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A review on ecology, distribution, phytochemistry, and pharmacological properties of the medicinally important plant *Pterocarpus santalinus* L. (Red sanders)

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ABSTRACT

Pterocarpus santalinus L., commonly known as Red sanders, belongs to the family Fabaceae. The plant is well-known for its distinctive wood, which has a stunning color, a delicate appearance, and exceptional technical features. The natural dye santalin, which is produced by the red wood, is used to color foodstuffs and pharmaceutical formulations. The decoction made from the heartwood is given numerous therapeutic characteristics in the ancient system of medicine. It has been used to induce vomiting as well as treat ulcers, mental disorders, and eye illnesses. It is known that the heartwood of Red sander trees has diaphoretic, aphrodisiac, anti-pyretic, anti-inflammatory, anti-helminthic, hemorrhage, and dysentery-preventing properties. Additionally, it has served as a cooling agent. It has been claimed that an ethanol extract of stem bark has anti-hyperglycemic properties. Various studies on the phytochemistry of stem bark extracts in ethanol extracts showed the presence of tannins, phenols, alkaloids, glycosides, flavonoids, and triterpenoids, as well as saponins. Isoflavone glucosides and two anti-tumor lignans, savinin, and calocedrin, are found in the heart wood. However, despite numerous claims of pharmacological activity, the species has not been thoroughly investigated. The current article emphasizes the phytochemistry, pharmacological potential, and applications of *P. santalinus.*

1. INTRODUCTION

Ayurveda uses medicinal plants to promote human welfare and treat a number of disorders, making it a healthy way of life. In India, ayurvedic medications are a traditional system of medicine that has a long history and is recognized by the government [1]. The system describes the medicinal plant, plant part, preparation technique, and application for the avoidance or mitigation of specific diseases, either alone or in combination with other plants. [2]. The World Health Organization (WHO) reports that over 80% of people in underdeveloped nations rely on these plants, particularly plant-based treatments, for their basic medical needs and employ traditional medicines and medicinal plants as therapeutic agents to preserve good health [3].

The plant *Pterocarpus santalinus* L., often called Red Sanders, Red Sandalwood, or Rakthachandan, is a member of the Fabaceae family. Red Sanders, is an endangered, essential medicinal angiosperm tree, is unique to the Eastern Ghats region of Andhra Pradesh, as well as the neighboring states of Karnataka and Tamil Nadu, hence endemic to India. It grows on arid, mountainous, frequently rocky soils in the Deccan Peninsula of India. The tree is renowned for its distinctive wood, which is exquisitely beautiful and colorful. The red pigment "santalin" and the yellow flavonoid "santal" found in the heartwood of the tree give it its distinctive red color. These compounds are used as coloring agents in pharmaceutical materials as well as evaluated for their therapeutic efficacies and used in drug formulations for the treatment of diseases like diabetes, skin conditions, inflammations, headaches, diaphoresis, dysentery diseases of the blood, stomach ulcers, and anthelmintics [5,39]. Among these species, only four are found in India, *P. santalinus, Pterocarpus dalbergioides, P. marsupium, and P. indicus.* The most endangered species is *Pterocarpus santalinus* [6]. Timber from *P. santalinus* is the species most valuable commercial component. It has historical and traditional importance and is used to make carvings, toys, and musical instruments [7].

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1.1. Distribution

The Red Sanders is native to a specific area within the Eastern Ghats, primarily in the Rayalaseema region of Andhra Pradesh. This region hosts a distinct tract of forest where the species is endemic. Approximately 15.5 lakh harvestable Red Sanders trees are estimated to exist within these forests. Among them, about 1.6 lakh hectares (equivalent to 1,600 square kilometers) fall under Andhra Pradesh's Protected Area Network. An additional estimated 9 lakh trees are found in reserve forest areas outside these protected zones. Beyond Andhra Pradesh, Red Sanders is also grown in small numbers in other Indian states, including Kerala, Maharashtra, Gujarat, Karnataka, Telangana, Tamil Nadu, Odisha, and West Bengal. *P. santalinus* is found in steep areas with a hot, arid climate. It thrives in the tropical regions of India, Taiwan, Philippines, Sri Lanka and China. In India, it is primarily found in the southern part of the Eastern Ghats, the Cuddapah, Kurnool, Prakasam, Nellore, and Chittor districts of Andhra Pradesh and restricted to Vellore and Chengalpattu districts of Tamil Nadu [Figure 1] [6,7].

1.2. Botanical Description

P. santalinus is a small to medium-sized deciduous tree with extremely tough, dark purple heartwood that tastes bitter. The bark is dark brownish black and is divided into rectangular plates by strong vertical and horizontal characteristics. The heartwood is between one and two centimeters thick. Blaze is a pale yellow hue with several pink striations that give off copious amounts of thick, crimson, sticky gum. Dropping and hairless branchlets are seen. The leaves are typically egg-shaped or orbicular with 3 leaflets. The base is heart shaped or spherical. The apex might also have a sharp notch or be rounded. The margin is lustrous, hairless, and leathery. The flowers are yellow, bisexual, about 2 cm long, fragrant, and stalked in simple or sparingly branching racemes. Uneven orbicularity exits within pods, about 5×4.5 cm and are flat. The smooth, reddish-brown, kidney-shaped seeds measure between one and two centimeters in length [1].

Figure 1: Distribution of Red sanders in India. Highlighted region indicates the geographical restriction of the tree species in Eastern Ghats.

P. santalinus is a small to medium-sized deciduous tree that has a dense, spherical crown that grows to a height of 10 to 15 m and a diameter of roughly 90 to 160 cm. When mature, the bark often has rectangular plates, is dark brown in hue, and is extensively fissured. It emits a crimson colored gum with multiple pink streaks when burned. The complex, pinnate leaves typically shed between January and March. As summer approaches, large yellow raceme flowers start to bloom and new foliage emerges**.** Temperature ranges from 11^{o}C to 46^{o}C, and rainfall ranges from 100 mm to 1,000 mm, which indicates a dry climate that prevails throughout the year. The slopes and soils in hilly areas, where the tree prefers to grow, are typically shallow, poor, stony, and well-drained [5].

1.3. Phytochemistry of *P. santalinus*

Alkaloids, flavonoids, terpenoids, phenolic chemicals, saponins, tannins, and glycosides were discovered in *P. santalinus* during phytochemical study. Additionally, non-specific metabolites such as triterpenes, sesquiterpenes, triterpene glucosides, isoflavones, and related phenolics were found. Specific phytoconstituents found in *P. santalinus* include beta sitosterol, lupeol, epicatechin, lignans, and pterostilbene's [8, 9, 10]. In *P. santalinus* certain metabolites, such as beta-eudesmol, cryptomeridiol, isopterocarpalone, pterocarptriol, santalins A, B, and Y, and pterocarpalone, have tremendous medicinal potential [11]. Some of most important phytochemicals reported from *Pterocarpus santalinus* is represented in the Figure 2 and Tables 1, 2.

The active portion of *P. santalinus* bark's phytochemical examination revealed the presence of flavonoids, glycosides, and phenols.

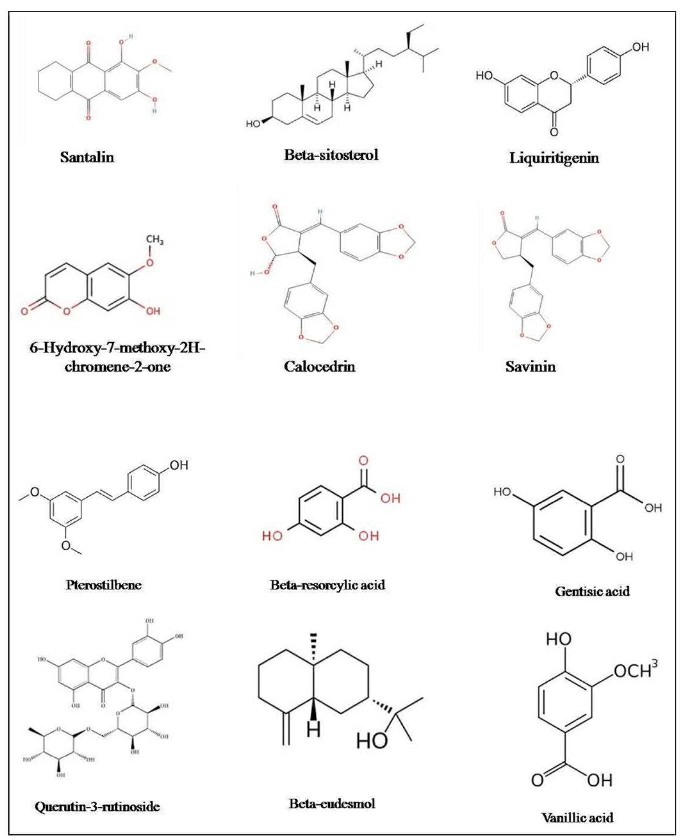

Figure 2: Chemical structure of some of the important phytochemicals isolated from the *P. santalinus.*

Table 1: Distribution of *Pterocarpus* species [2].

Pterocarpus species	Distribution
Pterocarpus acapulcensis	Mexico, Columbia to Venezuela
Pterocarpus albopubescens	Zaïre
Pterocarpus amazonum	Bolivia, Brazil North, Brazil West-Central, Ecuador, Guyana, Peru, Venezuela
Pterocarpus angolensis	Zimbabwe,northern Botswana, Mozambique and Namibia and northwards into other parts of Africa.
Pterocarpus antunesii	Southern Angola, Namibia, Botswana,Malawi, Mozambique, Zambia and Zimbabwe
Pterocarpus bernaii.	Malawi, Mozambique, Zambia and Zimbabwe
Pterocarpus claessenii	Zaïre
Pterocarpus dalbergioides	Andaman group of Islands, India
Pterocarpus erinaceus	West and Central Africa Senegal in the west to the Central African Republic, Guinea, Togo and Benin
Pterocarpus gilletii	Zaïre
Pterocarpus indicus	SE Asia and the Pacific, from Southern Burma to the West to the Solomon Islands in the East, including Sumatra, West Java, Borneo, Philippines, Sunda Islands, the Moluccas, New Guinea, and the Carolines
Pterocarpus lucens	Senegal to Ethiopia and Uganda, and subsp. Antunesii (Taub.) Rojo, from southern Angola and northern Namibia to Mozambique.
Pterocarpus macrocarpus	Myanmar , Thailand, Laos and Cambodia to southern Vietnam
Pterocarpus marsupium	India, Sri Lanka, and parts of Nepal and Bhutan
Pterocarpus mildbraedii	Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Benin, Nigeria,Cameroon, Equatorial Guinea, Gabon and the Usambara and Udzungwe Mountains (Tanzania)
Pterocarpus officinalis	Southern Mexico, Central America, the Caribbean, and northern South America
Pterocarpus orbiculatus	Central & Southern. Mexico
Pterocarpus rohri	Southern Mexico to Southern Tropical America
Pterocarpus rotundifolius	mesic and well-watered woodlands of Africa
Pterocarpus santalinoides	Senegal east to the Central African Republic and DR Congo, and in South America.
Pterocarpus santalinus	India (Southern portion of Eastern ghats, Andhra Pradesh and Tamil Nadu), Sri Lanka
Pterocarpus soyauxii	south-eastern Nigeria east to eastern DR Congo and south to northern Angola
Pterocarpus termannii	Gulf of Guinea
Pterocarpus tinctorius	Congo to Tanzania and Southern Tropical Africa
Pterocarpus villosus	Brazil Northeast
Pterocarpus zehntneri	Brazil Northeast, Brazil Southeast
Pterocarpus zenkeri	Cameroon

Table 2: Most potential phytochemicals reported from *Pterocarpus santalinus*.

Name of the Compound	Plant part	Reference
Acetyloleanolic aldehyde, Acetyl oleanolic acid	Sapwood	[22]
Lupenone, β-amyrone, epilupeol, β-amyrin, lupeol, stigmasterol, β-sitosterol	Leaves	[8,21]
Erythrodiol	Sapwood	[22]
Lupenone	Heartwood	[22]
Lupenediol	Bark	[8]
3-Ketooleanane	Bark	[23]
Isoliquiritigenin(2,4,40 -trihydroxychalcone)	Stem	[9,16]
Marsupsin, pterosupin, liquiritigenin	Heartwood	[9]
Neoflavones I and II	Stem	[20]
Hydroxy-20,40,50,7-tetramethoxyisoflavone	Heartwood	[9]
6-Hydroxy-7-methoxy-2H-chromen-2-one	Heartwood	[28]
Yellow 3-arylcoumarin derivative of santalin A	Stem	[26,27]
5-Hydroxy-7-O-(3-methyl)-but-2enylcoumarin	Heartwood	[29]
Isopterocarpolone, pterocarptriol, pterocarpdiolone	Heartwood	[22]
Pterocarpol	Heartwood	[22,24]
Eudesmol; α-, β-, and γ-isomer;β-santalol	Heartwood	[22,24]
Canusenol K, Canusenol L, Hamahasal A.12,15-Dihydroxy curcumene. (3β)-eudesmen-4(14)--ene-3Ent-4(15)-eudesmen-1α	Heartwood	[25]
Cryptomeridiol	Heartwood	[22]
Calocedrin	Heartwood	[18]
Savinin	Heartwood	[18]
Pterostilbene	Heartwood	[15,16,17]
7-Hydroxy-6-methoxy-coumarin-7-O-β-Dapiofuranosyl-(1--6)- β-D-glucopyranoside	Heartwood	[29]
40,5-Dihydroxy-7-O-methyl-isoflavone-30-O-β-D-glucoside	Heartwood	[10]

(Continued)

Table 2: (Continued)

Name of the Compound	Plant part	Reference
40,5-Dihydroxy-7-O-methyl-isoflavone-30-O-β-D-(300-E-cinnamoyl)-glucoside	Heartwood	[30]
7-Hydroxy-6-methoxy-coumarin-7-O-α-Larabinopyranosyl-(1--3)-β-Dgalactopyranosyl-(l--6)-β-Dgalactopyranoside	Heartwood	[14]
Santalin A	Stem	[35,36]
(-)-Fistenidol, santarubin A, santarubin B	Stem	[36,37]
Santalin, santal	Heartwood	[34,37]
Melanoxin-7, Pterolinuses A–J Melanoxoin-14, S-30-Hydroxy-4,40-dimethoxydalbergione-15, Hydroxybenzoic acid	Heartwood	[32,33]
Para-hydroxybenzoicacid, gentisic acid, αresorcylic acid, β-resorcylic acid, vanillic acid	Heartwood	[31]

Animal models used for biological testing of these bioactive substances revealed strong antidiabetic efficacy by lowering blood glucose and glycosylated hemoglobin levels, enhancing hyperlipidemia, and reestablishing insulin levels [12]. Steroids, flavonoids, carbohydrates, and mostly triterpenes, including lupenone, βamyrone, epilupeol, β-amyrin, lupeol, stigmasterol, and β-sitosterol, were found in *P. santalinus* leaves after phytochemical study. Triterpenes had antibacterial, analgesic, antioxidant, and anti-inflammatory properties.[13].

The heartwood of *P. santalinus* was examined phytochemically, and the results showed the presence of alkaloids, glycosides, phenolic compounds, flavonoids, terpenoids, carbohydrates, saponins, and tannins [14]. Pterocarpol, pterocarptriol, santalins A, B, and Y, isopterocarpalone, pterocarpodiolones, βeudesmol, and cryptomeridiol are among the other extremely specific metabolites found in P. *santalinus* [11]. It has been discovered that *Pterocarpus* species are abundant in terpenoids and isoflavonoids, along with associated phenolic compounds like epicatechin, lupeol, and β-sitosterol [14].

The secondary plant metabolites known as stilbenes are produced by phenylpropanoid pathways. E-stilbene (trans) and Z-stilbene (cis) are the two stereoisomer forms of stilbenes, which are phenolic chemicals. Pterostilbenemethyle, a particular resveratrol stilbene found in *P. santalinus* heartwood, has anti-inflammatory, antioxidant, antitumor, and anticancer properties [15,16,17].

Lignins and lignans are another group of plant metabolites. Certain lignins found in *P. santalinus* heartwood, such as salvin, calocedrin, and eudesmin, are important for the plant's defense against disease and insects [18]. Isoflavones are a class of secondary plant metabolites that are mostly present in *P. santalinus* and other Fabaceae members. Some of the isoflavones identified in *P. santalinus* include hydroxy-20,40,50,7-tetramethoxy- isoflavone, isoliquiritigenin (2,4,40-trihydroxychalcone) Marsupsin,pterosupin, liquiritigenin [16,19]. Neoflavones I and II were also present in the stem of *P. santalinus* [20].

Triterpenes, which are made up of three terpene molecules, are one of the most abundant and varied groups of plant metabolites. Important triterpenes that are identified in *P. santalinus* include lupenediol in leaves, lupenone, β-amyrone, epilupeol, β-amyrin, lupeol, stigmasterol, and betasitosterol in bark [8,21]. Erythrodiol in sapwood, acetyloleanolic aldehyde, and acetyloleanolic acid in heartwood [22]. 3-Ketoolenanewas is present in the bark of *P. santalinus* [23].Three isoprene units make up the class of terpenes known as sesquiterpenes. Sesquiterpenes are semiochemicals (that play a role in defense as pheromones or defense agents) in plants. Eudesmol; α-, β- and γ-isomer, β-santalol, pterocarpol, isopterocarpolone, pterocarptriol, pterocarpdiolone, and cryptomeridiol were some sesquiterpenes [22,24]. Canusenol K, canusenol L, hamahasal A, 12,15-dihydroxy curcumene, ent-4(15)-eudesmen-1α, and (3β)-eudesm-4(14) ene-3, are some of the sesquiterpenes discovered in *P. santalinus* [25].

One of the secondary metabolites in higher plants that is essential to pathogen defense and the response to abiotic stress is coumarins are one. The coumarin found in *P. santalinus* includes 3aryl coumarin in stem [26,27]. 6-hydroxy-7-methoxy-2H-chromen-2-one, and 5-hydroxy-7-O(3-methyl)-but-2-enylcoumarin in heartwood [28,29].

Thirty naturally occurring phenolic acids, mostly hydroxyl and polyhydroxy benzoic acids, have been shown to exhibit biological activity; of these, vanillic acid, gentisic acid, α- and β-resorcylic acid, and 3-hydroxybenzoic acid are of great importance to the pharmaceutical industry [29, 30, 31]. The heartwood of *P.santalinus* was found to include Pterolinuses A-J, melanoxin-7, melanoxoin-14, S-30-hydroxy-4, and 40-dimethoxydalbergione15, according to a comparison of nuclear magnetic resonance and mass spectrometry data. These neoflavonoids and benzofurans have anti-inflammatory and cytotoxic properties [33]. Some miscellaneous compounds, such as santalin and santalare, are present in the heartwood of *P. santalinus* [34]. Fistenidol, santarubin A, Santarubin B, and Santalin B are present in stem and Santalin Y can be found in the whole plant of *P.santalinus* [35, 36,37].

1.4. Pharmacological Potential of *P. Santalinus*

The pharmacology, ethnomedicinal, and phytochemical uses of *P. santalinus* were examined in earlier reviews. Due to the vast spectrum of biological activity of the bioactive chemicals found in the plant's heartwood, *P. santalinus* may one day be used to treat a variety of ailments. The heartwood and bark exhibited hepatoprotective, anti-inflammatory, antibacterial, and anti-diabetic effects, according to studies done both in vitro and in vivo. The heartwood of the plant is highlighted in Ayurveda, an Indian system of traditional medicine, as being applied externally to cure diabetes, jaundice, inflammation, skin conditions, headaches, and wound healing. The key phytocompounds found in the heartwood and other plant extracts are reviewed in this paper, which also provides a summary of the most recent research on their chemical profiles and pharmacological effects [38].

1.5. Antimicrobial Activity

Numerous adverse effects are linked to chemically synthesized medications used for the treatment of microbial disease. Both human and phytopathogens infections have acquired 'drug resistance' against common medications. As a result, it is urgently necessary to develop new antibiotics that are both safe and potentially effective against resistant microorganisms. Many researchers have looked at the antibacterial properties of *P. santalinus* leaf and stem bark extracts. In comparison to leaf extracts, the stem bark extract exhibited the highest level of activity on a few types of test organisms. The extracts demonstrated activity that depended on concentration. The plant's terpenoids, flavonoids, and steroids all had impressive MICs against *Bacillus subtilis.* This plant's methanol extracts have been shown to be effective antibacterial agents. Plant extracts derived from ethanol had the largest zone of inhibition against Bacillus subtilis and excellent inhibition against *Aspergillus niger.*

1.6. Anti-Inflammatory Activity

It has been demonstrated that rats with induced hind paw edema react favorably to *P. santalinus* heart wood (3% formalin extracts). From the plant extracts, five novel benzofurans and pterolinuses were isolated. These demonstrated strong anti-inflammatory action. When given to carrageenan-induced rat paws, *P. santalinus*'s methanolic wood extract showed anti-inflammatory properties. The extracts of glycosides, essential oils, flavonoids, and polyphenolic components all provided anti-inflammatory action. Numerous studies using animal models have proved the plant's intrinsic anti-inflammatory effects.

1.7. Anti-Oxidant Activity

P. santalinus ethanolic extract has shown strong antiulcer properties. This explains its ability to neutralize acids as well as its anti-inflammatory and antioxidant properties. Terpenoids, steroids, flavonoids, and carbohydrates are present in the methanolic extract of this plant. It significantly inhibited the DPPH radical (83.4% at a dosage of 25 mg/mL). Methanol extract exhibited impressive concentration-dependent free radical scavenging efficacy.

1.8. Anti-Diabetic Activity

Plant *P. santalinus b*ark extract has caused a significant hypoglycemic response in experimental animals. The ethanolic fractions (dosage of 0.25 g/kg body weight) showed remarkable anti-diabetic activity on artificially created normal and diabetic rats. Furthermore, blood glucose levels in normal rats given the same amount did not alter, and the animals' activity level was higher than that of diabetic rats given glibenclamide. Flavonoids, glycosides, and phenols showed considerable anti-hyperglycemic effect in experimental streptozotocin-induced diabetic rats by reducing blood glucose levels, lowering hyperlipidemia, and therefore restoring insulin levels. This was accomplished by decreasing gluconeogenesis and increasing glycolysis [4].

1.9. Other Pharmacological Activities

The plant is well-known for its distinctive wood, which has a stunning color, a delicate appearance, and exceptional technical features. The natural dye santalin, which is produced by the red wood, is used to color foodstuffs and pharmaceutical formulations. The decoction made from the heartwood is given numerous therapeutic characteristics in the ancient system of medicine. It has been used to induce vomiting as well as treat ulcers, mental disorders, and eye illnesses. It is known that the heartwood of Red sander trees has diaphoretic, aphrodisiac, antipyretic, anti-inflammatory, anthelmintic, tonic, hemorrhage, and dysentery-preventing properties. It's been employed as a cooling agent as well. It has been claimed that an ethanol extract of stem bark has anti-hyperglycemic properties. For scorpion stings and snake bites, the wood is also used in combination with other medications [3].

Among the plants used to cure diabetes is *P. santalinus*. Diabetes has long been treated with drinking water from cups filled with *P. santalinus* wood. *P. santalinus* is helpful in treating bilious affections, skin conditions such as anthelmintic, aphrodisiac, and alexiteric, as well as conditions of the eyes, stomach, ulcers, blood, and vomiting. It also helps with diabetes mellitus and its symptoms. For persistent diarrhea, an infusion of the fruit's decoction is used as an astringent tonic. The wood's paste has been used as an external cooling agent to cure headaches, ulcers, inflammations, and mental abnormalities. Stem bark powder with soft porridge has been used to treat diarrhea. It is well known that the lignan extracted from the heartwood prevents the synthesis of tumor necrosis factor alpha and T-cell growth. Heartwood's aurone glycosides have been identified as having anti-plasmodial activity and have being explored as a possible leishmanial medication. In CCl4-induced hepatotoxicity, methanol and heartwood aqueous extracts have demonstrated anti-hepatotoxicity. It has been claimed that *P. santalinus*, one of the constituents in Himoliv, a polyherbal and ayurvedic preparation, has hepatoprotective properties. Maximum action against *Enterobacter aerogenes, Alcaligenes faecalis, Escherichia coli, Pseudomonas aeruginosa, Proteus vulgaris, Bacillus cereus, Bacillus subtilis,* and *Staphylococcus aureus* was demonstrated by the stem bark extract. It is well known that ethanolic stem bark extract has anti-hyperglycemic properties. Additionally, the leaf extract shown greatest efficacy against *P. aeruginosa, A. faecalis, E. aerogenes,* and *E. coli.*

2. MAJOR THREATS

The population of *Pterocarpus santalinus* is decreasing as a result of human pressure and unlawful logging of "Red Sanders" forests. *P. santalinus* was present in a subset of 0.1 ha sample plots at a density of 16.75 per 0.1 ha. With regard to density, trees above 30 cm dbh were found at 9.19/0.1 hectare plots, whereas trees over 70 cm dbh were only found at 13.2 trees per ha. The average density of seedlings in the same sample plots was 0.74 per 0.1 hectare.

2.1. Habitat Specificity and Ecology

The average height of the medium-sized tree species *Pterocarpus santalinus* is between 10 and 15 meters. It can be found growing as pure strands or in mixtures with other natural species in dry deciduous woodlands. 2012: The majority of the species thrive on quartzite soil, which is a tight niche for them. It thrives in arid, hilly regions, frequently on rocky terrain. The species needs sunshine to survive, and it cannot stand water logging or shade. It will take the tree 50 to 60 years to develop to a 70 cm girth. Bees pollinate the trees, and seeds grow swiftly following the rainy season thanks to wind-distributed fruit and bee pollinated seeds. The range of the species is 150 to 900 meters.

2.2. Forest Fire

The red sanders are the rare species. But every year, grazers spark massive fires that severely harm the young seedlings.

2.3. Grazing

Cattle and deer will readily browse young plants, however, given the abundance of fodder grass nearby, the actual harm they cause is little.

2.4. Fuel

The biggest danger comes from man, who damages other trees beyond repair, making them useless and fit only for firewood, in his search for a tree with a strong heartwood and ideally wavy grain. Professional smugglers who operate close to the forests appear to have a say in what kind of silvicultural system should be used.

2.5. Trade and Use

Threatened by illegal timber harvest is this species. Red sands are scattered near impoverished settlements, where they are extracted and traded. The species is in risk because wood is a major source of livelihood. The hardwood species *Pterocarpus santalinus* is very expensive and beautiful. Furniture, musical instruments, carvings, and agricultural equipment are all made from its timber. Previously sought for in various regions of Europe, the wood is now highly sought after in China and Japan. It is concerning that P. *santalinus* is still around and that large amounts of red sanders wood are frequently seized from foreign markets.

2.6. Inbreeding

The remaining population of *Pterocarpus santalinus* is unbalanced due to the removal of the huge trees for timber, which results in decreased regeneration and greater decay and an instance of inbreeding. By removing superior phenotypes, the unlawful trade had a negative impact on the species population structure. In comparison to the quantity of flowers, the natural fruit set is relatively small (approximately 6%), with only xenogamous fruits maturing and the extinction of autogamous and geitonogamous fruit. As a result, the species is now at risk of further extinction.

2.7. Poor Natural Regeneration

The plant now experiences limited natural regeneration because to insufficient fruit set. Consequently, the species' population may continue to drop in the future, and due to the very tiny residual population, It is also expected to undergo inbreeding depression and genetic degradation.

2.8. Conservation Strategies

The tree population has been declining at an alarming rate in recent years. The majority of the time, the species is seen as common; however, it is considered one of India's critically endangered medicinal plants. Reasons for the decline in illegal felling, frequent forest fires, and possibly muted recovery in sensitive areas of distribution all have a direct impact on the species' population.

As a result, the species is listed in CITES' Appendix II of classified endangered species of wild animals and flora after being given an endangered status by the IUCN [2, 40]. The CITES aims to guarantee the continuation of wild international trade in animals and plants and protects overexploited species by preventing further exploitation. The solitary *Pterocarpus* species, *P. santalinus*, was included to CITES's Appendix II on February 16, 1995, at India's request. All species included in Appendix II, even those that aren't necessarily in danger of becoming extinct right now, could become extinct if trade in their specimens isn't strictly regulated to prevent uses that aren't consistent with their existence. Some ways to conserve these plant species can be outlined as following:

- Projects to Promote the Cultivation of Red Sanders.
- Awareness Campaigns.
- Encouraging National Red Sanders-Based Industries.
- Measures to Protect/Conserve Red Sanders.
- Mandate of Trade Policies.
- Export and import Government Rules.
- Curbing the Illegal Logging and Smuggling.
- Practicing effective *in situ* and *ex situ* conservation strategies [1].

3. CONCLUSION

Plants are a significant source of bioactive chemicals as natural products and have been used for medical treatment all over the world. In light of the recent development of cutting-edge medications for the treatment of numerous ailments, such as cancer and diabetes, scientific interest in oriental medicine has gradually grown. India has a rich history of medicinal plants, which are used by locals and traditional healers for a variety of ailments. The *P. santalinus* possesses significant hepatoprotective, antioxidant, antibacterial, and anti-inflammatory properties. Additionally, it also has anti-diabetic, hypolipidemic, anti-cancer, gastroprotective, and wound-healing effects. The medicinal benefits of the phytocompounds found in *P. santalinus* extract seem to work in concert to guard against a variety of disease consequences. Last but not least, the current evaluation offers the proof needed for other researchers to use *P. santalinus* as a successful natural remedy. It is advised that more preclinical and clinical research be conducted to fully assess the safety and therapeutic effectiveness of *P. santalinus*.

4. FUTURE PERSPECTIVES

The future research could explore more deeply into the ecological features of Red Sanders, such as its habitat needs, relationships with other species, and adaptation to environmental shifts. Sustainable management techniques and conservation initiatives can benefit from an understanding of their natural niche. With the use of satellite photography and sophisticated mapping methods, further research can improve our comprehension of Red sanders population dispersion. Land-use planning decisions can be informed by this, and priority locations for conservation can be identified. Further pharmacological studies are needed to elucidate the full range of therapeutic properties exhibited by Red sanders compounds. This includes exploring its potential efficacy in treating specific diseases, understanding mechanisms of action, and evaluating safety profiles. Biotechnological approaches, such as tissue culture and genetic engineering, hold promise for the conservation and sustainable utilization of Red sanders. These techniques can be employed for mass propagation, genetic improvement, and conservation of rare genotypes. Molecular docking is one of the essential computational approaches and a valuable tool that researchers can use to highlight the interactions of ligand molecules for drug discovery.

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6. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

7. CONFLICT OF INTEREST

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

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9. ETHICAL APPROVALS

As this is a review article based on previously published literature, no ethical approval or informed consent was required.

10. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

11. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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