Pharmacology and biochemistry of *Polygonatum verticillatum*: A review

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ABSTRACT

*Polygonatum verticillatum* (Linn.) All. syn. *Convallaria verticillata* Linn. is a valuable medicinal plant, distributed in the temperate Himalaya at the elevations 2 400 to 2 800 m. It is a perennial rhizomatous herb and contains various pharmacologically important secondary metabolites among which the most important are α-bulnesene, linalyl acetate, eicosadienoic, pentacosane, piperitone, docasane, diosgenin, santonin and calarene. It also possesses antimarial, anti-inflammatory, anti-inflammatory, anticonvulsant, lipoxigenase, urease inhibition, diuretic, tracheorelaxant, antidiarrheal, antispasmodic, antinociceptive, antifungal, antibacterial and bronchodilator activities. The plant also got importance in traditional systems of medicine due to its broad therapeutic potential especially of its rhizome. But in the past few years, over exploitation of plant parts caused the decline in the frequency of this species due to which it became threatened, endangered and vulnerable in different parts of the world. So efforts are being made in certain regions of the world for both ex-situ and in-situ conservation. This paper briefly reviewed the botanical, traditional, phytochemical, pharmacological and conservation related aspects of this plant.

1. Introduction

*Polygonatum* (King Solomon’s-seal, Solomon’s seal) is a genus of erect or decumbent perennial herbs belonging to the family Liliaceae representing about 57 species in the world. This genus is mostly distributed in the temperate regions of the northern hemisphere, most concentrated in the Himalayas. It also occurs in East Asia, where it is found mainly in China and Japan where 40 species of this genus were found[1]. In addition to this, they are also found in India, Pakistan, Korea, Nepal, Afghanistan, Bhutan, Russia and in moderate climate zones of North America and Europe. The Flora of Pakistan showed the presence of four different species of *Polygonatum*, including *Polygonatum multiflorum*, *Polygonatum geminiflorum*, *Polygonatum cirrhifolium* and *Polygonatum verticillatum* (*P. verticillatum*). These species are widely distributed in various part of the country including Hazara, Chitral, Swat and Kurram Agency[2,3]. The characteristic feature of this genus is thick, fleshy creeping sympodial rhizomes. According to Miller (1754) the generic name of *Polygonatum* is derived from its characteristic feature of rhizome which resembles to a great extent as yovi, a knee, because it has many little knees[4]. In the year 1753 Linnaeus listed three species of *Polygonatum* in his book ‘Species Plantarum’ under the genus *Convallaria*, namely, *Convallaria verticillata*, *Convallaria polygonatum* and *Convallaria multiflora*[5]. Later on, this was listed under the generic name *Polygonatum* by Alloni[6]. In the natural system of classification the family Liliaceae of Angiosperms was classified in the series Coronarieae by Bentham and Hooker[7,8]. The genus *Polygonum* is very important in term of their high medicinal value as most of their members are used in herbal medicine from thousands of years in different region of the world. All plant parts have some medicinal value but the most important of these parts is the rhizomes which contain many important medicinal activities like adaptogenic, antioxidant, cardiotonic, demulcent, diuretic, energizer, hypoglycemic, tonics, antibacterial and antifungal[9], and also used in the treatment of pulmonary problems for dry coughs.
and tuberculosis[10,11]. Many of their members can reduce the blood sugar level[12]. Due to high medicinal value, some of their members are overexploited and become threatened or vulnerable like *P. verticillatum* (Linn.) All. and *Polygonatum cirrhifolium* (Wall.) Royle[13].

*P. verticillatum* syn. *Convallaria verticillata* Linn. commonly known as whorled solomon’s seal is a perennial rhizomatous herb and distinguished medicinal plant of temperate Himalaya. It is frequently distributed between the elevations 2 400 to 2 800 m[14]. It is a highly valuable medicinal plant specially rhizome which in the form of syrup is used for the treatment of pain, pyrexia, burning sensation and for phthisis[15] in combination with other herbs as it promotes urine discharge[16]. The plant is also used as emollient, aphrodisiac, appetizer, galactagogue and tonic for weakness[17]. Rhizome of this plant is an important ingredient of Ashtavarga, a drug used in Ayurveda as a tonic and for aphrodisiac[18,19]. The plant also exhibits antifungal activities and used in the preparation of cosmetics as a skin tonic. Its rhizome (Meda/ Mahameda) is collected from wild and traded for medicinal purposes. This is one of the reasons that *P. verticillatum* is rapidly disappearing. So there is an urgent need for conservation of this plant[20].

### 2. Systematic position

According to phylogenetic system of classification of Hutchinson, the systematic position is: Kingdom: Plantae, Phylum: Angiosperms, Subphylum: Monocotyledons, Division: Corolliferae, Order: Liliales, Family: Liliaceae, Genus: *Polygonatum*, Species: *P. verticillatum*[21].

### 3. Distribution

*P. verticillatum* has worldwide distribution. Distributed from montane to alpine Himalaya, Kashmir to Northeast States; Sikkim, Southeast Tibet, West Asia, Europe (except Mediterranean region) [22] in temperate Himalayas[23] in Russia (W. Siberia, Caucasia) Afghanistan, Pakistan (Chitral, Dir, Swat, Hazara, Gilgit, Azad Jammu Kashmir), Kashmir, India, Nepal, Sikkim, Bhutan and China (Gansu, Nei Mongol, Qinghai, Shaanxi, Shichuan, Xizang). From Garhwal Himalaya the species was reported from Bhuna, Dunagiri and Niti[24], from Binsar by Gaur[22], and from Tungnath, Rudranath, Valley of Flowers and Dayara by Vashistha[25].

### 4. Vernacular name

The vernacular name of *P. verticillatum* is Solomon’s seal in English; Nor-e-Alam in Urdu; Basuchirda, Devamani, Pandura, Shakakul, Seal, Vasuchirida, Mahaimada in Hindi; Meda in Sanskrit; Salam mishri in Pahari; Keruwa, Khinraula in Nepali; Peramole in Pashto; Salam dana, mishri, mitha dodhu, Ra-mnye, Khol in Kashmiri; Saat Ashee in Gilgati or Balti; Lun Ye Huang Jing in Chinese.

### 5. Botanical description

*P. verticillatum* is a perennial rhizomatous herb, its rhizomes are usually tuber like, shortly branched and 0.7–1.5 cm thick. Stem usually erect, 2 to 4 feet/ 30–60 cm in height, angled and grooved, glabrous sometimes mottled. Leaves in whorls of 4 to 8, occasionally alternate near the base of stem, sometimes opposite near the apex, sessile, elliptic to narrowly lanceolate/linear, 4 to 8 × ¼ to ½ inch, or in case of lanceolate, 3½ × ¾ inch, tips usually acute but some time acuminate, margins entire, sometimes obtuse or slightly in rolled, lower surface is glaucous. Inflorescence racemes whorled, 2 to 3 flowered, peduncle 1–2 cm, bract < 1 mm or some time absent, pedicel 2.5–4.5 mm, hermaphrodite, perianth 8–9 mm or 1/3 inch, white or pale yellow, tinged with green, contracted in the middle, teeth inside, tip hairy. Stamens are epipetalous, filaments 0.5–1.0 mm, ovary 3 mm, style 2.5–3.0 mm. The flowering and fruiting takes place in the month of June to October. Fruit is in the form of berries which are red, becoming purple on maturation, 6–8 mm or ¼ inch in diameter[26].

### 6. Traditional uses

Ethnomedicinally, the plant is very important. Different parts of the plant in crude form or with some other ingredients are used for the...
cure of different diseases. For example, in some parts of Gilgit the root of the plant is utilized with milk and ghee as general tonic[27], in some other regions gastric flatulence and allergies are treated by the oral administration of this plant. In India this plant is used for the cure of spermatorrhoea and piles for this the fresh roots are broken into small pieces and kept in water for overnight and then crushed in same oral administration of this plant. In India this plant is used for the cure of different diseases. For example, in some parts of Gilgit the root of the plant is utilized with milk and ghee as general tonic[27], in some other regions gastric flatulence and allergies are treated by the oral administration of this plant. In India this plant is used for the cure of spermatorrhoea and piles for this the fresh roots are broken into small pieces and kept in water for overnight and then crushed in same water and taken daily in morning[28]. In another state of India the root powder of this plant is taken daily with water for leucorrhoea[29], the small pieces and kept in water for overnight and then crushed in same water and taken daily and nurished[10] and eaten mixed with dairy products and as a tonic of spermatorrhaea and piles for this the fresh roots are broken into small pieces and kept in water for overnight and then crushed in same water and taken daily in morning[28]. In another state of India the root powder of this plant is taken daily with water for leucorrhoea[29], the root paste in some area are applied on wounds. In some places the whole herb is utilized to cure appetite, as nervine tonic, for kidney trouble and to restores body strength[30]. Some other traditional uses from different areas are listed in (Table 1). In some Himalayan region this plant is consider as wild vegetable and the root of the plant is eaten raw[33,34] and in some areas the whole plant is cooked and utilized in raw form[53].

7. Phytochemistry

The plant contains many phytochemicals isolated from its different parts like the compound diosgenin isolated from rhizome of the plant[62]. The rhizome also contains galactose, galactose, sucrose and fructose[63,64]. The study showed that the aerial parts of plant contain saponins, alkaloids, phenols, flavonoids, tannins, etc.[63]. Chemical constituents of plant were identified in n-hexan fraction by using gas chromatography mass spectrometry, which showed that the aerial oily components of plant contain α-bulnesene, linalyl acetate, eicosadienoic, pentacosane, piperitone, docasane, and calarene[66]. By using mass and NMR spectra two compounds 2-hydroxybenzoic acid and β-sitosterol were isolated from the rhizome of P. verticillatum[67]. The rhizome of the plant also showed the presence of lysine, serine, aspartic acid, threonine, diosgenin, β-sitosterol, sucrose and glucose[68]. Two chemical compounds diosgenin and santonin were also isolated from the rhizomes of P. verticillatum[69]. To test the biological activities of the rhizome of this plant two different compounds, 5 hydroxymethyl-2-furaldehyde and diosgenin, were isolated from the rhizome with the help of bioactivity guided isolation[70]. The study by Khan et al. showed that the crude extract of P. verticillatum rhizome as well as its solvent extract has significant amount of alkaloid and saponin which are responsible for the bioactivity of the plant[71]. In another study the rhizome of the plant showed significant concentrations of flavonoid and phenolic compounds[72]. The aerial parts of the plant contain significant amount of alkaloid and phenolic content[70]. The study by Khan et al. indicated that the aerial parts of the plant contain different phytochemical including saponins, alkaloids, flavonoids, phenols, sterols, terpenoids and tannins[67]. Phytochemically, lectin has been isolated from the roots of P. verticillatum the lectine was obtained in purified form (120 mg/ kg) that contain high percentage of asparaginic acid (28%)[73]. Both the rhizome and aerial parts of plant were analysed for their phytochemicals both the parts showed the presence of saponin, alkaloids, glycosides, phenols, flavonoids, sterols and tannins, but the rhizome also showed the presence of anthraquinones and terpenoids[74]. By the use of various modern techniques such as high resolution electron ionization-mass spectrometry, 1D and 2D NMR, two new compounds were isolated from the rhizome of plant such as propyl pentadecanoate and 2/, 3/ dihydroxypropyl pentadecanoate[75].

8. Nutritional composition

The bulb and rhizome of the plant were analyzed for their nutritional composition the mineral profile of plant extract showed that the plant contained both micro and macronutrient at concentrations of P [(100.00 ± 0.00) mg/100 g], K [(13.33 ± 0.39) mg/100 g], Na [(37.82 ± 2.19) mg/100 g], Ca [[1338.30 ± 3.83] mg/100 g], Mg [(90.10 ± 0.80) mg/100 g], Fe [(23.64 ± 0.88) mg/100 g], Cu [(0.21 ± 0.01) mg/100 g], Mn [(28.64 ± 0.37) mg/100 g] and the nutritional constituents were at concentrations of moisture [(84.53 ± 4.69) g/100 g], protein [(16.20 ± 1.62) g/100 g], fat [(0.46 ± 0.06) g/100 g], fibre [(12.33 ± 0.57) g/100 g], carbohydrates [(17.07 ± 0.00) g/100 g], ash [(7.45 ± 0.79) g/100 g], energy value [(108.23 ± 9.73) Kcal/100 g] [76]. In another study the nutrient analysis of rhizome extract showed that the plant contained significant amount of both micro (Zn, Cu, Cr, Fe, Mn, Ni) and macronutrient (Ca, Na, K) which was determined by using atomic absorption spectrometry for micronutrients and flame
phometry for macronutrients analysis. In nutritional constituents the plant contained significant amount of proteins, fats, fiber, carbohydrates, ascorbic acid along with ash and moisture content[77]. Mineral profile of the aerial parts of P. verticillatum was also analyzed in different plant extracts the study showed that the plants contain significant amount of both micronutrient (Zn, Cu, Cr, Fe, Pb, Mn, Ni) and macronutrient (Ca, Na, K)[78].

9. Pharmacological activities

9.1. Antioxidant activities

Free radical scavenging activities of aerial parts of the plant were analyzed using 1,1-diphenyl-2-picrylhydrazyl (DPPH) by Khan et al., which showed the highest activities was the crude extract (IC$_{50}$: 122 µg/mL) and followed by ethyl acetate extract (IC$_{50}$: 137 µg/mL) and n-butanol (IC$_{50}$: 167 µg/mL) fractions[66]. The rhizome extract showed significant antioxidant activity in DPPH assay with the most potent antioxidant activity observed in chloroform (IC$_{50}$: 90 µg/mL) followed by ethyl acetate (IC$_{50}$: 93 µg/mL) and then n-butanol (IC$_{50}$: 95 µg/mL)[77]. Another study was conducted on the antioxidant potential of two compound diosgenin and santonin, isolated from P. verticillatum rhizomes for this purpose DPPH and reducing power assays were employed the result showed that both compounds exhibit strong antioxidant activity in DPPH assay the inhibitory concentration (IC$_{50}$) values for diosgenin is (65.80 µg/mL) and santonin (50.03 µg/mL), respectively. Similarly in reducing power assays the IC$_{50}$ values are diosgenin (62.10 µg/mL) and santonin (46.40 µg/mL), respectively[65].

9.2. Antimalarial activities

The antimalarial activities of different extracts of P. verticillatum aerial parts were checked against Plasmodium falciparum. The maximum potency was showed by n-hexane fraction (IC$_{50}$: 4.86 µg/mL), which was followed by chloroform fraction (IC$_{50}$: 5.71 µg/mL) but as compared to other the crude extract was less potent (IC$_{50}$: 21.67 µg/mL) against this pathogen[79]. The rhizome of P. verticillatum was tested for its antimalarial activity against same Plasmodium falciparum the result showed that the crude extract and its non polar fractions showed significant antimalarial activity[72].

9.3. Antipyretic activity

The antipyretic activity of rhizome and aerial parts of the plant were analyzed in Wistar rats and in Albino NMR imaging mice the Brewer’s-yeast-induced pyrexia in test organisms the organisms were treated separately with rhizome and aerial plant extracts and the result showed that both the extract exhibited marked antipyretic activity but the rhizome extract was more effective as compared to aerial parts which is dose dependant like rhizome showed (82.20%) at 200 mg/kg and aerial parts 64% at 200 mg/kg[80].

9.4. Anticonvulsant activity

The rhizome and aerial parts of the plant were analyzed for their anticonvulsant activity the convulsion were induced by pentylenetetrazole both the extract were separately analysed for this activity but the plant extracts didn’t show any effect against this activity[74].

9.5. Anti-inflammatory activities

The anti-inflammatory activity of P. verticillatum rhizome was tested in rat in which the carrageenan induced rat paw edema. Result showed that the plant rhizome showed marked reduction in edema the anti-inflammatory activity were shown at the test doses of 50, 100 and 200 mg/kg. At 200 mg/kg the protection is 65.22% which is similar to aspirin[81]. For again the same activity the aerial parts of plant were analyzed in wistar rats in this study with the help of carrageenan hind paw edema is induced the methanolic extracts of plant shows that the plant exhibit significant anti-inflammatory activity and reduction in paw edema in rats were observed at the test dose of (50, 100 or 200 mg/kg) but the maximum result was observed at the concentaration of 200 mg/kg (65.22%)[67].

9.6. Tracheorelaxant activity

P. verticillatum rhizome was studied for its tracheorelaxant activity in isolated guinea-pig tracheal tissues the result shows that P. verticillatum rhizome caused complete inhibition of the high K$^+$ and carbachol-induced contractions at the dose range of 0.01–10 mg/mL which is similar to verapamil which also cause relaxation of tissue[81].

9.7. Lipoxygenase activity

P. verticillatum rhizome was tested for inhibition of soybean lipoxygenase with UV absorbance based enzyme assay, the plant shows significant activity against lipoxygenase with resultant IC$_{50}$ value of (102 ± 0.19) µg/mL which is compared with that of the standard drug, baicalaim (22.6 ± 0.09 µg/mL)[81]. Same as that of rhizome the aerial parts of the plant were also tested for the same activity in different solvent extracts the study revealed that the plant contain significant lipoxygenase activity in all extracts, but ethyl acetate extracts was the most potent inhibitor of the enzyme (IC$_{50}$: 97 µg/mL), followed by aqueous fraction (IC$_{50}$: 109 µg/mL) and crude extract showed inhibition (IC$_{50}$: 125 µg/mL)[66]. Again the aerial parts of plant were also tested for its lipoxygenase activities the different dilution of plant showed significant lipoxygenase with IC$_{50}$ values of 102 mg/mL[67].
9.8. Urease inhibition activity

The urease inhibition activity of the aerial parts of the *P. verticillatum* is tested in the crude and its subsequent solvent fraction of the plant extract. The crude extract of plant exhibited significant reduction of enzyme (IC₅₀: 192.00 ± 0.09). When different fractionation were tested for the activity, n-butanol was the most potent fraction [IC₅₀: (166.00 ± 0.69) μg/mL] followed by the ethyl acetate [IC₅₀: (187.00 ± 0.77) μg/mL]. However, n-hexane and chloroform fractions were inactive in urease inhibition assay. This showed that plant exhibit significant urease inhibition activity[66].

9.9. Insecticidal activity

Aerial parts of *P. verticillatum* was tested for its *in vitro* insecticidal assay against *Tribolium castaneum, Stophilus oryzae, Rhyzopertha dominica* and *Callosobruchus analis* result of this this activity showed that two fractions n-hexane (50%) and chloroform (30%) showed moderate activity against *Rhyzopertha dominica*, on the other hand neither crude extract nor its solvent fraction showed any activity against other insects[82].

9.10. Antileishmanicidal activity

The aerial parts of *P. verticillatum* was tested for its *in vitro* antileishmanicidal activity against *Leishmania major* (strain DESTO) the crude extract and different solvent extracts were tested result showed that neither crude extract nor its solvent fraction showed any significant activity against *Leishmania major*[82].

9.11. Phytotoxicity assay

To test the phytotoxicity, aerial parts of *P. verticillatum* was tested against *Lemna aquinoctialis* Welv result of this study showed that the crude as well as the different solvent fraction of this plant showed outstanding phototoxicity against *Lemnaemna aquinoctialis* at the dose of 5, 50 and 500 μg/mL and complete growth inhibition was observed in the crude extract and aqueous fraction at the maximum dose (500 μg/mL)[82].

9.12. Antibacterial activity

The crude and different solvent extracts of plant rhizome were tested against various Gram-positive [*Bacillus subtilis* (*B. subtilis*), *Staphylococcus aureus* (*S. aureus*)] and Gram-negative [*Escherichia coli*, *Pseudomonas aeruginosa* (*P. aeruginosa*), *Salmonella typhi*, *Shigella flexeneri*] bacteria by using agar well diffusion method the plant extract show significant antibacterial activity against these bacteria specially against Gram-negative bacteria except *P. aeruginosa* in Gram-positive the *S. aureus* showed more sensitivity against this plant[83]. The aerial parts of plant is also analyzed for their antibacterial activities against same Gram-positive and Gram-negative bacteria in different extracts the result showed that in Gram-positive the plant extract is effective only against *B. subtilis* and in Gram-negative like rhizome the aerial plant extract are ineffective against *P. aeruginosa*[65]. The same activity was again tested by two compounds isolated from *P. verticillatum* rhizome diosgenin and santonin against various Gram-positive (*B. subtilis, Bacillus cereus, S. aureus and Staphylococcus epidermidis*) and Gram-negative bacteria (*Escherichia coli* and *Salmonella typhi*) bacteria both these compounds showed significant zone of inhibition against both the strain[69].

9.13. Antifungal activity

Different extracts of plant rhizome was tested against various fungi including (*Trichophyton longifusus, Candida albicans, Aspergillus flavus, Microspoum canis, Fusarium solani, Candida glabera*) by using agar tube dilution method the result of this study showed that the antifungal activity of this plant is only limited to the *M. canis* and *F. solani*[83]. The aerial parts of plant were also analyzed for their antifungal activity against the same six fungal strains by using same method the result of aerial plant extract was effective only against *Microspoum canis* and all other fungal strains were resistant to plant extract[65]. Again the antifungal activity was tested by isolated compounds diosgenin and santonin from *P. verticillatum* rhizome against different strains of fungi (*Aspergillus flavus, Aspergillus niger, Trichoderma harzianum* and *Fusarium oxysporum*) the result of this study showed that only santonin showed the marked antifungal activity against these strains of fungi[69].


Diosgenin and santonin two isolated compounds from the rhizome of *P. verticillatum* these two compounds shows marked attenuation on heat-induced protein denaturation in a concentration dependent manner with with maximum effect of 61.55% and 67.90% at 500 mg/mL, respectively[69].

9.15. Cytotoxic activity

The cytotoxic activity of *P. verticillatum* rhizome is tested by using its crude extract and its subsequent solvent fractions by using brine shrimp cytotoxic assay the result shows that only ethyl acetate fraction showed prominent cytotoxicity (LD₅₀: 492.846 μg/mL)[70]. Different fractions of the aerial parts of plant were also analyzed for its cytotoxicity by using same brine shrimp cytotoxic assay the assay shows that except the choloform assay all other fractions are safe and no toxicity was observed[78].
9.16. Antinociceptive activity

Crude methanolic extract of the rhizomes of *P. verticillatum* was tested for its antinociceptive activity in various pain models in rodents at the concentrations (50, 100 and 200 mg/kg) the plant showed significant antinociceptive activity in various pain models including visceral pain model, formalin test and hot plate test[71]. The aerial parts of plant were also analyzed for the same activity the the effect of plant extract were analyzed in different pain models in all the plant showed the marked antinociceptive activity from the result the author suggested that the plant may contain some pharmacologically active substances which may interfere with the blockade of the effect or the release of endogenous substances (arachidonic acid metabolites) which are responsible for the excitation of pain nerve endings[70].

9.17. Diuretic activity

The rhizome of *P. verticillatum* was tested for its diuretic activity in male Albino rats at concentration 300 and 600 mg/kg, the result of this study showed that the plant exhibit mild diuretic activity at concentration of 300 mg/kg and no activity were showed at the high dose concentration of 600 mg/kg[71]. The aerial parts of plant were also analyzed for their diuretic activity in male Wistar rats the plant show mild diuretic activity but found insignificant in both test doses at both test doses (300 and 600 mg/kg *p.o.*) when compared with the standarder drug hydrochlorothiazide[70].

9.18. Bronchodilator activity

The bronchodilatory activity of aerial parts of *P. verticillatum* were tested in the isolated tracheal tissues of rabbits the methanolic extract of plant parts show strong bronchodilator activities when tested against carbachol and K⁺ (80 mmol/L) so it induced contractions more ever it also showed Ca²⁺ channel blocker-like activity[67].

9.19. Antispasmodic activity

To test this activity the methanolic extract of *P. verticillatum* rhizome is used in the spontaneously contracting isolated rabbit jejunum the finding of this study showed that plant extract demonstrated dose-dependent relaxation of the spontaneous contractions in rabbit jejunum and the complete relaxation is at 10 mg/mL these result are similar to that of inhibitory activity of cromakalim and verapamil. The plant extract was also tested against low K⁺- and high K⁺-induced contractions, the plant showed inhibition at low K⁺-induced contractions, while high K⁺-induced contractions were partially inhibited[80].

9.20. Antidiarrheal activity

The methanolic rhizome extract of *P. verticillatum* was tested for its antidiarrheal activity in mice diarrhea is induce in test organism with the help of castor oil the study showed that the plant exhibited marked antidiarrheal activity reduction in diarrhea was in a dose-dependent manner which is 80% at 1 000 mg/kg, *p.o.* these result are similar with that of drug loperamide[80].

9.21. Anti-insulin activity

On the bases of traditional medicine system it was reported that the plant is utilized to treat diabetes. To check this plant was analyzed for their antidiabetic activity in dexamethasone which induced insulin resistant HepG2 cells but the result showed that the plant exhibited insignificant antidiabetic activities[56].

10. Conservation and management

*P. verticillatum* is a perennial herb distributed worldwide especially in Europe, Turkey, Afghanistan, India, Nepal, China, in North and Central Asia and in temperate Himalayas at the altitude of 2 400 to 2 800 m. The plant is highly medicinal and used in many traditional medicines as diuretic, in pain, pyrexia, burning sensation, phthisis, weakness, Aphrodisiac, tonic and galactagogue, emollient, appetizer and for kidney trouble. The plant is also used for food in some areas of the world different parts of plant were utilized as raw vegetable. Based on their traditional uses the plant was also analyzed for their pharmacological potential and the plant showed marked potential against many pharmacological activities. The plant parts are also utilized in many traditional herbal formulations. For all this the plant was collected in large number from wild by the local community.
11. Status of *P. verticillatum*

In many parts of the world the natural habitat of this plant is decline due to over exploitation, harvest in an uncontrolled way, overgrazing and lack of awareness is the reason for the decline of this species (Table 2). Secondly, in some regions of the world the plant were also utilized in herbal formulations and have some market value so the local people harvest plant before maturity due to which mature seed production become very low and large number of seeds destruction also take place. Furthermore, rhizome of the plant has much medicinal value so the whole plant is uprooted from the soil which also destroys the plant. Thus, there is a need for its in-situ as well as, ex-situ conservation and propagation to conserve this important medicinal plant.

11.1. Ex-situ conservation of *P. verticillatum*

In recent year the ex-situ conservation of plant is done by Lohani *et al.* (2012) in that study the scientist grow the plant rhizome in Medicinal Plant Garden of Central Council for Research in Ayurveda and Siddha, Ranikhet (29°38’ 60 N, 79°25’0 E), India[101]. During the growth of the plant they supplemented it with different organic fertilizer. Three types of organic fertilizers, namely farmyard manure, forest litter and vermi compost were used to check their effects on the survival, growth and yield of the plant. Total twelve treatments were arranged. The result of this study showed that in control the yield was lower as compared to litter, farmyard manure and vermi compost which showed higher economic yield. However, yield was highest at T3 (furrow + forest litter) as compared to other beds which was seen best for the growth of that plant[101]. Again in another region the rhizome of plant was cultivated farmyard manure and vermicompost to check their yield and compared with other plants, the plant showed good yield[102].

11.2. In-vitro micropropagation of *P. verticillatum*

Micropropagation of *P. verticillatum* was done by using stem disc explants. The study showed the multiple shoots were initiated on Murashige and Skoog medium prepared with different concentrations and combinations of cytokinins (0.25–10.00 mg/L) along with auxins (0.5–1.0 mg/L). From the different phytohormones used, benzylaminopurine (1.0 mg/L) with 1-naphthaleneacetic acid (0.5 mg/L) was found to be the most effective in producing maximum number of shoots. When in the same medium the regular subculturing of these in vitro multiple shoots was done it induced profuse growth of lateral roots. Individual shoots were excised and rooted in vitro on half strength MS medium supplemented with auxins viz, indole acetic acid, indole-3-butyric acid and 1-naphthaleneacetic acid (NAA) (0.5–1.0 mg/L) result showed that only NAA and indole-3-butyric acid could induced rooting on half strength of MS basal media. Where’s 0.5 mg/L NAA in half strength MS medium reflected better and longer roots[20].

12. Conclusions

*P. verticillatum* is an endangered but high valuable medicinal plant from temperate Himalaya. The plant has immense importance because of its efficacy towards various serious diseases which is also an important plant species with respect to its ethnomedicinal importance, so this importance builds a pressure on the plant regarding to its use. This pressure posed the serious threat towards its extinction. So there is an urgent need to conserve this species, sustainable harvesting methods are also urgently required.

Conflict of interest statement

We declare that we have no conflict of interest.
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