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Comprehensive review on *Plumbago indica*: Traditional, pharmacological insights and conservation strategies

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ABSTRACT

Plumbago indica, also known as *Indian leadwort* or *chitrak*, is a medicinal plant with a rich history in traditional medicine systems like Ayurveda and Chinese medicine. Its medicinal properties include herbal remedies, powders, and extracts derived from the roots of the plant and leaves, with scientific studies proving its pharmacological capabilities in addressing various medical conditions such as inflammation, oxidative stress, bacterial infections, hepatoprotection, and cancer. The demand for plumbagin in the market has witnessed an upsurge due to the lack of commercial viability in producing the required quantity from the roots of this seedless plant. This review offers a thorough analysis of the morphological traits, growth patterns, and reproductive techniques of this plant. Additionally, in this study, the pharmacological significance, trade market demand, toxicity issues, threat, conservation status, and suggestions for sustainable cultivation methods are also covered. To ensure its continuous availability, it also discusses conservation efforts and its potential for novel drugs.

INTRODUCTION

Traditional medical systems have used medicinal plants for centuries to treat various ailments [1]. According to WHO guidelines, herbal medicines are a sustainable alternative solution for detoxification [2]. Traditional medical systems have used *Plumbago indica* Linn, a wild medicinal plant, for centuries [3]. Tropical and subtropical areas of Asia and Africa are home to this plant, which belongs to the genus *Plumbago* [4,5]. Its botanical, traditional, and pharmacological features have led to extensive scientific attention, and the plant is a significant species within the Plumbaginaceae family [6].

Plumbago indica has a unique physical appearance, with its distinctive flower form and lanceolate leaves [7]. Its morphology varies depending on environmental conditions, with the foliage lustrous green and the blooms small, cylindrical, white, or light blue [8]. The plant's taxonomic profile includes its taxonomic classification, morphological analysis, cytology, molecular biology, and conservation genetics [9]. It has a long history of use in traditional herbal therapy, particularly in Ayurveda, for its digestive, anti-inflammatory, anthelmintic, expectorant, diaphoretic, diuretic, purgative, and so on, effects. People use its roots and leaves to treat various ailments, such as gastrointestinal disorders, dermatological conditions, respiratory ailments, and rheumatic disorders [10]. It has a lot of different plant chemicals, such as plumbagin,6-hydroxy plumbagin, plumbagic acid, 3, 3 – biplumbagin, droserone, elliptinone, and so on, among these maximum amount of plumbagin (5-hydroxy-2-methyl-1,4-napthoquinone) is present which is a therapeutic naphthoquinone found in *P. indica* roots. Plumbagin helps in fighting inflammation, bacteria, free radicals, and cancer [11,12]. The increasing recognition of the medicinal benefits of *Plumbago indica* has led to its higher demand in the pharmaceutical and herbal product sectors. However, concerns

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about excessive harvesting and unsustainable methods have arisen, necessitating measures to control commerce and encourage ethical acquisition [13].

In addition, it contains bioactive substances that can be harmful when consumed in large amounts, making accurate dosage and administration instructions crucial [14]. *Plumbago*

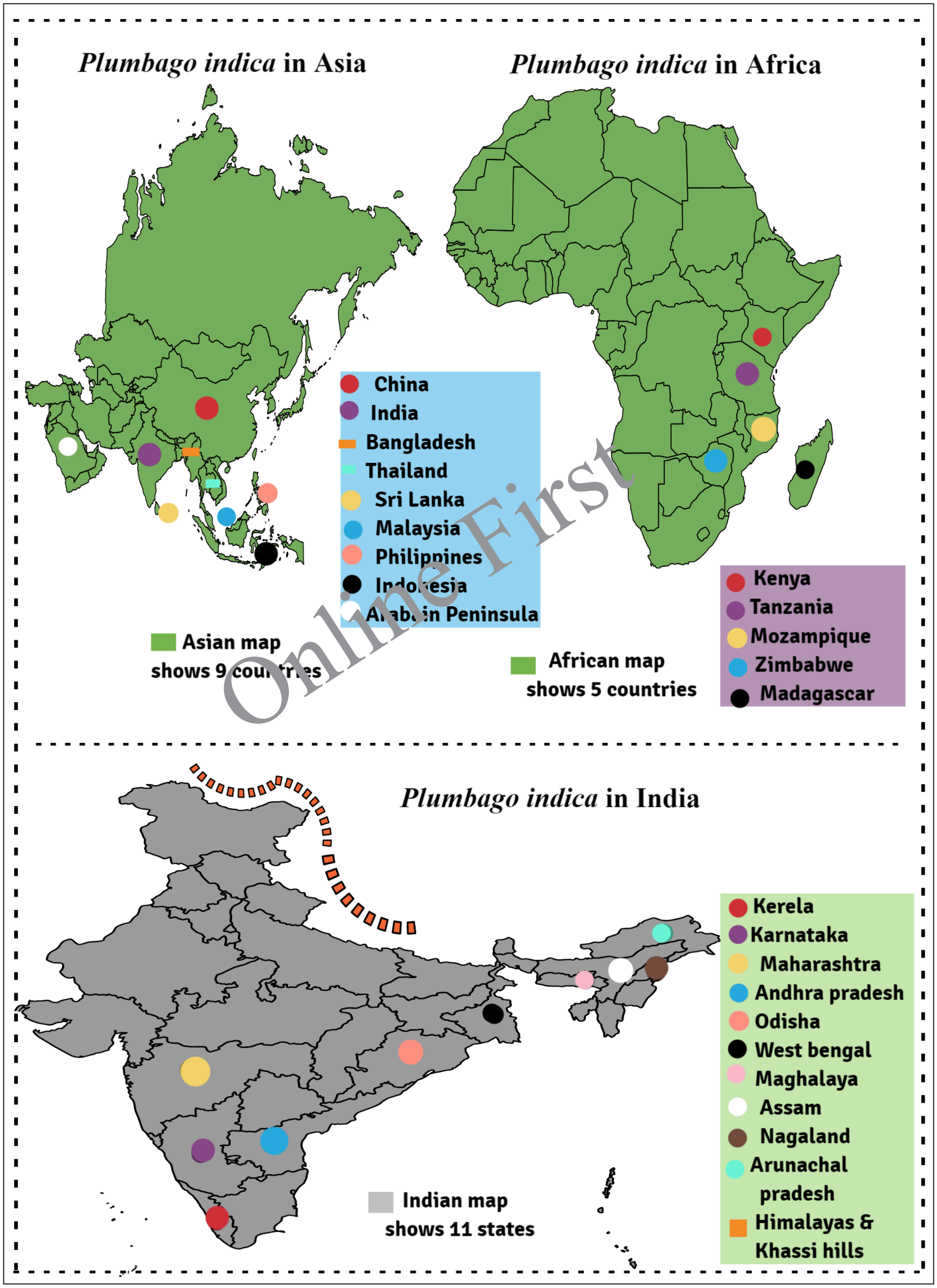


Figure 1. Worldwide and Indian geographical distribution of *P. indica*.

indica is at risk due to habitat loss, excessive use, and forest destruction. Preserving this species requires implementing conservation strategies such as habitat restoration, designated protected areas, and *ex situ* cultivation [9]. *In vitro* propagation techniques can help preserve the plant by facilitating large-scale reproduction of superior genetic varieties. Sustainable agricultural practices, such as agroforestry, organic farming, and biodiversity-friendly agriculture techniques, can increase the productivity of *P. indica* while reducing environmental impacts [15].

This review focuses on the botanical, traditional, and pharmacological significance of *Plumbago indica*, addressing conservation challenges and promoting sustainable practices. Prospects include exploring its phytochemistry, pharmacology, and genetic diversity, combining traditional knowledge with scientific methodologies for safe herbal products.

MATERIAL AND METHODS

Literature searches were conducted using scientific search engines and databases such as Google Scholar, PubMed, Scopus, Web of Science, Science Direct, and Wiley Online Library. A comprehensive investigation was conducted by examining various publications, theses, dissertations, and published floras to acquire comprehensive information.

ECOLOGY AND DISTRIBUTION

The field of ecology encompasses the study of the relationships between organisms and their environment, including the distribution patterns of species. *Plumbago indica* is a botanical species that is cultivated on a large scale in various Asian nations, including India particularly in the Eastern Himalayas and Sikkim region, as well as in the South, encompassing Andhra Pradesh, Kerala, Maharashtra, Nagaland, Manipur, Assam, Meghalaya, Arunachal Pradesh, Odisha, Khasi Hills, and West Bengal), Sri Lanka, Philippines, China, Malaysia, Indonesia, Bangladesh, and the Arabian Peninsula. The cultivation of this crop is also observed in various African nations, including Kenya, Tanzania, Zimbabwe, Mozambique, and Madagascar, as well as in Europe [16–19]. The geographical distribution of *P. indica* around the world and in India is shown in (Fig. 1).

BOTANICAL DESCRIPTION

Taxonomy

The classification of Plumbaginaceae is ambiguous due to their affinities with Centrospermae and Primulales. However, the taxonomical account provided is properly formatted and includes all relevant information [20]. *Plumbago indica* is classified according to its taxonomic characteristics, as shown in (Table 1).

Morphological description

Plumbago indica is a perennial botanical species characterized by its vertical stem, which can reach heights ranging from 1 to 5 m. The plant exhibits prominent elongated spikes that bear red, pentamerous, bisexual flowers measuring between 10 and 30 centimeters in length. The roots exhibit a distinct dark brown hue and emit a strong, pungent odor [17]. The identification of the genus is based on the presence of a pilose calyx, and the specimens within this group have the potential to exhibit perennial shrub characteristics.

The dimensions of the bracts are approximately 2–3 mm in length, exhibiting an oval morphology. The length of the peduncles ranges from 2 to 10 cm. Bisexual flowers frequently exhibit a symmetrical morphology. The calyx exhibits a length of 8–9 mm and possesses a tubular shape. It is characterized by glandular features and displays a crimson hue. The height of the corolla tube ranges from 0 to 1 mm. The calyx exhibits a tubular morphology with a diameter measuring 1.5 cm. The apex of the structure exhibits a rounded shape with a mucronate tip that is characterized by a purple to crimson coloration. Notably, this particular structure is devoid of stamens [21].

Cytology

Several researchers have conducted investigations on the chromosomal characteristics of *P. Indica* and have determined that the meiotic chromosome count is 2n = 14 [19]. It exhibits two distinct chromosomal counts, namely 2n = 28 and 2n = 12, which can be categorized as diploid and tetraploid, respectively, based on the fundamental chromosomal number of x = 7. However, the equation 2n = 12 necessitates additional investigation. This species exhibits polyploidy, and its chromosome number is variable [22,23].

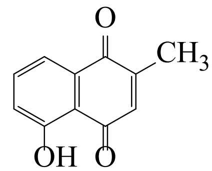
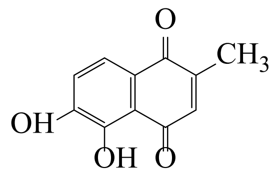
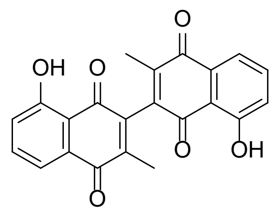
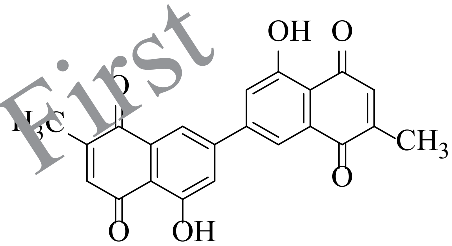
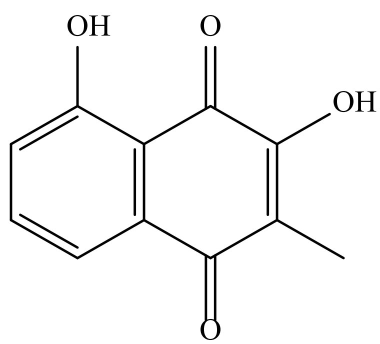
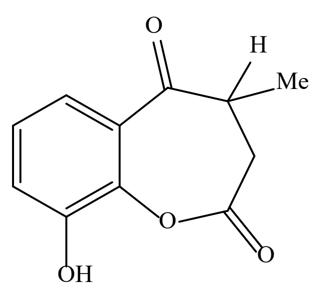
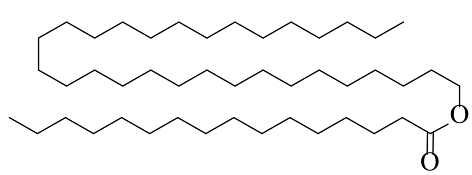
Molecular and genetic diversity

The topic of molecular and genetic diversity encompasses the examination of variations at the molecular and genetic levels within a population or species. The recognition of genetic variation holds significant importance in the efficient management and utilization of genetic resources. The utilization of molecular analysis of plant DNA is highly advantageous when conducting assessments of genetic stability. The utilization of Polymerase Chain Reaction (PCR)-based molecular markers has been employed in the evaluation of genetic fidelity in plantlets derived from cry storage. PCR and Random Amplified Polymorphic DNA (RAPD) technology play a crucial role in the evaluation of plant stability resulting from *in vitro* conservation. PCR has the capability to amplify a specific region of the genome, as defined by a pair of primers, when the gene sequence is already known. The utilization of a solitary oligonucleotide primer possessing an arbitrary

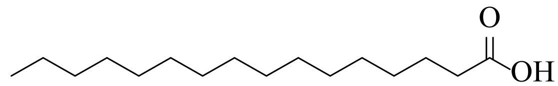
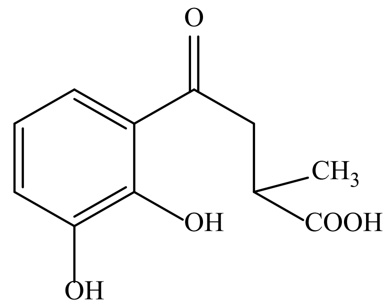
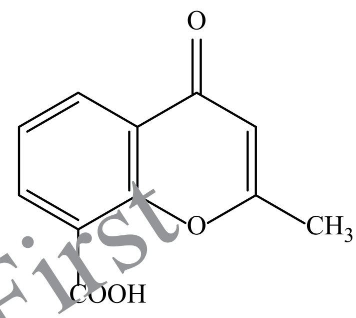
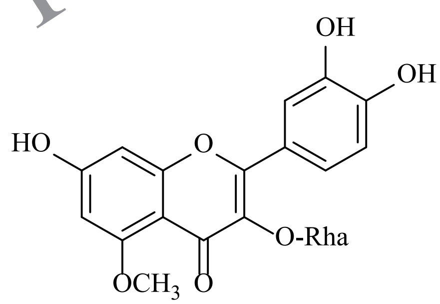
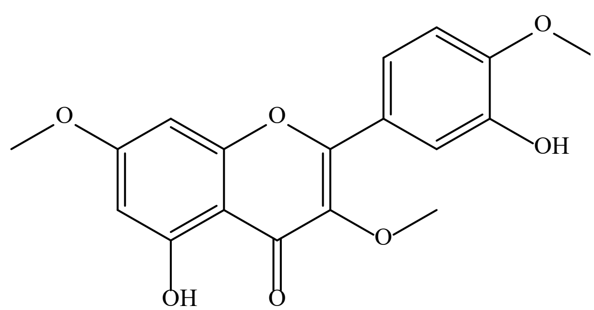
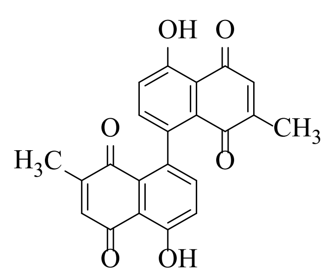
Table 1. Taxonomic classification of *Plumbago indica.*

Kingdom	Plantae
Subkingdom	Tracheobionta
Class	Magnoliopsida
Subclass	Caryophyllidae
Superdivision	Spermatophyta
Division	Magnoliophyta
Order	Caryophyllales
Family	Plumbaginaceae
Genus	*Plumbago*
Species	*Indica*

Table 2. Phytoconstituents and structures found in several parts of *P. indica*.

Plant part	Chemical group	Name of compounds	Structure	References
Roots	Naphthoquinones	Plumbagin		[24–26]
		6-Hydroxyplumbagin		
		3,3′-Biplumbagin		
		7,7´Biplumbagin		
	Lactones	Droserone		
		Plumbagic acid lactone		
	Esters	Myricyl palmitate		[14,23,26,27]

Continued

Plant part	Chemical group	Name of compounds	Structure	References
	Carboxylic acids	Palmitic acid		
		Plumbagic acid		
		Roseanoic acid		
	Flavonoids	Azaleatin		
		Ayanin		
		Maritinone		

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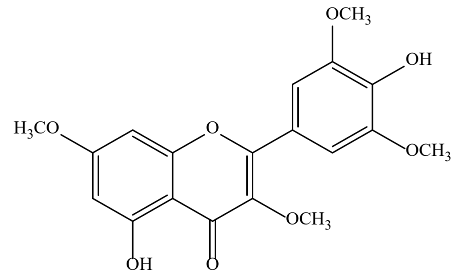
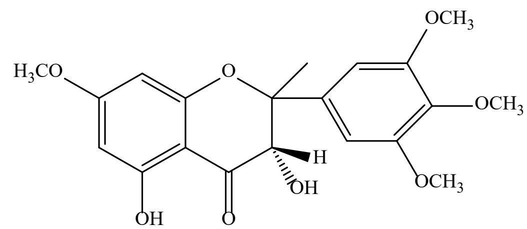
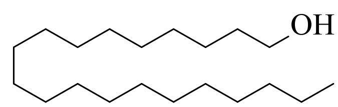
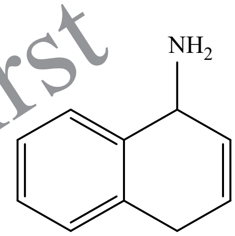
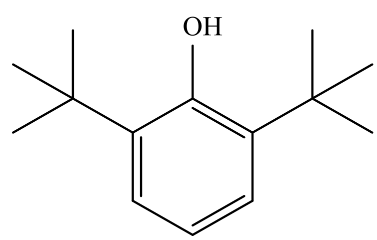
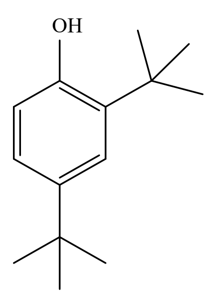
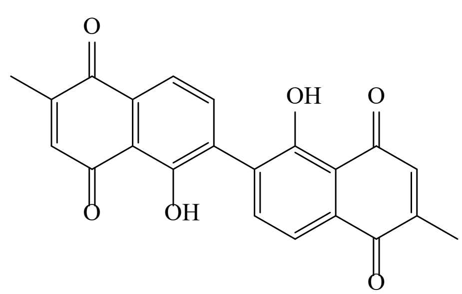
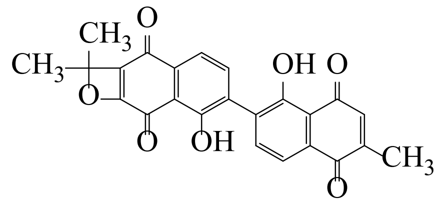
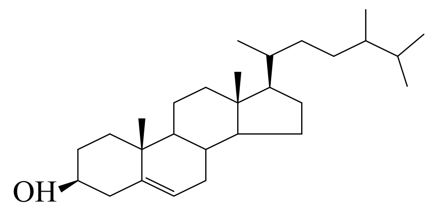
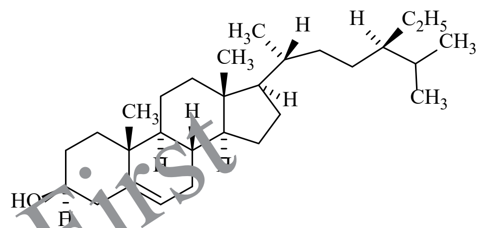
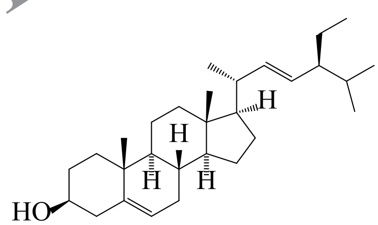
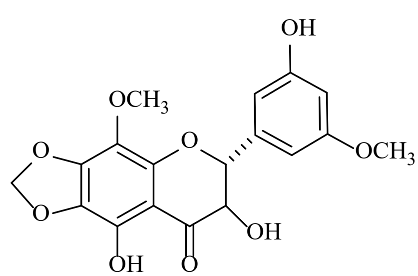
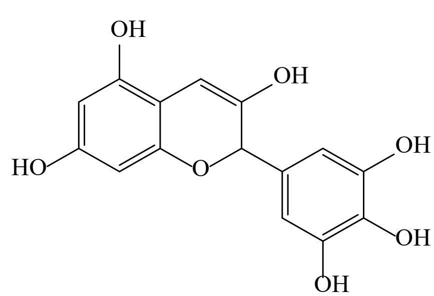
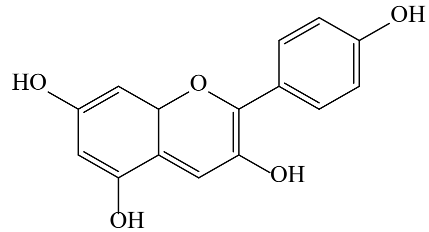
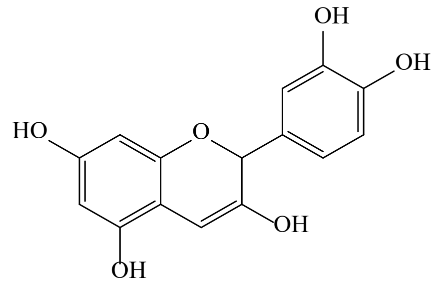
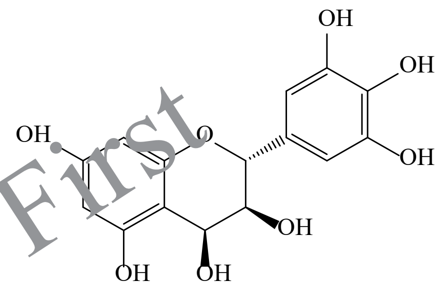
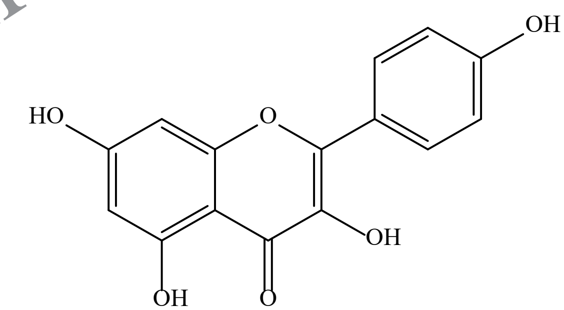
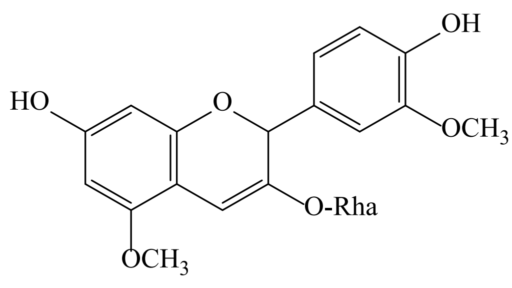
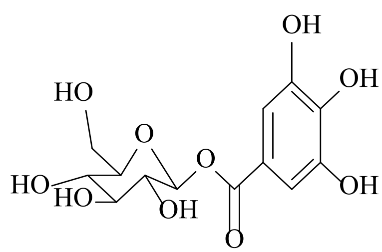
Plant part	Chemical group	Name of compounds	Structure	References
		Myricetin-3,3′,5′,7-tetra methyl ether		
	Flavonoids Ether	Ampelopsin-3′,4′,5′,7-tetramethylether		[28]
	Alcohol	Arachidyl alcohol		[21,23]
	Amines	α - Naphthylamine		
	Phenols	2,6-Di-tert-butyl phenol		[29]
		2,4-Di-tertbutyl phenol		
	Miscellaneous	Elliptinone		[25]

Continued

Plant part	Chemical group	Name of compounds	Structure	References
		Roseanone		[26]
Aerial part	Phytosterols	Campesterol		[23,30,31]
		β-Sitosterol		
		Stigmasterol		
	Miscellaneous	Plumbaginol		[23,30]
Flowers & Leaves	Flavonoids	Delphinidin		[32,33]

Continued

Plant part	Chemical group	Name of compounds	Structure	References
		Pelargonidin		
		Cyanidin		
		Leucodelphinidin		
		Kaempferol		
		Capensinin		
	Miscellaneous			
		Mono and di-galloylglucose		

nucleotide sequence, or the combination of arbitrarily primed oligonucleotides with PCR, results in the generation of DNA (RAPDs) fragments. These fragments serve as valuable markers for the identification and analysis of genetic alterations. The evaluation of genetic stability in micro propagated *Plumbago rosea* plants has been documented by multiple researchers [9,34].

TRADITIONAL APPLICATIONS

Plumbago indica, a widely recognized plant in the Indian System of Medicine, is used in traditional therapy to treat a variety of illnesses. Ayurveda and Siddha medicine prescribe the roots, bark, and leaves of the plant for numerous diseases. The root is known for its anthelmintic, expectorant, diaphoretic, diuretic, purgative, alterant, antioxidant, and aphrodisiac effects. It is used as a tonic to treat amenorrhoea and dysmenorrhea in Unani medicine. The leaves and bark have expectorant, diuretic, emmenogogue, and alterant properties that can be used to treat rheumatism, headaches, and splenopathy [23,35,36].

Medications derived from *P. indica* have undergone rigorous scientific testing and have demonstrated efficacy in treating various medical problems. People use poultices made from scraped bark to treat headaches and they apply the bark to the spine as a blistering plaster to treat fevers. In addition, they use roots along with black pepper for jaundice in the form of pills as well as used by Chakma for stomach pain. People use the root as an abortifacient and antifertility medication and they use the extracted juice as a potent sudorific [37].

The leaves and roots are also used for the treatment of dyspepsia, piles, dysentery, diarrhea, and to enhance the appetite. Myanmar uses Ayurveda to treat leprosy and syphilis due to its ability to inhibit vata and pitta. West Bengal uses a decoction of fresh roots as an abortifacient and in Bangladesh, they treat skin diseases by applying leaf and root juice topically. To produce sterility in women, 1 tablespoon every day for 3 days is prescribed [38].

PHYTOCHEMISTRY

Plumbago indica exhibits a high abundance of various alkaloids, flavonoids, saponins, glycosides, coumarins, alkylated phenols, triterpenes, fatty acids, sterols, and tannins. Plumbagin (5-Hydroxy-2-methyl-1, 4-naphthoquinone), a bioactive organic compound, is derived from the roots [12,17,29]. The structures of the phytoconstituents that are found in various sections of *P. indica* plant are presented in (Table 2).

PHARMACOLOGICAL IMPORTANCE

Plumbago indica, a botanical species, is known for its diverse bioactive compounds, and traditional medicine applications are highlighted in table 3 detailing its pharmacological effects and relevant references. Its medicinal properties are also outlined in **(**Table 3**)**.

TRADE AND MARKET DEMAND

The subject of trade and market demand is of significant academic interest; hence *P. indica* is highly valuable in the pharmaceutical and natural medicine industries because of its bioactive component, plumbagin, which covers its market dynamics, utilization, and cost.

Market demand and utilization

Plumbago indica is medically significant because it contains a substantial amount of plumbagin, a bioactive chemical. Herbal medication formulations should utilize new harvests of *plumbago* species to maintain appropriate concentrations of plumbagin. This will help ensure the intended therapeutic effects. Chitrakadi Vati is an Ayurvedic formulation that contains 1.65%–10% plumbagin, emphasizing the therapeutic significance of this component [39,40].

The need for medicinal products is increasing dramatically, resulting in a surge in demand for bioactive substances such as plumbagin. India had a demand of 1,285 metric tonnes of *Plumbago indica* roots between 2004 and 2006, and it is expected to increase by 10% annually. In India alone, the annual demand for plumbagin amounts to 7 metric tonnes. Commercial exploitation of *P. indica* is a significant concern because of its high demand, leading to overexploitation and posing a threat to its natural population [41,42].

Trade name and pricing

The trade name for *P. indica* is “Chitrak.” The price per kg ranges from 90 to 150 Indian rupees. The anticipated yearly trade volume for this plant is between 100 and 200 kg [43]. However, the price of the roots varies from Rs. 200 to Rs. 350 per kg, indicating its significant economic worth [44]. In addition, *P.indica*, known as Chitrak Root Extract (1 kg), costs around 2,230.00 Indian rupees [45].

Commercial sustainability

The cultivation of *P. indica* has the potential to be economically profitable, with the possibility of yielding up to Rs. 5 lakh per hectare over 3 years [44].

Economic feasibility

Growing *P. indica* offers a chance to make a significant income, particularly due to the potential for numerous harvests moreover, the plant can be harvested again from the same root system, increasing its economic value [44].

Commercialization and trade

Plumbago indica is one of the 242 plant species utilized for the production of herbal drugs in India, highlighting its importance in the pharmaceutical and herbal medicine sectors [46].

TOXICITY

The extract of the root of the *P. indica* plant has been categorized as a drug that poses the least risk to hamsters, falling into category 5. High doses of the ethanolic extract caused adverse effects in mice, including diarrhoea, skin rashes, leukocytosis, and raised blood phosphatase levels. The LD50 of the ethanolic extract was determined to be 1,250 mg/kg [47,48]. Mice showed higher tolerance to oral administration

Table 3. Pharmacological activities, plant parts, extracts, bioactive chemicals, model, and main findings

Pharmacological activity	Plant part	Extract	Bioactive compounds	Model	Main finding	References
Anti-bacterial activity	Roots	Hydroalcoholic extract (80% ethanol)	Plumbagin	*Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, S. aureus*	Effective antibacterial activity against tested strains	[5]
		Methanolic extract	-	*S. aureus, Salmonella typhi, Salmonella paratyphi*	Methanolic extract shows antibacterial efficacy with zones of inhibition (7.0–25.0 mm)	[49,50]
		Plumbago derivative	-	*Propionibacterium acnes, S. aureus, S. epidermidis*	PPE exhibits antimicrobial effects and stability under specified storage conditions	[24]
	Methanol extract	Plumbagin	-	*Methicillin-resistant Staphylococcus aureus*	Potent antibacterial effects in disc diffusion assay	[51]
Anti-cancer activity	Roots	Methanol extract	Plumbagin	Breast cancer (MCF-7 cells)	Inhibition of HIF-1 expression and PI3K/Akt/mTOR pathway	[52]
		Methanol and ethanol extracts	-	Prostate cancer cells	Exhibits cytotoxic effects and suppresses cancer cell growth	[53–55]
Anti-fungal activity	Roots	Plumbagin	-	*Aspergillus flavus, Talaromyces marneffei*	Inhibition of fungal growth	[56]
				C. albicans, B. dermatitides, Trichophyton spp., Microsporum spp.	Strong antifungal activity observed with zone inhibition (10.0–27.0 mm)	[57]
Anti-influenza activity	Roots	Methanolic and ethanolic extracts	Plumbagin	*Influenza A (H1N1) pdm09 virus*	The study demonstrates that inhibiting nucleoproteins and polymerase can potentially have anti-influenza properties at specific concentrations.	[58]
Anti-fertility activity	Roots	Ethanolic extract	Flavonoids, Plumbagin	Rats	Significant antifertility effects were observed, with specific dosage and percentage pre-implantation loss demonstrating anti-implantation effects.	[59]
	Stem	Acetone extract	-	Female albino rats	Exhibits anti-ovulatory effect with reversible action and strong estrogenic/anti-estrogenic activity	[60]
Hepatoprotective activity	Roots	Methanolic extract	-	Thioacemedicine-induced liver damage in rats	Protection against liver damage at specific doses	[61]
		Alcoholic extract		Paracetamol-induced liver damage in animals	Shows hepatoprotective effects comparable to Silymarin against liver damage	[62]
Antioxidant activity	Roots	Methanolic extract	-	*In vitro* antioxidant assays	Exhibits *in vitro* antioxidant activity and hydroxyl radical scavenging activity	[16]
Anti-*H. pylori* & cytotoxic activity	Roots	Ethanolic extract	-	HGE-17 cell lines	Anti-H. pylori and cytotoxic properties demonstrated	[63]
Analgesic & anti-inflammatory activity	Leaves	-	-	Carrageenan-induced paw edema in mice	Significant analgesic and anti-inflammatory effects observed	[64]
	Roots	Methanolic extract	-	Young Swiss albino mice	Significant reduction in pain response observed at specific dosage concentrations	[65]

Continued

Pharmacological activity	Plant part	Extract	Bioactive compounds	Model	Main finding	References
Anti-acne activity	Roots	Acetone extracts	-	*Malassezia furfur, Propionibacterium acnes, Staphylococcus epidermidis*	Effective inhibition of acne-causing bacteria	[66]
				P. acnes, S. epidermidis, M. furfur	Acetone extract exhibits anti-acne action against acne-causing bacteria	[67]
Anti-diarrhoea activity	-	-	-	Castor oil-induced diarrhoea in mice	Reduction in faecal pellets and latent period duration	[68]
			Plumbagin	Diarrhoeal conditions	Shows potential for treating diarrhoea by inhibiting specific channels	[69]
Macro-filaricidal activity	Roots	Methanol extract	-	*Cattle filarial parasite*	Demonstrates effectiveness against Setaria digitata	[70]
Genotoxicity activity	Roots	Ethanolic extract	-	*In vitro* cell model	Induction of cytotoxic effects at specific concentrations	[71]
Antimalarial Activity	Roots	Methanolic extract	Plumbagin	Mouse model infected with *Plasmodium berghei*	Demonstrates *in vitro* antimalarial activity at specific dosage levels	[72]
Cardioprotective Activity	-	-	Plumbagin	Animals treated with plumbago	Plumbago protects against doxorubicin-induced heart damage	[73–75]
Antiproliferative Effect	Roots	-	-	Breast and stomach cancer *cell lines*	Induces cell death in breast and stomach cancer cell lines	[36]

of the extract compared to intraperitoneal administration. Rat autopsy findings showed liver discoloration, enlarged spleen, decreased liver, thymus, testes, and kidney weight changes. Cytotoxicity studies showed a lower LD_{50} value for the extract than other species such as *Plumbago zeylanica* and *Plumbago auriculata* [48,63]. The extract caused an imbalance in oxidant-antioxidant substances in the liver, leading to chronic inflammation and cellular damage [58]. Niosomal plumbagin administration reduced mortality in BALB/c mice compared to free plumbagin [76]. Overall, the *P. indica* root extract has been found to be non-toxic and should be considered for further research.

THREAT AND CONSERVATION STATUS

The limited accessibility of the *P. indica* plant can be attributed to various factors, including the absence of a fruiting stage, slow growth, and extensive harvesting. It is special that over 30% of Ayurvedic formulations incorporate this particular species as an ingredient. However, it is currently on the IUCN Red List of Endangered Species, but its status may be different in different parts of the world [77–79].

Factors affecting population loss

The global decline in population and the increasing demand for herbal remedies are exerting pressure on medicinal plants on a global scale [5]. *Plumbago indica*, an endangered species, is currently being utilized in the pharmaceutical, nutraceutical, and herbal sectors [29]. The degradation of habitats and competition for resources are being caused by urbanization, invasive species, and illegal harvesting. A significant portion of the respondents exhibit a lack of awareness regarding the diminishing number of domesticated species resulting from the decline of wild medicinal plants. The proliferation of human endeavors and illegal extraction exacerbate the detrimental impact on indigenous populations [78].

Conservation measures

Cryopreservation is the only viable long-term conservation method for the propagation of *P.indica* species, requiring an effective *in vitro* regeneration system. It efficiently utilizes preserved propagules for future large-scale regeneration [80]. It potentially benefits from constitutional protections and regulatory measures, which serve to safeguard its natural habitats against activities such as deforestation and development. The promotion of cultivation in botanical gardens and nurseries has the potential to decrease the size of wild populations and mitigate the demand for specimens [15]. Conducting regular research and monitoring is of utmost importance to accurately evaluate the conservation status of plants and to implement measures that are effective [81].

In vitro propagation

Propagation of *P. indica* by explant culture and hormonal treatments in an organized laboratory environment. *In vitro* propagation involves cultivating plants from tissue cells and organs using explants from the mother plant. Auxins such as

IBA facilitate rooting, while cytokinins such as BAP, KN, and TDZ stimulate shoot induction and proliferation [82]. Nodal explants and leaf explants successfully induce bud initiation [83]. When treated with BAP during shoot multiplication, nodal explants are the most effective starting material for *P. indica* shoots. Callus regeneration is achieved by cultivating nodal segments in Murashige and Skoog medium supplemented with kinetin and 2,4-dichlorophenoxyacetic acid [84,85]. Acetic Acid, Indole Butyric Acid, and Putrecine result in the highest root production and regenerated shoots with a growth rate of 4.5 cm within 30–40 days [86].

Techniques and applications for large-scale plumbagin production from *P indica*

The production of plubagin from *Plumbago indica* root cultures has led to better ways to make chemicals on a large scale. Plumbagin can be extracted from the tissue-cultivated roots of *Plumbago indica*, but specific conditions must be met for high-level production. Adding chitosan to root cultures along with either β-alanine or methyl-β-cyclodextrin greatly increases the production of plumbagin. This makes it a cheap way to make a lot of therapeutic chemicals [87]. It is possible for the hairy root culture of *P. indica* to be a useful source of plumbagin because it grows shoots easily and can be changed into genetically modified plants [88]. Supplementing with l-alanine and adsorbing in situ greatly enhances plumbagin production in root cultures, making it an economical method for producing valuable therapeutic chemicals on a large scale [89]. Adding jasmonic acid to the culture conditions and stimulating them greatly raises the plumbagin levels in adventitious root cultures of *Plumbago rosea*, a plant that is used in ayurvedic medicine to treat a number of illnesses [90]. Regenerating transgenic plants and making *P. indica* roots hairy can produce consistent amounts of plumbagin. This implies that destroying the plant species in large numbers is not necessary, thereby simplifying its protection [91]. The addition of chitosan and methyl jasmonate significantly increases the generation of plumbagin in *P. indica* hairy root cultures and releases plumbagin into the culture medium [92].

The application adding of the outside hormones GA3 and NAA to the hairy roots of *P. indica* plants makes them grow faster and store more plumbagin, but adding 2, 4-D stops growth and production. Synthetic seeds prove to be an efficient method for preserving superior root clones [81]. Gamma-ray irradiation at a low dose of 20 Gy has a substantial effect on increasing plumbagin production in root cultures, with the highest output observed when the cultures are 10 days old [93]. Heat shock and *in situ* adsorption using Diaion® HP-20 greatly increase the production of plumbagin in root cultures, which has the potential to be used in commercial applications [94,95].

CULTIVATION PRACTICES

Cultivation practices refer to the various methods and techniques utilized in the cultivation and care of plants or crops. *Plumbago indica*, a highly adaptable angiosperm, exhibits robust growth in regions characterized by tropical and subtropical climates. This versatile plant species can be cultivated in various settings, including gardens, borders, and containers. Notably, container gardening proves advantageous in colder regions during the winter season [96]. This plant exhibits a preference for full sunlight rather than partial sunlight, and it is suitable for cultivation in various settings such as gardens, borders, or pots, particular plant exhibits resistance to both pests and diseases and can be propagated through either stem cuttings or seeds [97,33]. The exploitation and conservation status of the species highlights the difficulties in balancing market demand with the need to maintain its sustainability in its natural environment. Cultivation is a viable alternative to gathering plants from the wild because it offers economic prospects while simultaneously alleviating the strain on natural populations [98].

FUTURE PROSPECTS

Plumbago indica exhibits a wide range of potential applications in various fields such as horticulture, medicine, biodiversity conservation, sustainable agriculture, phytoremediation, traditional knowledge preservation, and the production of herbal products and cosmetics. The plant's vibrant blue or white flowers and lush green foliage contribute to its widespread popularity in both gardens and public areas. Ongoing research is being conducted with the aim of discovering novel bioactive compounds that may have promising implications in the fields of contemporary medicine, herbal remedies, and dietary supplements. The drought tolerance and pest resistance exhibited by *P.indica* make it an appropriate candidate for sustainable agriculture, phytoremediation, and the preservation of traditional knowledge.

CONCLUSION

In conclusion, *P. indica*, which is known as Indian leadwort or Chitrak, is well-known for its potential as a medicinal and possesses a wide range of applications in both traditional and modern medicine. The focus of this review is on the botanical, traditional, phytochemical, pharmacological, and conservation approaches used to understand the plant's therapeutic potential. The presence of bioactive chemicals like plumbagin, as well as other phytoconstituents like alkaloids, flavonoids, and terpenoids, found in different parts of the plant, may enhance the therapeutic efficacy. It is a valuable natural medicine resource that holds potential for the development of novel treatments and alternative therapies. To manage chronic diseases like diabetes, further research is necessary. We recommend investigating its potential in combination with other plants or traditional drugs, and in the preparation of formulations to significantly improve its efficacy.

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Bhagat, contributed to the initial idea conception, literature search, data collection, drafting, manuscript preparation, figure creation, and critical review. Hasandeep Singh, Balbir Singh, and Sarabjit Kaur reviewed and edited the manuscript for scientific accuracy and coherence. All authors have read and approved the final version of the manuscript submitted to the Journal of Applied Pharmaceutical Science. They can be authors per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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The authors report no financial or any other conflicts of interest in this work.

CONSENT TO PARTICIPATE

It is a review article, thus it is not applicable.

ETHICAL APPROVAL

This study does not involve experiments on animals or human subjects.

DATA AVAILABILITY

The data that support the findings of this study are available in standard research databases such as PubMed, Science Direct, or Google Scholar, and/or on public domains that can be searched with either key words or DOI numbers.

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