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A Comprehensive Review on Pterocarpus Santalinus (Red Sandalwood): Phytochemistry, Pharmacological Activities and Therapeutic Potential

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ABSTRACT

Pterocarpus santalinus are commonly known as Red Sandalwood or Rakta Chandan, is a medicinally and economically important plant belonging to the family Fabaceae. The species is particularly associated with the Eastern Ghats of southern India and is well known for its characteristic red-coloured heartwood. The heartwood has been traditionally used in Indian systems of medicine for several conditions, particularly inflammatory and skin-related disorders. Modern phytochemical investigations have demonstrated the presence of several classes of secondary metabolites including polyphenols, flavonoids, terpenoids, stilbenes, and other phenolic compounds.

Several pharmacological investigations have reported antioxidant, anti-inflammatory, antimicrobial, antidiabetic, anticancer, hepatoprotective, gastroprotective and wound healing properties of extracts and isolated constituents. Important compounds reported from the heartwood include santalinA, santalin B, savinin, pterostilbene related compounds and other phenolic constituents. Recent reviews have emphasized the need for systematic pharmacological, toxicological and clinical investigations to establish the therapeutic potential of the plant.

The present review summarizes the botanical characteristics, geographical distribution, traditional uses, phytochemical constituents, pharmacological activities, mechanisms of action, safety aspects and future pharmaceutical prospects of Pterocarpus santalinus. The available literature suggests that the plant represents a promising source of natural bioactive molecules then, further standardised and clinically relevant studies are necessary before therapeutic applications can be established.

Keywords: Pterocarpus santalinus, Red Sandalwood, Rakta Chandan, santalin A & B, Herbal pharmacophore.

1. INTRODUCTION

Medicinal plants have been used by human civilizations for centuries and continue to provide important sources of therapeutic compounds. A considerable proportion of modern pharmaceutical research is directed towards the discovery, isolation and characterisation of naturally occurring bioactive molecules. Plants contain diverse classes of secondary metabolites that may possess antioxidant, antimicrobial, anti-inflammatory, antidiabetic and other biological properties.

Pterocarpus santalinus is an important medicinal tree belonging to the family Fabaceae. It is commonly referred to as Red Sandalwood because of its characteristic reddish heartwood. Unlike the fragrant white sandalwood (Santalum album), Red Sandalwood belongs to the genus Pterocarpus. The plant has considerable traditional, medicinal, cultural and economic importance. The heartwood of Pterocarpus santalinus has historically been used in traditional medicine. Scientific investigations have subsequently focused on identifying its chemical constituents and evaluating biological activities. A comprehensive review published in the Journal of Ethnopharmacology in 2021 summarised traditional uses, phytochemistry and pharmacological properties of the species and reported approximately 85 chemical constituents. The reported chemical profile varies according to the plant part and extraction method. Heartwood is particularly rich in polyphenolic compounds and sesquiterpenes, whereas bark and leaves have been reported to contain triterpenoid constituents. Because of this combination of traditional use and modern pharmacological research, Pterocarpus santalinus has become an interesting subject for pharmacognosy, phytochemistry and pharmaceutical research.

2. TAXONOMICAL CLASSIFICATION

Taxonomical rank	**Classification**
Kingdom	Plantae

Taxonomical rank	**Classification**
Division	Angiosperms
Class	Eudicots
Order	Fabales
Family	Fabaceae
Genus	Pterocarpus
Species	Pterocarpus santalinus

Common names: Red Sandalwood, Red Sanders, Rakta Chandan.

3. BOTANICAL DESCRIPTION

Pterocarpus santalinus is a small to medium-sized deciduous tree. The most distinctive feature of the plant is its dense reddish heartwood. The colour of the heartwood is responsible for its commercial and cultural value. The plant belongs to the legume family Fabaceae. The bark, leaves and heartwood have been investigated for phytochemical and pharmacological properties, although the heartwood is the most extensively studied part. The wood is hard and dense and has traditionally been used for furniture, decorative articles, handicrafts and other applications. The same commercial demand has contributed to concerns regarding overexploitation and conservation.

4. GEOGRAPHICAL DISTRIBUTION

Pterocarpus santalinus is an Indian endemic species principally associated with the Eastern Ghats of southern India. The plant has also been reported in other tropical regions through cultivation and introduction. Its restricted natural distribution and commercial value have made conservation an important issue. The 2021 literature review notes that the species has experienced significant pressure from overexploitation and illegal trade. Conservation and sustainable cultivation are therefore important components of the future utilization of this medicinal plant.

5. PHARMACOGNOSTICAL IMPORTANCE

The heartwood is the principal medicinally investigated part of Pterocarpus santalinus. It possesses a characteristic reddish colour and contains several secondary metabolites.

Important diagnostic features

- Dense reddish heartwood
- Characteristic woody texture
- Presence of coloured phenolic compounds
- Hard and durable wood
- Rich source of secondary metabolites

Pharmacognostical evaluation is important for identification and authentication because commercially available plant materials may vary in quality and may be substituted or adulterated.

6.TRADITIONAL USES

- The medicinal use of P. santalinus has been documented in traditional Indian medicine. The heartwood has traditionally been associated with applications involving inflammatory conditions, skin disorders and other ailments.
- According to published reviews, traditional applications include external use for inflammation, skin disorders and wound-related conditions, while various preparations have also been associated with management of conditions such as diabetes and jaundice.
- Traditional claims provide a basis for scientific investigation but should not automatically be interpreted as proof of clinical efficacy.

7. PHYTOCHEMICAL CONSTITUENTS

Phytochemical investigations have demonstrated a diverse chemical profile in P. santalinus. Reported classes include:

- Flavonoids
- Polyphenols
- Phenolic compounds
- Terpenoids
- Tannins
- Stilbenes
- Iso-flavonoids
- Sesquiterpenes
- Triterpenoids
- Lignans
- Sterols

The distribution of these constituents varies between different plant parts.

7.1 Major constituents reported from heartwood

Important compounds reported in the literature include:

- Santalin A
- Santalin B
- Santalin Y
- Savinin
- Pterostilbene-related compounds
- Pterocarpol
- Pterolinus compounds
- Calocedrin
- Pterocarptriol
- Isopterocarpalone β-sitosterol
- Lupeol
- Epicatechin

The 2016 review specifically highlights santalin A and B, savinin, calocedrin, pterolinus K and L and pterostilbene-related compounds among important bioactive constituents.

8. MAJOR PHYTOCHEMICAL CLASSES

8.1 Flavonoids

Flavonoids are an important group of plant secondary metabolites. They are widely investigated because of their antioxidant and anti-inflammatory properties. Their biological effects are frequently associated with their ability to interact with reactive oxygen species and cellular signaling pathways.

8.2 Polyphenols

Polyphenolic compounds may contribute substantially to the antioxidant potential of plant extracts. They can act as free-radical scavengers and may influence oxidative stress-related cellular processes.

8.3 Terpenoids

Terpenoids represent another major group of plant secondary metabolites. Triterpenoid constituents have been reported particularly from the bark and leaves of P. santalinus.

8.4 Stilbenes

Stilbenes are phenolic compounds of pharmacological interest. Pterostilbene-related compounds have been investigated for antioxidant and other biological effects.

8.5 Tannins

Tannins are polyphenolic compounds that can interact with proteins and may contribute to antioxidant and antimicrobial properties.

9. PHARMACOLOGICAL ACTIVITIES

The major pharmacological activities reported for P. santalinus are summarized below. Activity Antioxidant Anti-inflammatory Antimicrobial Experimental evidence reported In vitro and experimental studies In vitro/in vivo studies Extract and constituent studies Antidiabetic Experimental animal studies Anticancer In vitro and experimental studies Hepatoprotective Experimental studies Gastroprotective Experimental studies Wound healing Experimental evidence Hypolipidemic Experimental evidence Antiviral Emerging experimental evidence The available evidence is predominantly preclinical, and additional clinical studies are required to establish therapeutic efficacy in humans.

10. ANTIOXIDANT ACTIVITY

Oxidative stress occurs when the production of reactive oxygen species exceeds the capacity of endogenous antioxidant defense mechanisms. Excessive oxidative stress can contribute to cellular damage and several chronic diseases. Extracts of P. santalinus have been investigated for antioxidant activity. Phenolic and polyphenolic constituents are considered possible contributors to this activity. Possible mechanisms Antioxidant effects may involve:

1. Free-radical scavenging

2. Reduction of oxidative stress

3. Metal-ion interactions

4. Protection against lipid peroxidation

5. Modulation of antioxidant defense systems The antioxidant activity reported in experimental studies supports further investigation of standardized extracts and isolated compounds.

11. ANTI-INFLAMMATORY ACTIVITY

Inflammation is a complex biological response involving immune cells, inflammatory mediators and signaling pathways. Traditional use of P. santalinus heartwood for inflammatory conditions has encouraged modern scientific investigation. The 2021 review specifically identifies anti-inflammatory activity as an important area of research. Potential mechanisms may involve modulation of inflammatory mediators and pathways. However, specific mechanisms can differ between extracts and isolated compounds. Pharmaceutical significance Anti-inflammatory phytochemicals may have potential applications in the development of complementary drug-discovery candidates, provided that efficacy and safety are established through appropriate studies.

12. ANTIMICROBIAL ACTIVITY

Microbial resistance has increased interest in discovering new antimicrobial molecules from natural sources. Different extracts and constituents of P. santalinus have been evaluated against microorganisms. The antimicrobial potential may be associated with phenolic compounds, tannins and other secondary metabolites. Possible mechanisms include: Disruption of microbial membranes Interaction with microbial proteins Enzyme inhibition Alteration of microbial metabolism Oxidative damage to microbial cells Further studies using standardized extracts and clinically relevant microorganisms are required.

13. ANTIDIABETIC ACTIVITY

Diabetes mellitus is a metabolic disorder characterized by persistent elevation of blood glucose levels. Plant-derived compounds have been investigated for their ability to influence carbohydrate metabolism and glucose regulation. Experimental studies have reported antidiabetic potential for P. santalinus. The 2016 review summarizes antidiabetic effects among the reported biological activities of the plant. Potential mechanisms may include: Reduction of

carbohydrate digestion Enzyme inhibition Improvement in glucose utilization Antioxidant protection Modulation of lipid metabolism However, these findings should be regarded as preclinical evidence rather than established clinical treatment.

14. ANTICANCER POTENTIAL

Cancer involves uncontrolled cellular proliferation, altered signaling and resistance to apoptosis. Natural products have historically contributed to anticancer drug discovery. Several constituents and extracts of P. santalinus have been investigated for cytotoxic or anticancer effects. Possible mechanisms described in natural-product research include: Induction of apoptosis Cell-cycle regulation Reduction of oxidative stress Modulation of signaling pathways Inhibition of cellular proliferation The available evidence requires further validation through mechanistic, pharmacokinetic, toxicity and clinical studies.

15. HEPATOPROTECTIVE ACTIVITY

The liver is a major organ involved in metabolism and detoxification. Oxidative stress and chemical exposure can cause hepatic injury. Experimental research summarized in previous reviews suggests hepatoprotective potential of P. santalinus. The potential protective effects may be related to antioxidant and anti-inflammatory properties. However, further controlled studies are necessary to establish the active constituents and mechanisms involved.

16. GASTROPROTECTIVE ACTIVITY

Gastric mucosal damage can result from several factors including oxidative stress, inflammation and chemical irritants. The literature has reported gastroprotective potential associated with P. santalinus. The 2016 review includes protective effects on gastric mucosa among the reported biological activities. Further investigations are necessary to determine whether specific compounds can provide reproducible protection and to establish dose-response relationships.

17. WOUND-HEALING POTENTIAL

Traditional use of the heartwood includes applications related to wounds and skin disorders. The possible wound-healing effect may involve several processes:

1. Reduction of inflammation

2. Antioxidant protection

3. Antimicrobial effects

4. Support of tissue repair Because wound healing is a complex process, further experimental studies should evaluate re-epithelialization, collagen formation, angiogenesis and inflammatory mediators.

18. DERMATOLOGICAL IMPORTANCE

The phytochemical and pharmacological characteristics of P. santalinus have also attracted interest in dermatology. A 2022 review specifically examined the phytochemistry, pharmacology and dermatological role of the species. Potential areas of investigation include: Skin inflammation Oxidative stress Microbial skin conditions Wound healing Cosmetic formulations Nevertheless, topical formulations require proper evaluation for irritation, sensitization, microbial quality and stability.

19. POSSIBLE MECHANISMS OF ACTION

The pharmacological effects of P. santalinus are likely to result from multiple constituents rather than a single compound. A simplified pharmacological pathway can be represented as:

Plant material

↓

Extraction

↓

Phytochemical constituents

↓

Interaction with biological targets

↓

Modulation of oxidative/inflammatory pathways

↓

Antioxidant / anti-inflammatory / other biological effects

The exact molecular mechanisms depend on the specific compound, extract, dose and experimental model.

20. PHARMACEUTICAL APPLICATIONS

Potential pharmaceutical applications of P. santalinus include:

1.Herbal formulations

Standardized extracts may potentially be incorporated into herbal preparations after appropriate safety and efficacy evaluation.

2. Topical preparations

Because of reported dermatological and wound-related potential, topical dosage forms may represent an area for research.

3. Antioxidant formulations

Phenolic-rich fractions may be investigated for antioxidant applications.

4. Drug discovery

Isolated phytochemicals can serve as lead molecules for medicinal chemistry and pharmacological studies.

21. QUALITY CONTROL AND STANDARDIZATION

Standardization is essential for converting a medicinal plant into a reproducible pharmaceutical ingredient. Important parameters include:

- Botanical authentication
- Macroscopic evaluation
- Microscopic evaluation
- Physicochemical parameters
- Moisture content
- Ash values
- Extractive values
- Phytochemical screening
- Chromatographic fingerprinting
- Marker-compound estimation
- Microbial quality
- Heavy-metal analysis
- Pesticide-residue testing

- HPLC, HPTLC, GC-MS, LC-MS and spectroscopic techniques may be used depending on the target constituents.

22. EXTRACTION METHODS

Extraction is a critical step in phytochemical research. Common extraction methods include:

1. Maceration

Plant material is soaked in a suitable solvent for a predetermined period.

2. Soxhlet extraction

A continuous hot extraction technique that can improve extraction efficiency.

3. Ultrasonic-assisted extraction

Ultrasound is used to improve solvent penetration and extraction of constituents.

4. Modern extraction techniques

Advanced techniques such as microwave-assisted extraction and supercritical-fluid extraction may also be explored.

The choice of solvent and extraction conditions can significantly influence the phytochemical profile and biological activity of the final extract.

23. SAFETY AND TOXICOLOGICAL CONSIDERATIONS

Although several experimental studies report promising biological activities, safety must be established before therapeutic use. Important toxicological parameters include: Acute toxicity Subacute toxicity Chronic toxicity Genotoxicity Reproductive toxicity Organ toxicity Drug–herb interactions The 2016 review specifically recommends further preclinical and clinical investigations to adequately evaluate safety and therapeutic efficacy. Therefore, traditional use alone should not be considered sufficient evidence of clinical safety.

24. CONSERVATION AND SUSTAINABILITY

The medicinal and commercial value of Red Sandalwood has resulted in considerable pressure on natural populations. Published literature has discussed overexploitation and illegal trade as important conservation concerns. Sustainable cultivation, controlled harvesting, authentication and conservation programs are important for ensuring continued availability of the species. Pharmaceutical research should ideally promote sustainable sourcing rather than increasing pressure on wild populations.

25. CURRENT RESEARCH STATUS

Research on P. santalinus has progressed from traditional medicinal observations to phytochemical isolation and pharmacological evaluation.

The 2021 Journal of Ethnopharmacology review highlighted approximately 85 reported chemical constituents and identified anti-inflammatory, antioxidant, anticancer and antiviral research as important areas of recent interest.

However, major research gaps remain:

- Limited clinical evidence
- Lack of standardized extracts
- Variation in phytochemical composition
- Limited pharmacokinetic information
- Need for better toxicity studies
- Need for well-designed human trials
- Limited information about compound bioavailability

26. FUTURE PROSPECTS

Future research should focus on:

1. Isolation of novel bioactive compounds.

2. Detailed molecular mechanism studies.

3. Standardization of extracts.

4. Pharmacokinetic and bioavailability studies.

5. Toxicological evaluation.

6. Development of suitable pharmaceutical dosage forms.

7. Clinical evaluation of promising preparations.

8. Sustainable cultivation.

9. Use of modern analytical techniques.

10. Investigation of synergistic effects between phytoconstituents. Integration of pharmacognosy, phytochemistry, pharmacology, pharmaceutical technology and molecular biology could significantly improve understanding of this plant.

27. DISCUSSION

The available literature demonstrates that Pterocarpus santalinus is a phytochemically diverse medicinal plant with considerable pharmacological research interest. The heartwood represents the most extensively investigated part and contains several phenolic and other secondary metabolites.

The reported antioxidant and anti-inflammatory properties are particularly relevant because oxidative stress and inflammation participate in many chronic pathological processes. Other reported activities such as antidiabetic, antimicrobial, anticancer and hepatoprotective effects further increase the potential pharmaceutical value of the species.

However, it is important to distinguish between traditional use, laboratory evidence and clinically established therapeutic efficacy. A large proportion of the available evidence remains experimental. Therefore, more rigorous studies are required before specific therapeutic claims can be made.

Standardization represents another important challenge. Differences in geographical origin, plant age, harvesting conditions, extraction solvents and processing methods can influence phytochemical composition. Consequently, future studies should use authenticated plant material and chemically characterized extracts.

28. CONCLUSION

Pterocarpus santalinus L.f. is an important medicinal plant with a long history of traditional use and significant phytochemical diversity. Its heartwood contains several classes of secondary metabolites, including polyphenols, flavonoids, terpenoids, stilbenes and other phenolic constituents.

Experimental research has reported antioxidant, anti-inflammatory, antimicrobial, antidiabetic, anticancer, hepatoprotective, gastroprotective and wound-healing potential. These activities make P. santalinus an attractive candidate for further pharmaceutical and medicinal chemistry research.

Nevertheless, promising laboratory findings should not be considered equivalent to proven clinical efficacy. Standardized extracts, well-characterized active constituents, pharmacokinetic studies, comprehensive toxicological evaluation and controlled clinical trials are required.

Sustainable cultivation and conservation are also essential because the species has considerable commercial value and has faced pressure from overexploitation. Overall, P. santalinus represents a promising natural source of bioactive compounds and deserves further systematic investigation for potential pharmaceutical applications.

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