, Thorny nightshade	English	(3)
2	Kateli, Oonth kateli	Hindi	(3)
3	Dusparsha, Kantakee, Kshudra, Nidigdhika, Vyaghri	Sanskrit	(3)
4	Leipungkhanga	Manipuri	(3)
5	Kantakaari, Kirugulla, Mullusonde, Digdhike	Kannada	(3)
6	Kateringani	Marathi	(3)
7	Nelamulaka, Vakudu	Telugu	(3)
8	Kantakaari	Bengali	(3)
9	Kantakaricunta, kantakarivalutana	Malayalam	(3)
10	Makhua Khurn	Thai	(20)

bronchial asthma, tympanitis, piles, dysuria, and rejuvenation (5). An Ayurvedic preparation 'Kantkari Ghrita', mentioned in Charaka Samhita, is a unique formulation to treat cough, cold, fever, asthma, and other cardiac diseases (5). An increasing number of studies have been carried out on phytochemistry and pharmacology of *S. virginianum* in the past few decades. Considering the importance of the plant in Ayurveda and other traditional systems of medicine, we aimed to systematically review the phytochemical constituents and pharmacological properties of the plant in detail with a comprehensive discussion on the mechanism of action of bioactive constituents.

Materials and Methods

The current review is a systematic analysis of 48 publications obtained from esteemed bibliographical databases, including Scopus, PubMed, Web of Science, ScienceDirect, Google Scholar, and Wiley Online Library. The search employed specific keywords such as '*Solanum virginianum*,' '*Solanum xanthocarpum*,' and their synonyms, in combination with terms like 'uses,' 'traditional,' 'ethnomedicinal,' 'phytochemistry,' 'bioactives,' 'compounds,' 'pharmacology,' 'activity,' etc., found in publication titles or keywords. The selected literature encompasses investigations on morphological and taxonomical aspects, synonyms, species distribution, traditional and ethnomedicinal uses, bioactive compounds, and various pharmacological activities (both *in vitro* and *in vivo*). Among the retrieved publications, 37 relevant articles were chosen for a detailed examination, while the non-relevant ones were excluded. The timeframe for data collection spanned from the earliest publication to December 2022. ChemDraw 14.0 software was utilized to depict the structures of the compounds under investigation.

Results

Morphological characters of the plant

Plant height: 50-70 cm, seldom woody at base. Entirely armed with sturdy needle-like, broad-based prickles (0.5–2 cm × 0.5–1.5 mm). Leaves ovate to ovate-oblong, 4–9 × 2

–4.5 cm, paired with unequal leaf laminae; bearing sessile stellate hairs along veins; petiole 2–3.5 cm; unequal sinuate leaf margin with 5–9 lobes or pinnately parted with acute apex. Inflorescence an elongate raceme with copious armed, unbranched peduncle. Flowers bluish-purple, campanulate calyx. Calyx lobes oblong, prickly pubescent; petals rotate, densely pubescent with stellate hairs. Fruiting sepals and pedicels sparsely pubescent, prickles, stellate hairs. Fruit a pale-yellow berry, 1.3–2.2 cm in diameter (2, 3).

Distribution and growing conditions

This plant species (1) is indigenous to India, Afghanistan, Pakistan, Nepal, Bangladesh, Cambodia, Gulf States, China South-Central, Egypt, Iran, Malaya, Thailand, Sri Lanka, Japan, Hainan, Oman, Jawa, Saudi Arabia, Myanmar, Taiwan, Vietnam, and Yemen. It exhibits a wide distribution in dry regions of India, East-West Himalaya commonly found as a weed in waste areas and along road-sides (6, 7).

Ethnomedicinal uses

Ethnomedicinal practices have been ingrained in human societies since ancient times. According to the World Health Organization (WHO), around 80% of the global population, particularly in developing and underdeveloped regions, still relies on ethnomedicine due to limited access and affordability of modern healthcare. These traditional practices have a longstanding history of benefiting humanity and have even contributed to the development of some modern medicines. Recently, developed countries are also recognizing the value of ethnomedicine, acknowledging its potential benefits. Therefore, preserving and promoting these well-established remedies from tribal communities can prove valuable for combating both communicable and non-communicable diseases. Through an inclusive survey of ethnomedicinal reports, *S. virginianum* has emerged as a frequently utilized plant in various traditional formulations, displaying notable efficacy. Its root, flowers, stem, and fruits have been documented for their therapeutic potential against multiple diseases, as outlined in Table 2

Phytochemical constituents

A standardized extraction method was developed for

Table 2. Ethnomedicinal uses

S. No.	Part used	Form of usage	Ethnomedicinal uses	Country/Province	References
1	Fruit	Juice	Sore throat and rheumatism	Tripura, India	(14)
2	Fruit	Extract of dried fruit	Cough and fever	Tripura, India	(14)
3	Fruit	Paste	Pimples and swellings	Tripura, India	(14, 33, 34)
4	Fruit	Juice	Throat infections and inflammatory disorders	Manipur, India	(33, 34, 35)
5	Fruit	Extract of dried fruit	Cough, fever and heart diseases	India	(33)
6	Fruit	Extract of dried fruit	Diabetes	Kondh tribes of Dhenkanal district of Orissa	(33)
7	Root	Poultice	Piles	South India	(4)
8	Seeds	Seeds with mustard oil fumigation	Against dental caries, tooth ache, pus, and swelling of gums	India	(4)
9	Seeds	Not mentioned	Cough and Asthma	India	(4)
10	Stem, flowers, and fruits	Not mentioned	Burning sensation in the feet accompanied by vesicular eruptions	India	(33, 36, 37)
11	Whole plant	Not mentioned	Hernia	Mukundara tribes of Rajasthan, India	(6)
12	Whole plant	Not mentioned	Asthma, bronchitis, cardio tonic, chest pain, cough, diuretic, fever, gonorrhoea, jaundice, skin diseases, toothache, tuberculosis, ulcers	Local people of Taindol village, Jhansi, Uttar Pradesh, India	(6)

quantification and fingerprint analysis of steroidal glycoalkaloid compounds from the whole plant methanol extract (8). The compounds identified were solasonine, solamargine, and β -2 solamargine. The pressurized extraction method showed higher percentage composition of all compounds: $1.74 \pm 0.23\%$, $2.59 \pm 0.18\%$, and $2.01 \pm 0.14\%$, respectively. From the fruit extract, compounds such as campesterol, sitosterol, cycloartenol, sitosterol, stigmasterol, cholesterol, cycloartenol, solamargine, stigmasterol glucoside, and β -solamargine were isolated (9). The fruit's methanol extract yielded campesterol and four other steroidal glycosides (10).

Bioassay-guided isolation of the fruit aqueous extract revealed active principles: β -sitosterol and stigmasterol (11). Phenolic contents (chlorogenic acid, gallic acid, caffeic acid, ellagic acid, and vanillic acid) were investigated in mature fruits from three agroclimatic regions in Madhya Pradesh, India, using HPLC. The compounds chlorogenic and vanillic acids in the fruit samples varied from 0.227 to 0.516% and 0.039 to 0.156%, respectively (12).

HPTLC analysis of methanol extracts from different plant parts detected triterpenoid compounds like ursolic acid, oleanolic acid, and lupeol. Lupeol content was rich in fruit ($6.81 \pm 0.23 \mu\text{g}/\text{mg}$ DWE) and stem ($6.179 \pm 0.61 \mu\text{g}/\text{mg}$ DWE) extracts, while root extract was rich in oleanolic ($24.67 \pm 0.582 \mu\text{g}/\text{mg}$ DWE) and ursolic acids ($8.48 \pm 0.31 \mu\text{g}/\text{mg}$ DWE), followed by stem extract (6.39 ± 0.97 and $1.07 \pm 0.19 \mu\text{g}/\text{mg}$ DWE, respectively). Stem extract had a higher concentration of β -sitosterol, followed by leaf, root, and fruit extracts. Root extract was rich in compounds campesterol and ergosterol, while fruit and root extracts were rich in withanolide B. (13). Figure 1 displays structures of some bioactive compounds of the plant.

Pharmacological activities

Anti-inflammatory activity

Albino rats were used to evaluate the anti-inflammatory

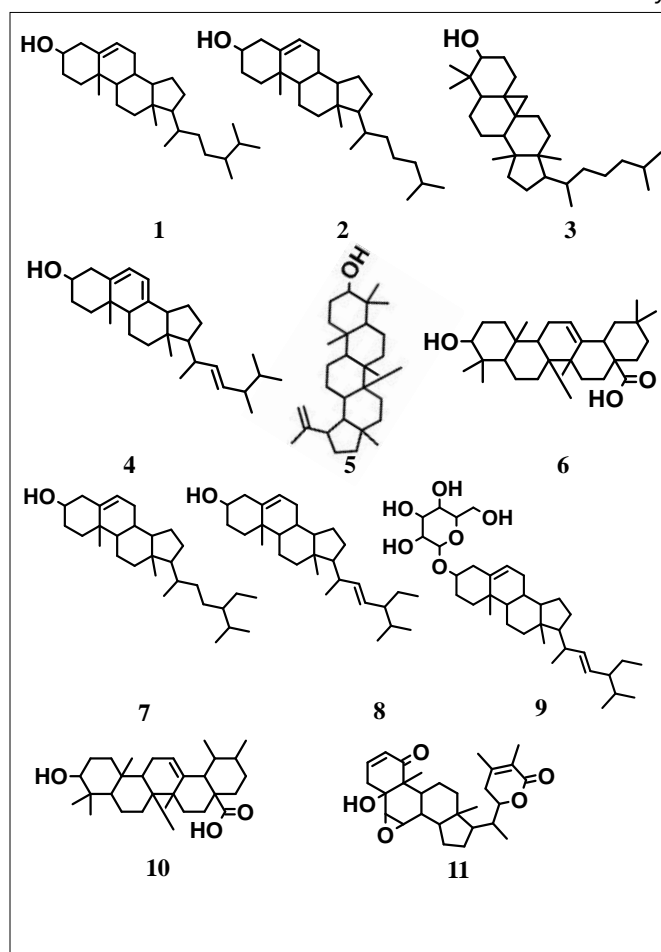


Fig. 1. Structures of bioactive compounds. Campesterol [1], Cholesterol [2], Cycloartenol [3], Ergosterol [4], Lupeol [5], Oleanolic acid [6], β -Sitosterol [7], Stigmasterol [8], Stigmasterol glucoside [9], Ursolic acid [10], Withanolide B [11].

properties of fruit methanol extract (100, 200, and 400 mg/kg doses) and aspirin (100 mg/kg dose) using the carrageenan-induced paw edema model. The 400 mg/kg dose of the fruit extract exhibited significant anti-inflammatory effects (0.80 ± 0.008 , 0.79 ± 0.003 , 0.77 ± 0.006 , 0.75 ± 0.01 , and 0.73 ± 0.003 ml at 0, 0.5, 1, 3, and 5 hours respectively), while aspirin showed 0.92 ± 0.003 , 0.91 ± 0.003 , 0.89 ± 0.003 , 0.86 ± 0.05 , 0.82 ± 0.003 mL paw volume at corresponding time intervals (14).

For the anti-inflammatory evaluation of leaf and seed extracts, albumin denaturation, protease inhibition, and membrane stabilization parameters were assessed. The leaf extract demonstrated higher albumin denaturation inhibition (25%) compared to the seed extract (8.33%). Diclofenac sodium, the standard reference, exhibited 13.88% inhibition of bovine serum albumin denaturation. The seed extracts showed inhibition rates of 61.11%, 27.77%, and 16.66% for acetone, ethyl acetate, and aqueous extracts, respectively (15).

Nephroprotective activity

The nephroprotective effect of fruit extract was assessed in Wistar rats (16). Nephrotoxicity was induced by intraperitoneal administration of gentamicin (100 mg/kg), and subsequently treated with fruit extract (200 and 400 mg/kg). The combined treatment resulted in a noteworthy rise in kidney weight, creatinine, blood urea nitrogen, and renal lipid peroxidation. Conversely, it led to a significant reduction in urine output, renal enzymatic, and non-enzymatic antioxidants.

Anti-asthmatic activity

The anti-asthmatic potential of petroleum ether, ethanol (95%), and water extracts of flowers was investigated using *in-vitro* and *in-vivo* models (17). The ethanol extract-treated group exhibited a significant dose-dependent contraction of the goat tracheal chain. In mice, doses of 50 and 100 mg/kg of the extract significantly ($p < 0.05$) reduced milk-induced eosinophilia (25.5 ± 5.71 and 18.16 ± 0.912 , respectively) compared to the control group (43.2 ± 0.663). The extract offered mast cell protection of 74.39% and 78.26% at 50 & 100 mg/kg doses, respectively, in comparison to the standard disodium cromoglycate (83.81%). Moreover, the extract demonstrated a significant down-regulation of capillary permeability by 62%, suggesting its potential in treating asthma and other allergic reactions (17).

Cardioprotective activity

The cardioprotective efficacy of the whole plant ethanol extract of *S. surattense* was assessed using the isoproterenol-induced myocardial infarction model (18). The extract exhibited significant myocardial protection at a dose of 400 mg/kg compared to 200 mg/kg, leading to noteworthy modulation of various antioxidant parameters and improvement in the overall antioxidant defense mechanism of the myocardial tissue. Moreover, the extract resulted in a notable increase in plasma lactate dehydrogenase (LDH) and creatine kinase-muscle/brain (ck-MB) enzymes in myocardial injured animals (18).

Hepatoprotective activity

Hepatoprotective effect of petroleum ether fruit extract was studied in acute liver-toxicity-induced Sprague-Dawley rats (7). The extract at 400 mg/kg dose showed the highest percentage protection (67.71%, 75.66%, 54.52%, 67.88%, and 72.34%) in marker enzymes. Antioxidant enzymes (catalase, reduced glutathione, and superoxide dismutase) also increased (110.81 nmol/mg, 145.17 unit/mg, and 59.83 unit/mg of protein, respectively).

Ethanol extract of the whole plant was investigated for hepatoprotective activity in an animal model with isoniazid and rifampicin-induced acute liver injury (19). Whole plant extract at 125 and 250 mg/kg doses significantly reduced serum levels of enzymatic and non-enzymatic markers. Liver histopathology of animals treated with 125 mg/kg dose extract showed significant hepatoprotective activity, characterized by well-established cytoplasm, prominent nuclei, sinusoid, and central vein in the hepatic cells.

Immunomodulatory activity

Ethanol and water extracts of fruit, root and whole plant were carried for immunomodulatory properties through carbon tetrachloride-induced oxidative stress, delayed-type hypersensitivity reaction, carbon clearance test and cold water swim endurance stress test in Wistar rats (6). The fruit aqueous extract at 200 mg/kg dose showed a notable increase in swimming survival time ($365.83 \pm 32.84\%$), hypersensitivity (58.82%), reduction in carbon clearance (0.148 ± 0.02) and oxidative stress parameters.

Larvicidal activity

The larvicidal activity of crude ethanol extract of the whole plant was assessed against *Aedes aegypti* and *Culex quinquefasciatus* larvae, reporting LC_{50} values of 788.10 mg/L and 573.20 mg/L, and LC_{90} values of 1288.91 mg/L and 1066.93 mg/L, respectively (20). The leaf ethanolic extract displayed potential larvicidal effects on *Culex quinquefasciatus* larvae of first to fourth instars, with respective LC_{50} values of 155.29 ppm, 198.32 ppm, 271.12 ppm, 377.44 ppm, and 448.41 ppm (21). For culicine species' fourth instar larvae, both fruit and root extracts were tested. The root aqueous extract exhibited increased mortality rates at 24 and 48 hours, with rates of $66.67\% \pm 4.71$ and $96.67\% \pm 4.71$, respectively, while the fruit extract showed higher mortality rates of $90.00\% \pm 2.89$ and $100.00\% \pm 2.89$ at 24 and 48 hours, respectively (22).

Mosquitocidal activity

The larvicidal efficacy of fruit extract was evaluated against *Aedes aegypti* larvae (Reference 23). The results demonstrated significant activity ($p < 0.05$) at concentrations of 100, 150, 200, 250, and 300 ppm, with corresponding LC_{50} values of 170.91, 195.07, 221.45, 253.18, and 279.52 ppm, respectively. When the fruit extract was used in combination with copepods, a notable increase in predatory efficiency of up to 8.7% was observed.

Antimicrobial activity

Antifungal activity of *S. virginianum* methanol extracts from various parts was evaluated using the agar well diffusion method against *Aspergillus niger*. The fruit and stem

extracts demonstrated the highest efficacy at 100 µg/mL with 27 mm and 19 mm inhibition zones, respectively (24).

Regarding the leaves' methanol extract, it exhibited notable antibacterial activity against *Pseudomonas aeruginosa* (12 ± 0.5 mm), *Salmonella typhimurium* (10 ± 0.6 mm), *Staphylococcus aureus* (09 ± 1.0 mm), and *Escherichia coli* (07 ± 1.3 mm). The minimum inhibitory concentration (MIC) ranged between 3.2 to 6.9 µg/mL while the minimum bactericidal concentration (MBC) ranged from 6.0 to 14.5 µg/mL (25).

Furthermore, antimicrobial efficacy evaluation of different whole plant extracts revealed that hydroethanol extract at 50 µg/ml. exhibited significant antibacterial activity against *S. aureus* (15 mm) and *E. coli* (8 mm), followed by ethanol (13 and 7 mm) and aqueous extracts (10 and 6 mm), respectively (26).

Antinociceptive activity

Antinociceptive property of methanol extract of aerial parts was analyzed in Swiss mice model (27). The extract at 500 mg/kg oral dose showed significant writhing inhibition (73.08 %) when compared to standard acetylsalicylic acid (85.63%).

Antispermatogetic/antiandrogenic properties

The antispermatogetic potential of solasodine, derived from fruits, was investigated on the male genital tract of *Canis familiaris* (dogs). Administration of the compound at 20 mg/kg dose, every alternate day for 30 days, resulted in infertility, accompanied by testicular lesions and pronounced impairment of spermatogenic elements (28).

Antioxidant activity

The chloroform and methanolic seed extracts displayed noteworthy DPPH activity (IC₅₀: 197.245 and 201.04 µg/ml. respectively) compared to the standard ascorbic acid (IC₅₀: 239.36 µg/ml.) (25). Additionally, the ethanol extracts from seeds and leaves exhibited considerable DPPH free radical scavenging activities with inhibition rates of 44.68% and 36.17%, respectively (15).

Molluscicidal activity

The molluscicidal activity of the entire plant's ethanolic crude extract was examined against snail species *Biomphalaria glabrata* and *Schistosoma mansoni*. Significant molluscicidal effects were observed against *B. glabrata* and *I. exustus*, with LC₅₀ values of 163.85 and 198.00 mg/L and LC₉₀ values of 219.33 and 236.80 mg/L, respectively (20).

Antidiabetic activity

The antidiabetic potential of hydro-methanol extracts from the whole plant was assessed in normal and alloxan-induced diabetic rats (29). Administration of powdered extract at 200 and 400 mg/kg doses resulted in significant reductions in blood glucose levels by 10.55%, 12.83%, 34.08%, and 37.29% in normoglycemic and alloxan-induced diabetic rats, respectively.

For evaluating the antidiabetic activity of leaf extracts from field-grown and *in-vitro* raised plants against alloxan-induced diabetic rats, a dose of 100-200 mg/kg was used (30). The results indicated that the methanol

extract from both samples demonstrated noteworthy anti-hyperglycemic activity at 200 mg/kg. Additionally, the leaf's ethanol extract showed effective antihyperglycemic and antihyperlipidemic activities (31, 32).

Anthelmintic activity

Ethanol extract of the whole plant showed potent wormicidal activity in earthworms at 100 mg/mL concentration (26).

Toxicity studies

Acute oral toxicity analysis of petroleum ether and hydroethanolic extract of the plant revealed that both the extracts did not show any toxicity effects on experimental animals at the highest dose of 2000 mg/kg (7, 16, 18).

Discussion

S. virginianum is a significant component in Indian traditional medicine, especially Ayurveda and used to treat various diseases. Its roots are vital in formulations like Kantkari Ghrita, Dasmul Asava', and Dashmularishta. The plant's leaf juice and fruits have been employed traditionally to address ailments such as sore throat, rheumatism, diabetes, and inflammatory disorders. Phytochemical profiling of different extracts reveals the presence of compounds like solamargine, solasonine, campesterol, β-sitosterol, cycloartenol, sitosterol, chlorogenic acid, and vanillic acid in varying compositions. Acute toxicity studies demonstrate the extracts' safety up to 2000 mg/kg in experimental animals. Moreover, various *in vitro* and *in vivo* pharmacological assessments suggest its anti-inflammatory, nephroprotective, anti-asthmatic, hepatoprotective, immunomodulatory, antimicrobial, larvicidal, antinociceptive, antispermatogetic, antioxidant, and anti-diabetic potentials.

The pharmacological activities of *S. virginianum* plant parts, especially the fruit, are attributed to their higher phenolic content in the ethanol extract (34). The aqueous extract of the fruit exhibits effective hypoglycemic activity, suggesting insulin-like effects, enhancing peripheral glucose utilization, and causing extra pancreatic effects (33). The ethanol extract of the plant shows significant cardio-protective effects by reducing heart tissue antioxidant biomarkers (GSH, SOD, CAT), increasing lipid peroxidation (LPO) levels, and restoring biochemical and histopathological alterations (18). The hydroethanolic extract of the fruit demonstrates hepatoprotective activity at 400 mg/kg dose, with normalization of hepatic enzyme levels and antioxidant enzymes (LPO, GSH, SOD, CAT) and attenuation of hepatic necrosis and inflammatory cell infiltration (7). Although the reported pharmacological effects validate traditional claims, the underlying cellular and molecular mechanisms remain unclear. Understanding the combinational effects of crude drug constituents and isolated compounds on signaling pathways is essential to bridge traditional uses and modern pharmacological applications.

Conclusion

S. virginianum, a crucial medicinal plant in Ayurveda and ethnomedicine, has undergone phytochemical analysis unveiling diverse bioactive compounds. Contemporary research attests to its broad pharmacological properties. Nonetheless, establishing quality control parameters and conducting clinical trials on traditional formulations are imperative to validate its versatile therapeutic effects. Additionally, robust methodologies are necessary to ensure consistent efficacy of traditional medicine for enhanced human health.

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Authors contributions

PB and SJ conceptualized work plan, compiled the data and wrote the manuscript. SGG and HVH carried out research analysis, reviewed and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors declare no competing interests to declare.

Ethical issues: None.

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