Indian Journal of Natural Products and Resources
Vol. 16(1), March 2025, pp. 49-59
DOI: 10.56042/ijnpr.v16i1.12159

Polygonatum verticillatum (L.) All.: Systematic information on ethnomedicine, phytochemistry and pharmacological properties

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Received 28 June 2024; revised received 21 January 2025; accepted 07 February 2025

Polygonatum verticillatum (L.) All. is a perennial herb commonly known as whorled solomons seal belonging to the Asparagaceae family and has a long history of uses in folklore and Indian and Chinese systems of medicine. The *P. verticillatum* is categorised under Astavarga group of drugs. It is widespread in Europe, China, Pakistan, and the Western Himalayas of India. Aerial and rhizome parts of the plant exhibit antipyretic, anticonvulsant, antimalarial, and antioxidant activities and are also used to treat spermopiotic, burning sensation, phthisis and urine-related problems. The aim of this review is to provide a systematic update on the ethnomedicinal and pharmacological uses, chemistry and formulations of *P. verticillatum*. Exhaustive bibliographic research has been carried out by different search engines like Sci Finder, Google Scholar, Scopus-Elsevier, various chemical abstracts, Medline, Web of Science, Directory of Open Access Journal (DOAJ) from inception until November 2024. In addition, books, non-English journals, and local literature were reviewed and included. As per the scientific literature, *P. verticillatum* has been reported to have less than thirty compounds, while the genus is reported to contain more than 116 compounds. A systematic update on *P. verticillatum* has been discussed with the aim of highlighting the importance of this plant.

Keywords: Ethnomedicinal, Liliaceae, Pharmacology, Phytochemistry, *Polygonatum verticillatum* Linn

IPC code; Int. cl. (2021.01)− A61K 36/00, A61P

Introduction

Medicinal plants play a pivotal role in addressing contemporary health challenges, including antibiotic resistance, chronic diseases, and the demand for sustainable therapies. As natural reservoirs of bioactive compounds, they offer an alternative to synthetic drugs, which often come with significant side effects and contribute to the growing issue of antimicrobial resistance. Many plant-derived metabolites, such as alkaloids, flavonoids, and terpenoids, exhibit potent antimicrobial, anti-inflammatory, and antioxidant properties, making them invaluable in combating resistant pathogens[1]. In the context of chronic diseases like diabetes, cardiovascular disorders, and cancer, medicinal plants offer therapeutic potential due to their multitarget mechanisms and lower toxicity. For instance, polyphenols from plants like green tea and turmeric have been shown to modulate metabolic pathways, reduce oxidative stress, and improve overall health outcomes. Such holistic benefits align with the growing preference for integrative and preventive medicine. Moreover, medicinal plants support the shift toward sustainability in healthcare. They can be cultivated with minimal environmental impact, unlike many synthetic drugs that rely on energy-intensive manufacturing processes. Ethnobotanical knowledge from indigenous communities further underscores their significance, providing insights into traditional uses and inspiring novel drug discovery. By harnessing the potential of medicinal plants, we can not only address present health issues but also pave the way for a more sustainable and inclusive approach to global healthcare.

The genus *Polygonatum* is a perennial herb (Asparagaceae) consisting of 71 species distributed throughout areas of the temperate Northern Hemisphere, such as China, Japan, Korea, India, Russia, Europe, and North America[2,3]. According to Miller, the name *Polygonatum* is acquired from the word yovi, which means knee, because it has many little Knees. Flora of India indicates the presence of *P. multiflorum*, *P. verticillatum*, and *P. cirrifolium*[4-6].

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Polygonatum species have been used in eastern countries, particularly Chinese and European medicines, for approximately 5000 years. *P. vericillatum* is an essential part of Astavarga group and is used to make the polyherbal Ayurvedic formulation Chyavanprash[7]. Rhizomes of this plant have medicinal properties and are consumed by folk people as part of food in various parts of the world[8]. *P. verticillatum* is rasayana and effective for pain, body weakness, senility, pyrexia, burning sensation, tuberculosis and lung disorders[9]. Rhizomes of the plant exhibit diverse biological activities, including antioxidants, antispasmodic, antidiarrheal, antipyretic, trachea-relaxant, anti-inflammatory, antimicrobial antinociceptive and diuretic[10-13]. In Ayurveda, the rhizomes of *P. verticillatum* are used as aphrodisiac or tonic for weakness[14-16]. *Polygonatum* plants have been widely used for functional food and ornamental purposes. This review gives a detailed insight into *P. verticillatum* and covers its classification botany, ecology, morphology, folk uses, phytochemistry, pharmacology, and formulations.

Classification in the plant kingdom

According to the APG III (Angiosperm phylogeny group) system of classification, *P. verticillatum* belongs to the kingdom Plantae, phylum Angiosperms, subphylum Monocotyledons, division Corolliferae, order Asparagales, family Asparagaceae, and genus *Polygonatum*[17].

Synonyms

P. verticillatum has many vernacular names depending on the region. In English, the plant is known as Solomon's seal, whereas, in Urdu and Sanskrit, it is known as Nor-e-Alam and Meda, respectively. In Hindi, Devamani, Pandura, Basuchidra, Shakakul, Vasuchhidra, Seal, and Mahamaida are the various names of plants. In addition, the local name of the plant in pahari (Local language of Himachal Pradesh, India) is salam mishri, in Nepali its keruwa, khinraula, peramole in Pashto, mithadodhu, Ra-mnye, salam dana mishri, khol in Kashmiri, and Saat Ashee in Gilgati. The plant is called Lun Ye Huang Jing by Chinese people[14].

Geographical distribution

P. verticillatum has worldwide distribution and is distributed in European countries, Turkey, the North and Central parts of Asia, Afghanistan, Pakistan, India, Nepal, China and Tibet up to the range of 4500 masl. In India, it is distributed in the temperate region of the Himalayas from Jammu and Kashmir (2000-3600 masl) to Sikkim (2600-4000 masl), Himachal Pradesh and Uttarakhand (1600-3500 masl)[14].

Botanical description

P. verticillatum is an erect and tall herb. The rhizomes of plants look like tubers of approximate thickness 0.7-1.5 cm and dull white in colour. Stem is usually 2-4 feet tall, erect, angled and grooved. Leaves are in the form of 4-8 whorls, which may be elliptical, lanceolate or linear. lanceolate leaves are generally 3½ × ¾ inches. Tips of leaves are acute, acuminate, obtuse or slightly rolled. Flowers are in whorl of 2-3, peduncle are 1-2 cm in length, bract may be present or absent. Pedicels are 2.5-4.5 mm, perianth, 8-9 mm white or sometimes green-tinged hermaphrodite. Stamens are epipetalous, filaments are 0.5-1.0 mm, ovary is 3 mm, and 2.5-3.0 mm style. Fruit berries are 7 mm in size and are green initially and red to orange in later stages of maturation. In Months from June to October, flowering and fruiting take place[18] (Fig. 1).

Population and threat status

The unlawful collection of *P. verticillatum* rhizomes is still ongoing despite the state medicinal plant board of Uttarakhand's prohibition on gathering this species from the wild. As a result, the species is classified as vulnerable and endangered[19]. In a report by Lahoni *et al.*, the study was conducted on the following five locations of Uttrakhand: Bhatkot, Vinayak, Balloni in Almora (1), Way to Sunder dhunga, Way to Kafni, Khati, Phurkia in Bageshewar (2), Vanasur, Debidhura, Khetikhan in Champawat (3), Ramgarh, Mukteshwer, Gagar in Nainital (4) and Lilam, Thal, Munsyari, Bhamangupha in Pithoragarh (5)[20]. The parameters studied were frequency, density, abundance, total basal cover (TBC), important value index (IVI), concentration of dominance (Cd) and distribution pattern (R/F ratio). The highest frequency (80%) was found in location 4 and the least in location 2 (50%). The highest density of 4.40 plant/m^2 was observed in location 2, whereas the least, 2.60 plant/m^2 was in location 5. The highest TBC of 0.91 cm^2, was found in location 2 and the least in location 5, i.e. 0.35 cm^2. IVI was highest at 51.68 in location 5 and least at 28.84 in location 2. Cd was highest 0.30 in location 2 and lowest 0.10 in location 4. The R/F ratio indicates the contiguous distribution of plants in

Fig. 1 — a) Fresh aerial part, b) Aerial part with fruit, and c) Rhizomes of *P. verticillatum*.

all locations except Mukteshwer and Gagar, where distribution was random. The study indicated a critically endangered status for this plant in all the sites studied and found it vulnerable and endangered in the Kumaun region[20]. In another study, population and status are accessed in the Kumaun and Garhwal regions of Uttarakhand. Studied sites were Kilburry, Jageshwar, Chaubattia, Doonagiri, and Abbott Mount in the Kumaun region. In the Garhwal region, Bhavisya Badri, Tungnath, Dayara, Bharsar, and Binsor sites were studied. In Kumaun, the lowest frequency was recorded in Chaubattia 50, with 1.13 plants/m^2 density and 8.99 IVI. Meanwhile, in Garhwal, the lowest frequency, 43.33, was recorded in Binsor, with 2.27 plants/m^2 density and 15.69 IVI. The threat category of *P. verticillatum* was accessed using major parameters (i.e. distribution range, habitat preference, population size, extraction trend, use pattern, native and endemic species). *P. verticillatum* is found vulnerable in the study area based on the above parameters[21].

Conservation strategies

P. verticillatum is listed under Schedule 8 of the Wildlife and Countryside Act, 1981, emphasising its need for conservation. Lohani *et al.* reported that planting beds enriched with forest litter and furrow structures yielded the best growth and morphological features compared to other treatments, such as plain + litter and row + litter[20]. In other areas, including the Kumaun Himalaya, Mankial Valley in the Hindukush Range of Pakistan, District Swat in Pakistan, North-West Himalaya, and Himachal Pradesh in India, the plant is classified as endangered, reflecting a severe population decline and an urgent need for conservation measures[21]. The plant is also listed as threatened in regions like Changa Valley in District Shangla, Pakistan, Garhwal Himalaya in India, Lohba Range of Kedarnath Forest Division, and District Kinnaur in Himachal Pradesh, India, where its population is at risk of becoming endangered without protective actions[22]. In several areas such as Kinnaur (Himachal Pradesh), Manali Wildlife Sanctuary, Trans-Himalayan Ladakh, Dhauli Ganga in Central Himalaya, Bhabha Valley, Uttarakhand Himalaya, Mornaula Reserve Forests, Nanda Devi National Park, Jammu and Kashmir, and other parts of the Indian Himalayan Region, the species is considered vulnerable, indicating a high risk of endangerment over the medium term[23]. It is categorised as rare in Kumaun, West Himalaya, and District Shangla in Khyber Pakhtunkhwa, Pakistan, where its small and localised populations make it highly susceptible to environmental changes. In the Lohba Range of Kedarnath Forest Division, Garhwal Himalaya, India, the species is described as uncommon, with limited occurrences that require monitoring to prevent potential declines. Organic fertilisers significantly enhanced soil fertility, vegetative growth, and overall yield without adversely affecting the soil. Seeds of *P. verticillatum* exhibit low germination rates (15%) under control conditions; however, germination improved to 60% when seeds were treated with 100 ppm gibberellic acid (GA) at -20°C[21]. Tiwari *et al.* demonstrated successful *in-vitro* shoot regeneration using MS (Murashige and Skoog) medium fortified with various plant hormones, including Indole acetic acid (IAA), indole butyric acid (IBA),

and naphthalene acetic acid (NAA) (0.5–1.0 mg/L). The optimal medium composition for regeneration included myo-inositol (100 mg/L), polyvinylpyrrolidone (0.05%, *w/v*), and agar (0.7%, w/v). Additionally, 1.0 mg/L thidiazuron (TDZ) combined with 2,4-D (1.0 mg/L) was most effective for callus induction in *P. verticillatum*[22]. Further, *P. verticillatum* can be propagated in spring by dividing rhizomes and planting them about 5 cm apart in enriched compost soil under shaded conditions. Seeds should be sown in a shaded greenhouse in early autumn. Germination is slow, and seedlings require several years to attain adequate size. Once established, they should be transplanted into individual pots for overwintering in shady areas, followed by permanent planting in spring. The ideal cultivation period spans March to October. *P. verticillatum* thrives in deep, rich soil and semi-shaded areas. It is intolerant of heat and drought, making such environments unsuitable for growth.

Ethnomedicinal uses

Rhizomes of many *Polygonatum* species are traditionally utilised for therapeutic purposes. In around over 5000 years of history, *P. verticillatum* has been applied in various remedies in the Asia continent. The different parts of the *P. verticillatum* are used for health benefits, alone or in combination with other ingredients. For example, *P. verticillatum*, when consumed with milk or ghee, acts as a general tonic for the body. The paste form of the plant is used in bone fracture by the Bhotiya tribe of Uttarakhand. In the Chamba and Kangra districts of Himachal Pradesh and Uttarakhand, the rhizomes serve as aphrodisiacs alone or mixed with *Bombax ceiba*, *Asparagus fillicinus* and *Dactylorhiza hatagirea*[9,22,23]. Tablets containing *P. verticillatum*, *Ficus religiose*, *Artemisia parviflora* and *Emblica officinalis* are used for diuretics and kidney functions[24]. Roots of plants are used to cure spermatorrhea, piles and leucorrhoea[25,26]. In Pakistan, gastric, genital and digestive problems are treated by the raw plant of *P. verticillatum*. In China, rhizomes of the plant are used to cure cancer[27-31]. Whereas rhizomes of *Polygonatum orientale* and *Polygonatum sibiricum* used in the treatment of diabetes[32] and *P. verticillatum* were also scientifically reported for the same[33]. *P. sibiricum* rhizomes also enhance the immune system and prevent aging[34]. Rhizomes of *P. orientale* act as aphrodisiac, anti-gout agents and tonics for general weakness, whereas *P. odoratum* is used to cure impotency, heart disease and lung disorders[35,36]. *Polygonatum kinganum* is also used to treat lung troubles and ringworms. Moreover, *P. verticillatum* also has similarities in traditional claims to other species of the *Polygonatum*, which are listed in Table 1.

Phytochemistry

P. verticillatum, a valuable medicinal plant from the Himalayan region, possesses significant but underexplored phytochemical potential. Traditional medicine systems attribute a variety of therapeutic properties to this plant, including anti-inflammatory, antioxidant, and antimicrobial activities. However, its relevance to modern pharmacology remains largely untapped, warranting systematic research to unlock its potential. Preliminary studies have identified bioactive compounds such as alkaloids, flavonoids, saponins, and polysaccharides in *P. verticillatum*. These metabolites are known for their diverse pharmacological activities, including modulating metabolic pathways, reducing oxidative stress, and exhibiting antimicrobial properties. To harness this medicinal plant, research should prioritize targeted isolation and characterization of specific compounds using advanced analytical techniques like UPLC-PDA, LC-MS, and NMR spectroscopy. Bioassay-guided fractionation can help identify active constituents with precise pharmacological activities.

Table 1 — Ethnomedicinal uses of various parts of *P. verticillatum*

S. No	Part used	Uses	References
1	Roots	Used for wound healing, anaemia, kidney troubles, sexual disorders, vaginal discharge, menstrual problems, piles, gastric and digestive problems, and rheumatism acts as a nerve and body tonic for general weakness, appetiser, vitaliser, rejuvenator in raw form.	7
2	Rhizomes	Act as an aphrodisiac, diuretic, general body tonic, wound healer, appetiser, anticancer and galactagogue.	11
3	Fruit	Used for the treatment of fever, anorexia, seminal weakness, general debility, strangury, and urinary problems. It is also used as an aphrodisiac, tonic, nerve tonic, heat promoter for the body, and appetiser. Fruit is edible as a vegetable.	12
4	Green foliage	Utilised as a vegetable when cooked with other herbs.	14
5	Whole herb	It acts as an appetiser and nerve tonic and is used for kidney trouble and body strength.	14

Furthermore, investigating the mechanisms of action at the molecular level through *in vitro* and *in silico* approaches will provide insights into their therapeutic potential. Clinical validation is equally critical to translate laboratory findings into practical applications. Rigorous studies on the safety, efficacy, and pharmacokinetics of *P. verticillatum* extracts or isolated compounds are essential. Standardization of extraction methods, quality control, and development of dosage formulations will enhance its acceptance in modern medicine. Therefore, earlier literature revealed that different classes of compounds have been isolated from the whole part or respective aerial and underground parts of the *Polygonatum* genus. Major classes in the *Polygonatum* genus include saponins and flavonoids, while the other classes, such as steroids, fatty acids, fatty esters, alkaloids, lignoids and benzoquinones, also show their presence. Around 116 compounds have been reported from the *Polygonatum* genus. The phytochemistry of *P. verticillatum* has not been much explored, and very few phytochemicals have been isolated so far, which include fatty acid, fatty esters, alkaloids, steroidal saponin, steroids, homoisoflavonoids, sesquiterpene lactone and some miscellaneous compounds. A list of isolated compounds from *P. verticillatum* is highlighted in Fig. 2 and Table 2. History also suggested that species of *Polygonatum* are less explored, and this fact paves a path for future research opportunities to discover new chemical entities from unexplored species.

Saponins

Saponins found in *Polygonatum* species are divided into two types, steroidal and triterpenoidal[37]. Steroidal saponin possesses a C_{27} skeleton, whereas triterpenoidal type consists of C_{30}. Steroidal saponins are further classified into furostanol, cholestane and spirostanol steroidal saponins. All saponins were isolated from the rhizomes of the *Polygonatum*. Furostanol type saponins are found in *P. kingianum* and *P. sibiricum* while cholestane type are in *P. odoratum.* The steroidal saponins are found in *P. odoratum, P. sibiricum*, *P. verticillatum* and *P. kingianum.* A few triterpenoidal saponins have also been reported from plants of this genus, especially from *P. sibiricum* and *P. kingianum*. The investigation of these saponins is pioneered by Yu[38]. From *P. verticillatum* three saponins namely (25S)-spirost-5-en-3*β*-ol-3-O-*β*-D-glucopyranosyl-(1→3)-[*β*-D fucopyranosyl-(1→2)]-*β*-D-glucopyranosyl-(1→4)-*β*-D-galactopyranoside has been reported[39], 26-O-*β*-d-glucopyranosyl-22ξ-hydroxy-(25R)-furost-5-en-3*β*, 26-diol, 3-O-*β* [xylopyranosyl (1→3) *α*-l-rhamnopyranosyl (1→2) *β*-d-glucopyranoside] (1) and 3-O-*β*-d-xylopyranosyl (1→3) *α*-l-rhamnopyranosyl (1→3) *β*-d-glucopyranoside diosgenin were reported[40].

Flavonoids

The Polygonatum genus contains major flavonoids that include flavonoids, homoisoflavonoids, homoisoflavanone, isoflavone, isoflavone, flavonoid glycoside, isoflavone glycoside, flavanone glycoside, flavones glycoside, dihydrochalcone. All these classes of compounds are isolated from different parts of *P. odoratum.* Rutin, quercetin and kaempherol, homoisoflavonoids including 5,7–dihydroxy-3-(4-methoxybenzyl)-8-methylchroman-4-one,5,7–dihydroxy-3-(2-hydroxy-4-methoxybenzyl)-8-methylchroman-4-one and 5,7–dihydroxy-3-(2-hydroxy-4-methoxybenzyl)-chroman-4-one have been reported from *P. verticillatum*[8,41].

Fatty esters

Propyl pentadecanoate and 2′,3′-dihydroxy propyl pentadecanoate have been isolated from the aerial part of *P. verticillatum*. This class has not been reported from other plant species so far[42].

Miscellaneous compounds

In addition to the above compounds, some steroids like diosgenin, sitosterol, santonin a sesquiterpene lactone, 5-hydroxymethyl-2-furaldehyde, and 2-hydroxybenzoic acid have been isolated from *P. verticillatum*[42].

Pharmacology

Antioxidant activity

Plants are rich sources of natural antioxidants, which play a vital role in protecting cells and tissues from oxidative damage caused by free radicals. Free radicals, such as reactive oxygen species (ROS) and reactive nitrogen species (RNS), are byproducts of normal metabolic processes but can cause cellular damage when produced in excess. This oxidative stress is linked to the onset of various chronic diseases, including cardiovascular disorders, cancer, diabetes, and neurodegenerative conditions. Antioxidant activity of leaves, rhizomes and isolated compounds of *P. verticillatum* were performed using 1, 1-diphenyl-2-picrylhydrazyl (DPPH) and the highest activity was reported from the crude aerial extract (IC_{50}: 122 µg/mL) followed by ethyl acetate extract (IC_{50}: 137 µg/mL) and *n*-butanol extract (IC_{50}: 167 µg/mL[42].

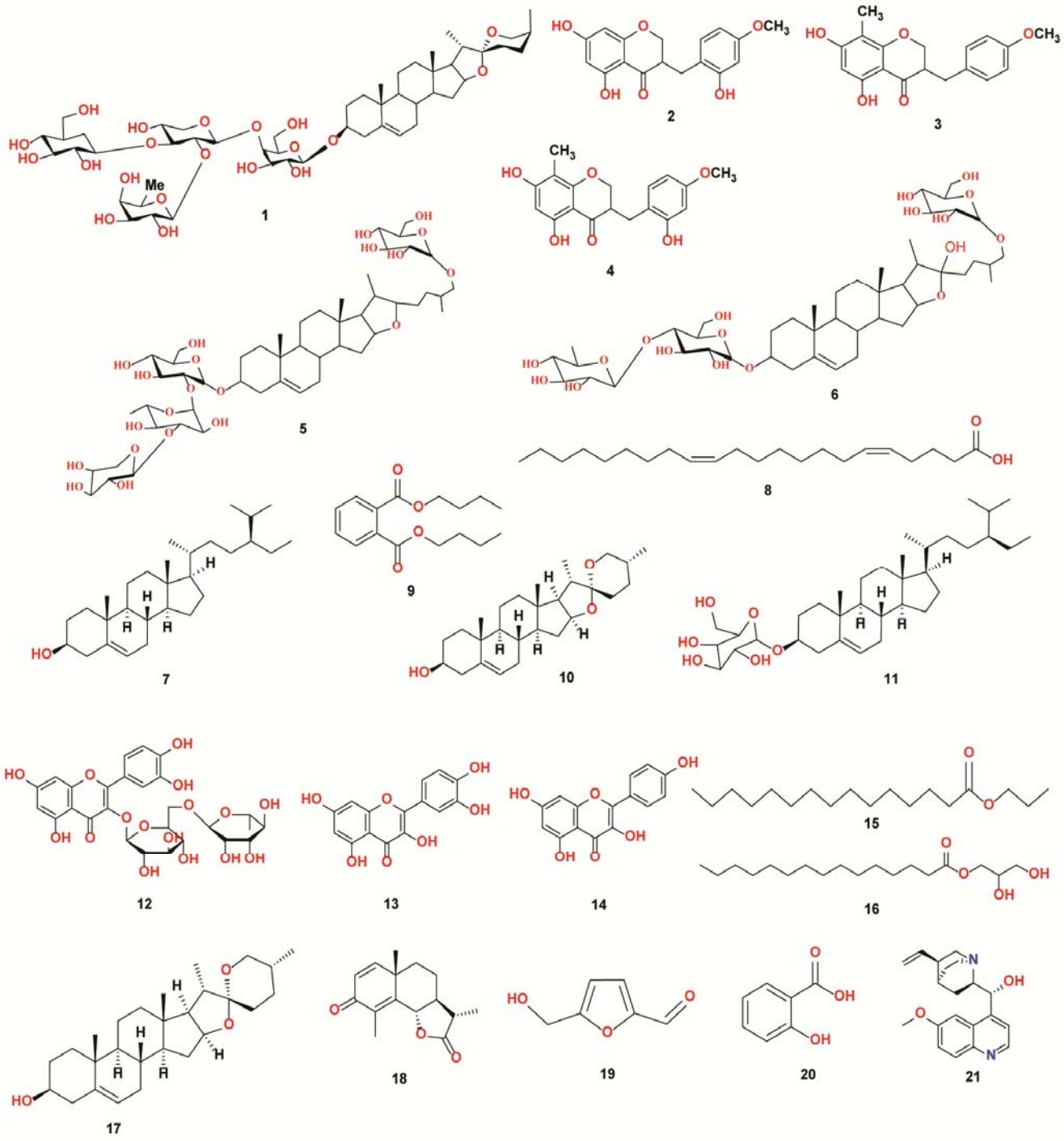

Fig. 2 — Phytochemistry of *P. verticillatum*.

Whereas rhizomes have maximum activity in the chloroform extract (IC_{50}: 90 µg/mL) followed by ethyl acetate (IC_{50}: 93 µg/mL) and then *n*-butanol (IC_{50}: 95 µg/mL)[43]. The two isolated compounds (diosgenin and santonin) from the rhizomes of *P. verticillatum* exhibited significant activity with IC_{50} of 65.80 and 50.03 µg/mL, respectively[10].

Antimalarial activity

The different extracts and fractions of aerial and rhizome parts of *P. verticillatum* were reported to have antimalarial potential against *Plasmodium falciparum*. The *n*-hexane fraction of aerial parts shows IC_{50}: 4.86 µg/mL while the chloroform parent extract has IC_{50}: 5.71 and 21.67 µg/mL,

Table 2 — Isolated compounds from *P. verticillatum*

S. No.	Isolated Compound	References
1	(25S)-Spirost-5-En-3*β*-Ol-3-O-*B*-D-Glucopyranosyl-(1→3)-[*β*-D Fucopyranosyl-(1→2)]-*β*-D-Glucopyranosyl-(1→4)- *β*-D-Galactopyranoside	39
2	5,7–dihydroxy-3-(2-hydroxy-4-methoxybenzyl)-chroman-4-one	8
3	5,7–dihydroxy-3-(2-hydroxy-4-methoxybenzyl)-8-methylchroman-4-one	8
4	5,7–dihydroxy-3-(4-methoxybenzyl)-8-methylchroman-4-one	8
5	26-O-*β*-D-Glucopyranosyl-22ξ-Hydroxy-(25*R*)-Furost-5-En-3*β*,26-Diol,3-O- *β*[Xylopyranosyl (1→3) *A*-L-Rhamnopyranosyl (1→2) *β*-D-Glucopyranoside]	40
6	3-o-*β*-d-xylopyranosyl (1→3) *α*-l-rhamnopyranosyl (1→3) *β*-d-glucopyranoside diosgenin	40
7	*β*-sitosterol	42
8	5z,13z-Docosadienoic Acid	42
9	Dibutylphthalate	42
10	Diosgenin	42
11	*β*-sitosterol-3-*o*-*β*-d-glucopyranoside	42
12	Rutin	41
13	Quercetin	41
14	Kaempferol	41
15	Propyl pentadecanoate	42
16	2′,3′-dihydroxy propyl pentadecanoate	42
17	Diosgenin	42
18	Santonin	42
19	5-hydroxymethyl-2-furaldehyde	42
20	2-hydroxybenzoic acid	42
21	Quinine	42

respectively[44]. The extracts and fractions of rhizomes were also reported for antimalarial activity[45].

Antipyretic activity

The methanolic extract of rhizomes and aerial parts of the *P. verticillatum* were found to be antipyretic against Brewer's-yeast-induced pyrexia in Wistar rats and albino NMRI mice. Earlier reports suggested that rhizomes were more effective than aerial parts (82 and 64%) at a dose level of 200 mg/kg, respectively[46].

Anticonvulsant activity

The aerial and rhizomes parts were assessed for the anticonvulsant potential in the pentylenetetrazole convulsion-induced model, and it was found both parts didn't have anticonvulsant activity[47].

Anti-inflammatory activity

The hydroalcoholic extract of rhizomes of *P. verticillatum* showed anti-inflammatory potential by reduction of carrageenan-induced paw oedema in rats. The activity was reported to be 65.22% at 200 mg/kg and comparable to aspirin[46]. Lipoxygenase inhibitors are used to control arachidonic acid metabolism and also have a role in the treatment of inflammatory disorders such as inflammatory bowel disease. Khan and his group observed the inhibition of soybean lipoxygenase by the rhizomes and leaves of *P. verticillatum*. The rhizomes showed significant inhibition of lipoxygenase (IC_{50}: 102±0.19 µg/mL) in comparison to claimed previous reports, i.e. IC_{50}: 22.6±0.09 µg/mL[48]. Ethyl acetate fraction was also found to have maximum activity with IC_{50}: 97 µg/mL, followed by water fraction and crude extract. The rhizomes of *P. verticillatum* were preliminary screened for antispasmodic activity using an *in-vitro* model of rabbit jejunum contraction. The methanol extract showed complete relaxation of contraction at 10 mg/mL in a dose-dependent manner and was found compatible with cromakalim and verapamil. The extract inhibited the low K^+induced contractions, while high K^+induced contractions were partially inhibited[47].

Antinociceptive activity

The various pain models in rodents, like visceral, formalin and hot plate models, were used for the evaluation of aerial parts of *P. verticillatum* at 50, 100,

and 200 mg/kg concentration[48]. The extract of the aerial part showed marked activity that might be due to the presence of some pharmacologically active substances and may interfere with the line of defense[40].

Bronchodilator activity

The dose of 0.01–10 mg/mL of *P. verticillatum* rhizomes has inhibition of the high K+ and carbachol-induced contractions in guinea-pig tracheal tissues and is comparable with verapamil (Muscle relaxant drug). This found that the *P. verticillatum* has tracheorelaxant activity[43]. Similarly, in another study, methanolic extract of leaves of *P. verticillatum* was assessed for tracheorelaxant activity using isolated tracheal tissues of rabbits. The plant extract was strongly found and reported to have bronchodilator activities against carbachol and K^+ (80 mmol/L) induced contaction[47].

Urease inhibition activity

The crude extract of aerial parts of *P. verticillatum* exhibited a significant reduction of urease enzyme. The *n*-butanol faction was most potent, followed by ethyl acetate, while *n*-hexane and chloroform fractions did not show the activity[49].

Antimicrobial activity

The crude extract, fractions and isolated compounds of leaves and rhizomes of *P. verticillatum* were tested for their antimicrobial potential against Gram-positive and Gram-negative bacteria. The rhizomes showed significant antibacterial activity against *S. aureus*, *E. coli*, *S. typhi* and *S. fllexeneri*[50]. Aerial parts showed effectiveness against *B. subtilis* and *P. aeruginosa*. The isolated compound diosgenin and santonin showed a significant zone of inhibition against both strains[48]. In another case, Sharma *et al.* reported antimicrobial potential extract, fractions and isolated homoisoflavonoids from the rhizomes of *P. verticillatum*[8]. 5,7-dihydroxy-3-(2-hydroxy-4-methoxybenzyl)-8-methylchroman-4-oneshowed good zone of inhibition as compared to other homoisoflavonoids isolated from *P. verticillatum*. In an antifungal activity, rhizomes and leaves showed limited effect on *M. canis* and *F. solani* while *Trichophyton longifusus*, *Candida albicans* and *Aspergillus flavus* were found resistant[10]. At the same time, santonin showed marked antifungal activity against these strains, contrary to diosgenin.

Insecticidal activity

In-vitro insecticidal assay, aerial parts of *P. verticillatum* showed moderate activity for n-hexane (50%) and chloroform (30%) fractions against *Rhyzopertha dominica*[48].

Antileishmanicidal activity

In-vitro anti-leishmanicidal activity was assessed by Saeed *et al*., and they did not find any activity of crude extract and subsequent fractions of aerial parts of *P. verticillatum* against Leishmania major[48].

Phytotoxicity

At the dose of 5, 50, and 500 µg/mL of crude extract and subsequent fractions of the plant showed phtotoxicity against *Lemna acquinoctialis* with complete growth inhibition at a maximum dose of 500 µg/mL[48,51].

Diuretic activity

Diuretic activity of rhizomes and aerial part of *P. verticillatum* was tested in male Albino rats and male Wistar rats, respectively, at concentrations 300 and 600 mg/kg. Plants exhibit mild activity at a concentration of 300 mg/kg compared to the standard drug hydrochlorothiazide[48,52].

Antidiarrheal activity

The rhizomes of *P. verticillatum* were reported for their antidiarrheal activity in diarrhoea-induced mice. *P. verticillatum* exhibited a marked reduction in diarrhoea compared to the well-known drug loperamide in a dose-dependent manner[11].

Anti-insulin activity

According to the traditional system of medicine, *P. verticillatum* is consumed to treat diabetes. In validation of this plant, the preliminary study was conducted on insulin-resistant HepG2 cells and observed the antidiabetic potential in insulin-resistant HepG2 cells[33,53].

P. verticillatum based products

Tailas (Vachadi, chitrakadi, rasaymahapadma, dhanwantharam, Maharishi amritkalash), astavargachurna, chayavanprash rasayan, ghritas (mahakalyan, mahamayura, jivaniya, vajikaran, Divya falghrit), brahinigutika and indrokt are some of the formulation of *P. verticillatum*[7]. Detailed descriptions of some of the formulations are listed in Table 3.

Table 3 — Herbal formulation of *P. verticillatum*

Traditional system	Name	Ingredients	Uses	References
Indian	Divya falghrit	*Rubia cardifolia, Glycyrrhiza glabra, Terminalia chebula*, *Terminalia bellirica*, *Emblica officinalis, Curcuma longa, Ferula asafoetida, Picrorhiza kurroa, Nymphaea nouchali, Polygonatum verticillatum, Lilium pohyphyllum, Withania somnifera, Asparagus racemosus*	Infertility and pregnancy-related disorders in women	5
	Maharishi amrit kalash	*Emblica officinalis, Polygonatum verticillatum, Asparagus racemosa, Boerhaavia diffusa, Gmelina arborea, Terramnus labialis, Solanum xanthocarpum, Oroxylum indicum, Pedalium murex*	Antioxidant	15
	Patnjali chyawanprash	*Sida cordifolia, Piper longum, Teramnus labrialis, Pistacia integerrima, Phyllantus niruri, Vitis vinifera, Terminalia chebula, Tinospora cordiofolia, Pterocarpus santalinus, Hapenaria acuminate, Curcuma zedoaria, Polygonatum verticillatum, Adhatoda vasica, Polygonatum cirrifolium,Cyperus rotundus, Boerhavia diffusa, Lilium pohyphyllum, Elettoria cardamomum, Emplica officinalis, Nymphea nouchali, Vidarikand Pueraria tuberosa, Roscoea alpina,*	Rejuvenator tonic	23
	Dhanwantharam oil	*Sesamum indicum Oil, Sida retusa, Gmelina arborea, Aegle marmelos, Stereospermum suaveolens, Dolichos biflorus, Polygonatum verticillatum, Polygonatum Sp., Cedrus deodara, Schleichera trijuga, Rosea procera, Rosea Sp., Santalum album, Hemidesmus indicus, Valeriana jatamansi, Microstylis wallichii, Microstylis muscifera, Trigonella foenum-graecum, Oroxylon indicum, Boerhavia diffusa, Acorus calamus, Withania somnifera, Commiphora myrrha, Ipomoea palmata, Asparagus racemosus, Emblica officinalis, Terminalia bellerica, Terminalia chebula, Glycyrrhiza glabra, Puacedanum graveolens, Terminus labialis, Phaseolus trilobus, Elettaria cardamomum, Eugenia caryophyllus, Ziziphus jujuba, Cinnamomum zeylanicum, Rock Salt, Asphaltum, Desmodium gangeticum, Hordeum vulgare, Pseudarthria viscida, Solanum Xantho carpum, Solanum indicum, Premna latifolia, Tribulus terrestris,*	Rejuvenator of skin	24

Conclusion

Genus *Polygonatum* is one of the essential plant species of Astavarga group and consist of 71 species, out of which the phytochemistry of *P. odoratum* has been well explored, but *P. verticillatum* is least explored species of this genus. Around 116 molecules have been isolated and reported from the genus to date, and homoisoflavonoids are one of them. This plant is a critically endangered medicinal plant found in the temperate Himalayan region, valued for its remarkable effectiveness in treating various severe ailments. Its prominent role in traditional medicine has made it highly sought after, leading to significant exploitation and putting immense pressure on its natural populations. This unsustainable utilisation poses a serious risk to the species survival, emphasizing the need for urgent conservation measures. Developing and implementing sustainable harvesting practices is essential to preserve this valuable plant, ensuring its continued availability and safeguarding its ecological and medicinal significance for future generations.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgement

The authors thank CSIR, India, for financial support (MLP-0203).

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