International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Hardwickia binata Roxb. (Anjan): A Comprehensive Review of its Botany, Ethnomedicinal Uses, Phytochemistry, and Socio-Economic Importance

[1]Dr. Bhuraji Narware [2]Dr. Vikas Singh [3]Dr. Monika Tyagi [4]Dr. Rajesh Sharma

[1,2] PG Scholar (Ayu), Dravyaguna Department, A & U Tibbia College & Hospital, Karol Bagh New Delhi.
[3]Assistant Professor (Ayu), Dravyaguna Depatment, A & U Tibbia College & Hospital, Karol Bagh New Delhi
[4] Professor (Ayu), H.O.D, Dravyaguna Department, A & U Tibbia College & Hospital, Karol Bagh New Delhi.

ABSTRACT :

Hardwickia binata Roxb., commonly known as Anjan, is a monotypic, deciduous tree species of the family Fabaceae, endemic to the arid and semi-arid regions of the Indian subcontinent. It stands as a keystone species of profound ecological and economic significance. This review provides a comprehensive synthesis of the current scientific knowledge on *H. binata*, covering its botanical characteristics, geographical distribution, ethnobotanical applications, phytochemical composition, and scientifically validated pharmacological activities. Morphologically, the tree is distinguished by its unique bifoliolate leaves, graceful drooping branches, and remarkable hardiness. Traditionally, various parts of the plant, including the bark, leaves, seeds, and oleo-gum-resin, have been extensively used in folklore medicine to treat a wide array of ailments such as diarrhea, leprosy, worm infections, gonorrhea, and cancer. Phytochemical investigations have revealed a rich repository of bioactive compounds, including phenolic compounds, flavonoids, tannins, saponins, and notably, a novel diterpenoid named Harbinatic acid, which has been identified as a potent inhibitor of DNA polymerase β. Scientific validation studies have confirmed its broad-spectrum pharmacological potential, demonstrating significant antimicrobial, antifungal, antioxidant, anti-inflammatory, and cytotoxic activities against various human cancer cell lines. Beyond its medicinal value, *H. binata* is a vital economic resource, yielding one of India's hardest and most durable timbers, nutritious fodder for livestock, and strong bark fiber for ropes and composites. Its deep-rooting nature and drought tolerance make it an ideal species for agroforestry systems, contributing to soil conservation, restoration of degraded lands, and carbon sequestration. This review consolidates the multifaceted importance of *H. binata*, highlighting its potential for sustainable development and underscoring the need for integrated research and conservation efforts.

1.0 Introduction

1.1 Historical and Botanical Context

Hardwickia binata Roxb., widely known by its vernacular name 'Anjan', is a remarkable deciduous tree native to the Indian subcontinent.[1] It occupies a unique botanical position as the sole species within the genus *Hardwickia*, belonging to the legume family, Fabaceae (subfamily Detarioideae, though often cited under the historical subfamily Caesalpinioideae in older literature).[1] The genus was formally described by the Scottish botanist William Roxburgh in 1811, who named it in honor of Major-General Thomas Hardwicke, a British soldier and naturalist who made significant contributions to the study of Indian flora and fauna.[1]
The tree's cultural resonance extends deep into Indian history, with mentions in ancient texts that underscore its long-standing relationship with human civilization and the natural world. It is described in classical Sangam literature, where its bark and sweet-smelling oil are noted as being favored by elephants.[1] Furthermore, it is mentioned as one of the trees present in the Asokavanam in the epic Ramayana, the grove where Sita was held captive.[1] This historical and cultural embedding signifies the tree's enduring presence and importance in the Indian landscape for millennia.

1.2 Socio-Economic and Ecological Significance

Hardwickia binata is far more than a botanical specimen; it is an interdisciplinary keystone species that forms the backbone of many rural economies and ecosystems in the arid and semi-arid regions of India.[3] Its ability to thrive in harsh, degraded environments where other species fail makes it an invaluable asset for both ecological restoration and sustainable livelihoods. The tree is a quintessential multipurpose species, providing a trifecta of essential resources: timber, fodder, and fiber. Its wood is renowned for being one of the hardest and heaviest in India, prized for its durability and resistance to decay, making it a first-class timber for construction and agricultural implements.[2]
Ecologically, its role is equally profound. The deep taproot system allows it to anchor in rocky, shallow soils, preventing erosion and initiating ecological succession on degraded lands.[2] This characteristic makes it an ideal candidate for large-scale afforestation programs and a cornerstone of agroforestry systems, where it contributes to soil conservation, moisture retention, and potentially nitrogen fixation. Its integration into silvopasture and agrisilviculture models provides a sustainable source of nutritious fodder for livestock, particularly during the critical dry seasons, thereby supporting animal husbandry, a vital component of the rural economy.[3]

1.3 Scope of the Review

The profound and varied importance of *Hardwickia binata* necessitates a holistic and integrated understanding of its biology, utility, and potential. While numerous studies have focused on specific aspects of the tree, a comprehensive synthesis is required to bridge the knowledge gaps between its different domains of significance. This review aims to critically evaluate and consolidate the existing scientific literature on *H. binata*. It will systematically cover its taxonomy and detailed morphology, geographical distribution and ecological adaptations, rich phytochemical profile, extensive traditional and modern pharmacological applications, diverse economic uses, and current conservation status. By weaving together these disparate threads of knowledge, this article seeks to provide a definitive, single-source reference for researchers, foresters, pharmacologists, and policymakers, thereby catalysing future research and promoting the sustainable management of this invaluable natural resource.[6]

2.0 Botanical Description and Taxonomy

2.1 Scientific Classification and Nomenclature

The taxonomic classification of *Hardwickia binata* places it firmly within the plant kingdom's higher orders [1]:

- **Kingdom:** Plantae
- **Clade:** Tracheophytes (Vascular plants)
- **Clade:** Angiosperms (Flowering plants)
- **Clade:** Eudicots
- **Clade:** Rosids
- **Order:** Fabales
- **Family:** Fabaceae (Legume family)
- **Subfamily:** Detarioideae (or Caesalpinioideae in older systems) [1]

The genus *Hardwickia* is monotypic, containing only the single species *H. binata*.[1] This botanical singularity underscores its unique evolutionary path. Across its native range, the tree is known by a variety of vernacular names, reflecting its widespread cultural and economic importance. These include 'Anjan' (Hindi, Marathi, Sanskrit), 'Acha' or 'Calam' (Tamil), 'Yepi' or 'Narepi' (Telugu), and 'Kammara' (Kannada).[2]

2.2 Detailed Morphology

Hardwickia binata is a handsome and easily recognizable tree, possessing a distinct morphology adapted to its environment.

- **Habit:** It is a moderate to large-sized deciduous tree that can attain heights of 24 to 36 m, with a trunk girth of up to 4 m.[2] In favorable, crowded conditions, it develops a long, clean, and cylindrical bole reaching 12–15 m, but in open or poor soil conditions, it may branch lower down.[2] The crown is conical in its youth, gradually broadening with age, and is characterized by graceful, slender, drooping branchlets that give the tree a feathery appearance.[2]
- **Bark:** The bark undergoes a notable transformation with age. On saplings and young trees, it is smooth and almost silvery-white, becoming progressively dark grey, rough, and marked by irregular vertical cracks as the tree matures. The mature bark can be 1.2–2.5 cm thick and exfoliates in narrow flakes.[1]

Figure 2. Identification plaque for *Hardwickia\ binata* (family Leguminosae), commonly known as Anjan. Photograph by the author, taken in Madhya Pradesh, India

- **Leaves:** The leaves are one of the most distinctive features of the tree. They are alternate and uniquely bifoliolate, consisting of just two leaflets joined at the base, which gives them a kidney-shaped or butterfly-like appearance reminiscent of the leaves of *Bauhinia* species.[2] The leaflets are small, typically 2–6 cm long and 2–3 cm wide, greyish-green, and coriaceous (leathery) in texture.[1]

Figure 1. Leaves of a *Hardwickia binata* tree against the bark. Photograph by the author, taken in Madhya Pradesh, India.

- **Flowers:** The flowers are small, inconspicuous, and pale yellowish-green, arranged in lax axillary and terminal panicled racemes.[2] Taxonomically, the flowers are significant for being apetalous (lacking petals) and actinomorphic (radially symmetrical), features that are relatively uncommon and point towards specific pollination strategies.[13]
- **Fruit and Seed:** The fruit is a flat, samaroid pod—a dry, indehiscent fruit with a wing-like structure to aid dispersal. The pod is oblong-lanceolate, 5–7.6 cm long and 1–1.5 cm wide, leathery, and narrowed at both ends.[1] It contains a single, flat, exalbuminous (lacking endosperm) seed near its apex. This winged structure is a clear adaptation for anemochory, or wind dispersal.[4]

2.3 Phenology and Reproductive Biology

The life cycle of *H. binata* is closely synchronized with the seasonal rhythms of its semi-arid habitat. The tree is deciduous, shedding its leaves for a brief period towards the end of the cold or winter season.[2] New foliage, often tinged with a distinctive reddish or copper color, emerges in April, making the tree conspicuous with its full, feathery canopy during the hot summer when many associated species are leafless.[2]

The flowering season typically occurs between July and September, varying slightly with locality.[1] The pods develop through the subsequent months and ripen by the following April or May. The dispersal of the light, winged pods coincides perfectly with the strong, dry winds prevalent at the end of the hot season, ensuring they are carried significant distances from the parent tree.[2] While the tree produces some seeds annually, prolific or gregarious seeding events occur every 3 to 5 years, a phenomenon often triggered by preceding drought conditions.[2] The flower structure and pollen morphology suggest that pollination is primarily achieved by wind (anemophily), though bees have also been observed as pollinators.[13]

2.4 Taxonomic Relationship with Colophospermum mopane

A significant point of taxonomic interest is the proposed congeneric relationship between the Indian *Hardwickia binata* and the southern African Mopane tree, *Colophospermum mopane*. Research by Breteler et al. (1997) presented compelling evidence suggesting that these two monotypic genera should be merged.[13] This argument is not based on superficial similarity but on a suite of unique, shared characteristics that are rare within the Caesalpinioideae. These include the absence of bracteoles on the flower stipe, a flower and pollen structure strongly indicative of wind pollination, and a similar chromosome number.[13]

The ecological parallels are also striking; both species dominate dry savanna ecosystems, one north of the equator in India and the other south of the equator in Africa.[13] This deep-seated similarity in morphology, reproductive biology, and ecology points not to convergent evolution—where unrelated species independently evolve similar traits—but to a shared, ancient ancestry. This suggests a common progenitor that existed before the continental drift separated the Indian subcontinent from the African landmass, placing *H. binata* not just as an Indian endemic but as a living relic of the ancient supercontinent of Gondwana. Based on this evidence, the reclassification of the mopane tree as *Hardwickia mopane* has been formally proposed.[1]

3.0 Geographical Distribution and Ecological Profile

3.1 Natural Habitat and Distribution

Hardwickia binata is endemic to the Indian subcontinent, where it is found in discontinuous, isolated blocks and patches across the drier regions of central and southern India.[4] Its core distribution includes the states of Madhya Pradesh, Maharashtra, Chhattisgarh, Andhra Pradesh, Karnataka, and Tamil Nadu, with some presence in Uttar Pradesh and Bihar.[4]

The tree is a characteristic species of tropical dry deciduous forests, dry savannas, and degraded woodlands.[2] It is particularly noted for its ability to colonize and thrive on dry, shallow, and gravelly soils, as well as on rocky terrain where most other tree species cannot establish themselves.[1] In certain areas of Maharashtra, Madhya Pradesh, and Andhra Pradesh, it grows in such abundance that it forms nearly pure stands, which are officially designated as "Hardwickia Forest" type, a testament to its dominance in these specific ecological niches.[4]

3.2 Biophysical Limits: Climatic and Edaphic Requirements

The ecological profile of *H. binata* is defined by its exceptional adaptation to harsh, resource-limited environments. This resilience makes it a crucial component of India's dryland ecosystems.

- **Climate:** The species is quintessentially a tree of hot and dry climates, characterized by long drought periods, low to moderate annual rainfall, and intense summer heat.[2] It thrives in areas with a mean annual rainfall between 250 mm and 1500 mm and can withstand mean maximum temperatures ranging from 43°C to 47°C.[14] While seedlings are sensitive to drought and frost in their first year, they become remarkably hardy from the second year onwards.[2]
- **Altitude:** *H. binata* is primarily a lowland species, typically found at altitudes from sea level up to 300 m.[2] However, its range can extend up to 1500 m in the western Himalayas, indicating a degree of adaptability to higher elevations.[1]
- **Soils:** The tree is not edaphically demanding and can grow on a wide variety of geological formations, including sandstone, conglomerate, quartzite, granite, and schist.[2] It shows a preference for well-drained, light to medium-textured soils, such as sandy loams or characteristic quartzose reddish gravelly sand.[2] It tolerates a soil pH range from acidic to neutral (5.0 to 7.5).[7] Its most critical adaptation is its powerful and deep taproot system, which can tenaciously penetrate fissures in solid rock to access deep-seated moisture and nutrients.[2] This ability makes it a pioneer species, capable of colonizing barren, rocky ground. Conversely, the species is intolerant of waterlogged or poorly drained soils.[14]

3.3 Associated Flora and Phytosociological Characteristics

As a signature species of tropical dry deciduous forests, *H. binata* is often found in association with other hardy, drought-resistant species. It is a characteristic component of teak (*Tectona grandis*) forests, indicating its place within this specific forest community.[9] Phytosociological studies conducted in these forest types consistently show the dominance of the Fabaceae (Leguminosae) family, to which *H. binata* belongs.[20] The tree's presence and dominance are key indicators of a forest ecosystem adapted to severe moisture stress and poor soil conditions. Its ability to colonize and thrive on degraded lands positions it as a powerful ecological engineer. It does not merely inhabit these harsh environments; it actively modifies them. By establishing a foothold, its deep roots stabilize the soil, its leaf litter provides organic matter that improves soil fertility, and its canopy creates a microclimate that can facilitate the establishment of other, less hardy species, thereby initiating a process of ecological succession and restoration. This functional role makes it a primary candidate for afforestation and rehabilitation projects aimed at combating desertification in India's semi-arid regions.

4.0 Phytochemical Composition

Hardwickia binata is a veritable reservoir of diverse phytochemicals, with different parts of the tree synthesizing distinct classes of compounds that underpin its wide-ranging medicinal and industrial applications. Modern analytical techniques have begun to map this complex chemical landscape, revealing a wealth of bioactive molecules.

4.1 Major Phytoconstituents across Plant Parts

Comprehensive phytochemical screenings have consistently revealed a broad spectrum of secondary metabolites across the leaves, seeds, husk, bark, heartwood, and roots. The major classes of compounds present include carbohydrates, proteins, amino acids, steroids, saponins, glycosides, flavonoids, tannins, phenolic compounds, lipids, quinones, and volatile oils.[6] A notable and consistent finding across multiple studies is the absence of alkaloids in most plant parts, which helps in its chemical characterization.[15]

The distribution of these compounds is not uniform, indicating specialized biosynthetic pathways in different tissues. This compartmentalization of bioactivity suggests that specific parts of the plant can be targeted for the extraction of particular therapeutic agents.

- **Heartwood:** This part is particularly rich in flavonoids and related polyphenols, containing compounds such as β-sitosterol, (+)-taxifolin, eriodictyol, (+)-catechin, (+)-epicatechin, and (+)-mopanol.[7] These compounds are well-known for their potent antioxidant and cardioprotective properties.
- **Leaves, Seed, and Husk:** These parts are abundant in phenols, flavonoids, saponins, glycosides, and tannins, contributing to their use as fodder and in remedies requiring antimicrobial and astringent action.[7]

- **Root Bark Exudates:** This exudate is a chemically complex mixture, containing a wide array of constituents including carbohydrates, glycosides, fixed oils, proteins, saponins, tannins, phytosterols, phenolic compounds, and flavonoids.[7] Its traditional use in cancer treatment has made it a focus of intensive research.

Plant Part	Phytochemical Class	Presence/Absence	Key Compounds Identified
Heartwood	Flavonoids, Steroids	Present	(+)-taxifolin, eriodictyol, (+)-catechin, (+)-epicatechin, (+)-mopanol, β-sitosterol [7]
Leaves	Phenols, Flavonoids, Saponins, Tannins, Glycosides, Steroids	Present	Phenolic compounds, Linoleic acid ethyl ester, Ethyl oleate [18]
Bark	Tannins, Saponins, Phenols, Steroids, Alkaloids	Present	Tannins, Phenolic compounds [15]
Seed & Husk	Phenols, Flavonoids, Saponins, Glycosides, Tannins	Present	Thymol (husk only), Linoleic acid ethyl ester [18]
Root Bark	Diterpenoids, Phenols, Flavonoids, Saponins, Tannins	Present	Harbinatic acid, cis-9-Hexadecenal, n-hexadecanoic acid, Squalene [6]
All Parts	Alkaloids	Generally Absent	Not detected in most extracts [15]

4.2 Isolation and Characterization of Key Bioactive Compounds

The most significant discovery from bioactivity-guided fractionation of *H. binata* extracts is the isolation of **Harbinatic acid**. This novel diterpenoid was isolated from an active methyl ethyl ketone extract and was structurally established as 3α-O-trans-p-coumaroyl-7-labden-15-oic acid. Crucially, it was identified as a potent inhibitor of DNA polymerase β, with an IC50 value of 4.7 µM.[6] DNA polymerase β is a key enzyme involved in the base excision repair pathway of DNA, and its inhibition is a validated strategy in cancer chemotherapy to enhance the efficacy of DNA-damaging agents. This discovery provides a direct molecular mechanism that could explain the traditional use of the plant's root bark in treating cancer.

4.3 Analytical Profiling (GC-MS, FTIR)

Modern analytical techniques have enabled a more detailed chemical fingerprinting of *H. binata* extracts, revealing a multitude of individual compounds with known biological activities.

- **Fourier-Transform Infrared Spectroscopy (FTIR):** Analysis of crude powders from leaves, seed, and husk has confirmed the presence of characteristic functional groups, including hydroxyl (O-H) from alcohols and phenols, amine (N-H) from amines and amides, carbonyl (C=O) from carboxylic acids and esters, and various C-H and C=C bonds from alkanes, alkenes, and aromatic rings.[18] This provides a broad chemical overview consistent with the presence of the phytochemical classes identified in preliminary screenings.
- **Gas Chromatography-Mass Spectrometry (GC-MS):** This powerful technique has allowed for the separation and identification of numerous individual volatile and semi-volatile compounds. A study on the root bark exudates identified 22 distinct organic compounds. Among these were cis-9-Hexadecenal, n-hexadecanoic acid, squalene, and several fatty acid esters like 9,12,15-Octadecatrienoic acid ethyl ester.[18] Many of these compounds are known to possess antimicrobial, anti-inflammatory, hepatoprotective, and anticancer properties, providing a scientific basis for the plant's diverse therapeutic claims. Similarly, GC-MS analysis of ethanolic extracts from leaves, seed, and husk identified other bioactive molecules, including linoleic acid ethyl ester, ethyl oleate, and thymol, which are known for their antimicrobial, antioxidant, and cancer-preventive activities.[18]

5.0 Ethnobotanical and Traditional Applications

The rich phytochemical profile of *Hardwickia binata* is mirrored by its extensive use in traditional and folk medicine systems across the Indian subcontinent. For centuries, local communities have relied on this resilient tree as a versatile pharmacy, developing a sophisticated body of ethnobotanical knowledge that is now guiding modern scientific inquiry.[6]

5.1 Role in Traditional Indian Medicine Systems

H. binata is a well-established component of folklore medicine, employed for a vast spectrum of ailments ranging from common infections to chronic diseases. Its application spans treatments for diarrhea, leprosy, parasitic worm infections, indigestion, gonorrhea, chronic cystitis, leucorrhoea, and cancer.[6] The use of nearly every part of the plant—roots, bark, leaves, seeds, wood, and resin—highlights its central role in traditional healthcare practices.[6]

5.2 Documented Folkloric Uses for Various Ailments

The ethnomedicinal applications are often highly specific to the plant part used, reflecting a nuanced understanding of the differential distribution of bioactive compounds within the tree.

Ailment/Condition	Plant Part Used	Method of Preparation/Administration	Community/Region of Use
Breast Cancer	Root Bark Exudate	Traditional preparation (details proprietary to tribe)	Malayali tribes, Chitteri Hills, Tamil Nadu [6]
Diarrhea, Dysentery, Worms, Leprosy	Bark, Seeds	Decoction or powder, leveraging astringent tannins	Widespread traditional use [7]
Gonorrhea, Leucorrhoea, Chronic Cystitis	Oleo-resin (Balsam)	Often combined with cubebs and sandal	Widespread traditional use [1]
Headache, Constipation	Leaves	Aqueous paste applied dermally (headache); used as a purgative (constipation)	Natives of Chhattisgarh region [7]
Rheumatism	Leaf and Bark	Decoction or paste	General folk medicine [15]
Diuretic	Resin	Ingestion	General folk medicine [1]

This detailed traditional knowledge forms a valuable repository of therapeutic leads. The most striking example is the specific use of root bark exudates for breast cancer by the Malayali tribes. This is not a vague claim of "anti-cancer" properties but a targeted application for a specific disease using a specific plant part. This precision provided a direct and compelling starting point for modern pharmacological research, which ultimately led to the validation of its cytotoxic potential and the isolation of the potent compound Harbinatic acid.[6] This successful transition from ethnobotanical claim to molecular mechanism exemplifies a powerful validation loop, demonstrating how traditional wisdom can streamline and focus the drug discovery process.

5.3 Non-Medicinal Traditional Uses

Beyond its role as a medicinal plant, *H. binata* is deeply integrated into the material culture and daily life of rural communities.

- **Fiber:** The tough inner bark yields a strong fiber known as 'yepi' fiber, which has been traditionally used for making durable ropes, cordage, and even sails for boats.[2] According to the 12th-century Sanskrit encyclopedia *Manasollasa*, ropes made from *Hardwickia* fiber were strong enough to be used in the capture of wild elephants.[1]
- **Resin and Fodder for Elephants:** The connection between the tree and elephants is a recurring theme. The resin exuded from the heartwood is traditionally used as a dressing to treat the sores and wounds of elephants.[1] Furthermore, ancient Sangam literature notes that elephants are particularly fond of consuming the tree's bark and leaves, highlighting its role as a natural fodder source for megafauna.[1]

6.0 Pharmacological Properties and Scientific Validation

The extensive ethnobotanical uses of *Hardwickia binata* have prompted numerous scientific investigations to validate its therapeutic claims and elucidate the underlying pharmacological mechanisms. *In vitro* and *in vivo* studies have confirmed a wide spectrum of bioactivities, providing a strong evidence base for its traditional applications and opening avenues for the development of novel pharmaceuticals.

6.1 Antimicrobial and Antifungal Activity

Various extracts of *H. binata* have demonstrated significant broad-spectrum antimicrobial activity. Studies using the agar well diffusion method have shown that ethanolic and petroleum ether extracts of the leaves exhibit potent inhibitory effects against a range of human pathogens. These include Gram-positive bacteria such as *Bacillus subtilis* and *Staphylococcus aureus*, and Gram-negative bacteria like *Escherichia coli* and *Pseudomonas aeruginosa*.[6] The petroleum ether extract, in particular, showed very high zones of inhibition (22-23 mm) against *Proteus vulgaris*, *S. aureus*, and *Vibrio vulnificus*.[7] Furthermore, a methanolic extract of the bark has been found to be effective against pathogenic fungi, including the opportunistic yeast *Candida albicans* and the mold *Aspergillus niger*, with one study reporting inhibition zones of 28-31 mm.[23] This broad-spectrum activity supports its traditional use for treating various infections.

6.2 Anticancer and Cytotoxic Potential

The most compelling area of pharmacological research on *H. binata* is its anticancer potential, directly inspired by its traditional use against breast cancer.[6] This traditional knowledge has been substantiated by modern *in vitro* studies. Various solvent extracts from the leaves of *H. binata* have been tested for cytotoxicity against human cancer cell lines using the MTT assay. These studies confirmed that the extracts possess the ability to inhibit the growth of human breast cancer (MCF-7) and human cervical cancer (HeLa) cell lines in a dose-dependent manner.[26]

The scientific basis for this activity has been significantly advanced by the isolation of Harbinatic acid, a novel diterpenoid that acts as a potent inhibitor of DNA polymerase β.[6] By targeting this crucial DNA repair enzyme, Harbinatic acid can induce apoptosis or enhance the cell-killing effects of other chemotherapeutic agents, providing a clear molecular mechanism for the plant's anticancer effects. This positions *H. binata* as a promising source for the development of new anticancer drugs.

6.3 Antioxidant and Anti-inflammatory Properties

The high concentrations of phenolic and flavonoid compounds found throughout the plant are responsible for its strong antioxidant properties. Multiple studies have confirmed this activity using various assays, most commonly the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay.[15] Both leaf and bark extracts have shown significant free radical scavenging capacity, with an aqueous extract of the bark and an ethanol extract of the leaf being particularly potent, exhibiting low IC50 values of 11.59 µg/ml and 12.45 µg/ml, respectively.[24]

The plant's anti-inflammatory potential is also linked to its rich phytochemistry. GC-MS analysis of the root bark exudate identified compounds like n-hexadecanoic acid and cis-9-hexadecenal.[25] n-Hexadecanoic acid is known to competitively inhibit phospholipase A2, an enzyme that initiates the inflammatory cascade by releasing arachidonic acid from cell membranes.[25] This mechanism supports the traditional use of the plant for inflammatory conditions like rheumatism. The plant's efficacy in treating complex diseases like cancer may arise not only from direct cytotoxicity but also from the synergistic effects of its multiple bioactive compounds. The cytotoxic action of agents like Harbinatic acid could be complemented by the antioxidant and anti-inflammatory activities of its flavonoids and phenols. This combination can combat the oxidative stress and chronic inflammation that are known to be key drivers in the initiation and progression of cancer, suggesting that a multi-component extract might offer a more holistic therapeutic benefit than a single isolated compound.

6.4 Other Bioactivities

Beyond the well-documented antimicrobial and anticancer effects, preliminary reports suggest a wider range of pharmacological activities for *H. binata*. These include analgesic, cardioprotective, and broader anti-inflammatory properties.[6] While these areas are less extensively researched, the presence of cardioprotective flavonoids like catechin and taxifolin in the heartwood provides a strong rationale for further investigation into its potential benefits for cardiovascular health.

7.0 Economic Importance and Commercial Utilization

Hardwickia binata is a cornerstone of the rural economy in the semi-arid regions of India, providing a diverse portfolio of high-value products derived from nearly every part of the tree. Its economic significance is rooted in its exceptional hardiness and the superior quality of its timber, fodder, fiber, and resin.

7.1 Timber: Properties and Applications

The wood of *H. binata* is its most valuable commercial product, renowned for its extreme hardness, density, and durability. It is widely considered one of the hardest and heaviest timbers in India.2 The heartwood is a rich, dark reddish-brown, often streaked with purple or black, making it aesthetically pleasing.[9] Its key properties include high resistance to decay, termites, and wood-boring insects, classifying it as a Class-I timber.[1]

Due to these exceptional characteristics, the timber is in high demand for applications requiring great strength and longevity. It is extensively used in heavy construction for beams, bridge foundations, mine props, and railway sleepers.[2] It is also used for agricultural implements that must withstand immense stress, such as cart wheels, pestles, and ploughs, as well as for durable flooring and wheel work.[1]

7.2 Fodder: Nutritional Value and Role in Livestock Systems

In regions characterized by fodder scarcity, the leaves of *H. binata* serve as a critical nutritional resource for livestock. The leaves are highly palatable and provide quality nutritious fodder, particularly during the lean summer months when other green forage is unavailable.[3] The crude protein content of the leaves ranges from 9% to 15%, which is comparable to many cultivated leguminous fodders.[9] It is a preferred fodder for cattle, goats, sheep, and buffaloes.[2] The tree's "epicormic" branching habit, which allows for limited lopping of branches from the main trunk, makes it particularly suitable for sustainable fodder harvesting.[9] Its central role in silvopasture systems is a testament to its value in integrating animal husbandry with forestry, providing a reliable and resilient fodder supply chain.[3]

7.3 Bark Fiber: Extraction, Properties, and Uses

The bark of *H. binata* is the source of a strong, durable fiber, traditionally known as 'yepi' fiber.[14] This fiber has been employed for centuries in the making of heavy-duty ropes, cordage, and sails.[2] The extraction process typically involves a water retting process, where the bark is soaked for an extended period to separate the fibers.[34] Recent material science research has focused on characterizing this natural cellulosic fiber for modern applications. Studies have shown that treating the fiber with an alkali solution (e.g., sodium hydroxide) significantly improves its properties by removing amorphous components like hemicellulose and lignin. This treatment enhances the fiber's crystallinity, tensile strength, and thermal stability, making it a promising candidate for use as a reinforcement material in eco-friendly natural fiber reinforced composites.[34]

7.4 Oleo-Gum-Resin: Composition and Industrial Applications

The heartwood of *H. binata* exudes a viscous oleo-gum-resin, also referred to as a balsam.[1] This exudate has both traditional medicinal and modern industrial applications. In folk medicine, it is used as a diuretic and as a component in formulations for treating sexually transmitted diseases like gonorrhea and leucorrhoea.[1] Commercially, the oleo-resin is harvested for use in the manufacture of high-quality varnishes, owing to its resinous properties.[1] Chemical analysis of the oleo-resin has shown that it is composed of a high percentage of volatile oil (around 40-48%) and resin acids, with specific gravity and saponification values similar to Copaiba Balsam.[36]

The economic uses of the tree exhibit a remarkable synergy, particularly within an agroforestry context. The management of *H. binata* for fodder production in silvopasture systems necessitates regular pruning of the canopy to allow sufficient light for understory grasses.[37] This single management action yields multiple benefits: the pruned leaves provide immediate "top feed" for livestock, the branches provide firewood for domestic energy, and the practice promotes the healthy growth of the main trunk, which continues to mature into high-value timber.[3] This integrated, multi-output model maximizes land productivity and provides a diversified and resilient income stream for farmers in resource-scarce environments.

8.0 Silviculture, Agroforestry, and Conservation

The silvicultural characteristics of *Hardwickia binata*, particularly its resilience and multipurpose nature, make it a species of immense value for sustainable land management, ecological restoration, and climate change mitigation in India's drylands.

8.1 Propagation, Cultivation, and Management Practices

- **Propagation:** The primary methods for propagating *H. binata* are direct sowing of seeds and transplanting nursery-raised seedlings, with direct sowing often yielding higher success rates in the field.[5] The seeds are orthodox, meaning they can be dried to low moisture content and stored for long periods, retaining viability for over five years under freezing conditions and up to two years at ambient temperatures.[4] Pre-soaking the seeds in water for 24 hours is recommended to break any minor dormancy and hasten germination, which is epigeous (cotyledons emerge above the ground).[5]
- **Nursery and Planting:** In the nursery, seedlings are highly susceptible to direct, intense sunlight, making shading essential for their survival and healthy growth.[4] Stump planting, using stumps prepared from one-year-old seedlings, is another effective propagation technique.[35] While *in vitro* micro-propagation protocols have been developed to facilitate mass propagation, they have encountered challenges such as the leaching of phenolic compounds from explants, which can inhibit growth.[4]
- **Silvicultural Management:** *H. binata* responds well to pollarding (cutting the top and branches of a tree to encourage new growth at the top) but coppices poorly (fails to regrow from the stump if cut at ground level).[2] In agroforestry systems, management focuses on canopy pruning to regulate light penetration to understory crops or pastures. Studies have shown that pruning up to 50-75% of the canopy height can optimize the productivity of the entire system.[10]

8.2 Role in Agroforestry Systems

H. binata is an exemplary tree for agroforestry in arid and semi-arid landscapes. Its deep taproot system minimizes competition for water and nutrients with shallow-rooted agricultural crops, a critical trait for successful intercropping.[9] Its drought hardiness and provision of multiple products (fodder, fuel, timber) enhance the resilience and economic viability of farming systems.[3] It is widely integrated into:

- **Silvopasture Systems:** Planted in combination with perennial fodder grasses like Buffel grass (*Cenchrus ciliaris*), Dhawalu grass (*Chrysopogon fulvus*), and Guinea grass (*Panicum maximum*) to create sustainable grazing lands that provide both grass and nutritious tree fodder.[3]
- **Agrisilviculture Systems:** Intercropped with agricultural crops such as mustard (*Brassica campestris*), where proper tree density management is crucial to balance timber production with crop yield.[42]

8.3 Contribution to Soil Conservation and Carbon Sequestration

The ecological benefits of incorporating *H. binata* into land-use systems are significant. Its robust root system binds the soil, reducing erosion on degraded and sloping lands.[14] Furthermore, the tree is a powerful tool for climate change mitigation through carbon sequestration. Long-term (37-year) field trials in semi-arid western India have demonstrated that *H. binata*-based agroforestry systems substantially increase soil organic carbon (SOC) stocks compared to fallow agricultural land. These systems were found to sequester up to 37.86 Mg C ha^{-1} in the top 90 cm of soil, representing a significant sink for atmospheric carbon dioxide.[43] The implementation of soil and moisture conservation practices, such as the construction of staggered trenches or bunds within these systems, further enhances their ecological function by increasing soil moisture content, nutrient availability, and overall productivity.[3]

8.4 Conservation Status, Threats, and Future Outlook

The conservation status of *Hardwickia binata* presents a notable paradox. On a global scale, the International Union for Conservation of Nature (IUCN) has assessed the species as being of 'Least Concern', indicating that it is not currently at risk of extinction worldwide.[45] This assessment is based on its relatively wide distribution across the Indian subcontinent.

However, this global status masks severe regional threats. In the state of Bihar, for example, government biodiversity officials have reported that the tree is on the verge of local extinction.[47] The primary drivers of this alarming decline are anthropogenic pressures, including habitat destruction through deforestation for agriculture and infrastructure, and increasing pollution.[47] This discrepancy highlights a critical issue in conservation: a species can be globally secure but functionally extinct in specific ecosystems where it plays a vital ecological and cultural role. The loss of regional populations leads to an erosion of genetic diversity and the disappearance of the unique ecosystem services that these populations provide. This situation calls for a multi-scale conservation strategy that moves beyond global assessments to implement targeted, localized protection and restoration efforts, particularly in areas where the species is facing immediate and severe threats. Given its immense value for climate change mitigation, rural economies, and as a source of novel medicines, the conservation of *H. binata*'s genetic resources and the sustainable management of its populations should be a high priority.

9.0 Conclusion and Future Directions

Hardwickia binata Roxb. emerges from this comprehensive review as a species of exceptional importance, a true multipurpose tree that is deeply interwoven with the ecological, economic, and cultural fabric of the Indian subcontinent. Its remarkable adaptations to harsh, arid environments, combined with its ability to provide high-value timber, nutritious fodder, strong fiber, and a plethora of medicinal compounds, position it as a keystone resource for sustainable development. The convergence of extensive ethnobotanical knowledge with modern scientific validation has illuminated its vast pharmacological potential, particularly in the fields of antimicrobial and anticancer research, with the discovery of compounds like Harbinatic acid validating its traditional use and opening new frontiers for drug discovery. Its role as an ecological engineer in restoring degraded lands and its proven capacity for carbon sequestration make it an invaluable asset in the global effort to combat desertification and mitigate climate change. The successful integration of *H. binata* into agroforestry systems demonstrates a time-tested model for enhancing land productivity, diversifying rural incomes, and building resilient agricultural landscapes.

Despite its strengths, the species faces a precarious future in certain regions due to anthropogenic pressures, highlighting the urgent need for conservation strategies that protect not only the species as a whole but also its vital, locally adapted populations. Moving forward, a concerted and interdisciplinary research effort is required to fully unlock the potential of this remarkable tree.

Future research should prioritize:

- **Advanced Pharmacological and Clinical Studies:** Moving beyond *in vitro* assays to conduct rigorous *in vivo* studies and eventually clinical trials to validate the efficacy and safety of standardized *H. binata* extracts and isolated compounds for treating cancer, microbial infections, and inflammatory diseases.
- **Conservation Genetics:** Undertaking comprehensive genetic diversity assessments of remaining wild populations, especially in threatened regions like Bihar, to inform *ex-situ* and *in-situ* conservation programs and to identify elite genotypes for breeding programs.
- **Agroforestry Optimization:** Conducting long-term studies to optimize the management of *H. binata*-based agroforestry systems, focusing on tree density, pruning regimes, and species combinations to maximize synergistic benefits, including yield, soil health, and carbon sequestration.

- **Sustainable Value Chain Development:** Establishing sustainable and equitable value chains for *H. binata* products—from certified timber to standardized medicinal extracts and high-performance natural fibers—to ensure that the economic benefits flow back to the local communities who are the traditional custodians of this resource.

By integrating scientific innovation with traditional knowledge, *Hardwickia binata* can continue to serve as a powerful engine for ecological restoration, economic prosperity, and human health for generations to come.

10. REFERENCES

1. Hardwickia - Wikipedia, accessed August 1, 2025, https://en.wikipedia.org/wiki/Hardwickia
2. Hardwickia binata Fabaceae - Caesalpinioideae Roxb., accessed August 1, 2025, https://apps.worldagroforestry.org/treedb/AFTPDFS/Hardwickia_binata.PDF
3. View of Performance of anjan tree (Hardwickia binata)-based silvopasture systems under moisture-conservation practices in semi-arid conditions, accessed August 1, 2025, https://pub.isa-india.in/index.php/ija/article/view/208/97
4. Know Your Trees - Hardwickia binata (Indian Black Wood) - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/profile/A_N_Arunkumar/publication/335680325_Know_Your_Trees_-_Hardwickia_binata_Indian_Black_Wood/links/5d73d20a299bf1cb808fdc04/Know-Your-Trees-Hardwickia-binata-Indian-Black-Wood.pdf
5. (PDF) COMMERCIAL UTILIZATION AND NURSERY PRACTICES ..., accessed August 1, 2025, https://www.researchgate.net/publication/334605089_COMMERCIAL_UTILIZATION_AND_NURSERY_PRACTICES_OF_ANJAN_HARDWICKIA_BINATA_ROXB_A_MPTS
6. A Review on “Anjan” Hardwickia binata Roxb: Its Phytochemical Studies, Traditional uses and Pharmacological activities, accessed August 1, 2025, https://phcogrev.com/article/2021/15/29/105530phrev2021157
7. A Review on “Anjan” Hardwickia binata Roxb.: Its Phytochemical Studies, Traditional Uses and Pharmacological Activities, accessed August 1, 2025, https://phcogrev.com/sites/default/files/PharmacognRev-15-29-65.pdf
8. (PDF) Hardwickia binata based silvipasture: a time tested model for augmenting fodder production under semi arid India - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/publication/378371873_Hardwickia_binata_based_silvipasture_a_time_tested_model_for_augmenting_fodder_production_under_semi_arid_India
9. Hardwickia binata - Agroforestree Species profile, accessed August 1, 2025, https://apps.worldagroforestry.org/treedb2/speciesprofile.php?Spid=957
10. (PDF) Tree-canopy management and soil quality index of Hardwickia binata Roxb. based agroforestry system in Bundelkhand, Central India - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/publication/335220326_Tree-canopy_management_and_soil_quality_index_of_Hardwickia_binata_Roxb_based_agroforestry_system_in_Bundelkhand_Central_India
11. PlantFAdb: Hardwickia binata - Anjan - Fatplants, accessed August 1, 2025, https://fatplants.net/plantfadb/plants/11724
12. Hardwickia binata Roxb. - Herbarium JCB, accessed August 1, 2025, https://indiaflora-ces.iisc.ac.in/FloraPeninsular/plants.php?name=Hardwickia%20binata
13. Colophospermum reduced to Hardwickia (Leguminosae-Caesalpinioideae), accessed August 1, 2025, https://sciencepress.mnhn.fr/sites/default/files/articles/pdf/a1997n2a9.pdf
14. Hardwickia binata | CABI Compendium, accessed August 1, 2025, http://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.26505
15. Preliminary examination of bioactive components and bioactivity of Hardwickia binata Roxb. extracts obtained through conventional extraction methods - NewBioWorld, accessed August 1, 2025, https://newbioworld.org/HTMLPaper.aspx?Journal=NewBioWorld;PID=2022-4-1-3
16. Hardwickia binata / IPlantz, accessed August 1, 2025, https://www.iplantz.com/plant/1731/hardwickia-binata/
17. Anjan tree - Hardwickia binata - RAD, accessed August 1, 2025, https://rozendale.com/index.php/db-plants/details/131/433
18. (PDF) A Review on “Anjan” Hardwickia binata Roxb: Its ..., accessed August 1, 2025, https://www.researchgate.net/publication/352233068_A_Review_on_Anjan_Hardwickia_binata_Roxb_Its_Phytochemical_Studies_Traditional_uses_and_Pharmacological_activities
19. Hardwickia binata - Useful Tropical Plants, accessed August 1, 2025, https://tropical.theferns.info/viewtropical.php?id=Hardwickia+binata
20. (PDF) Phytosociological observations on tree species diversity of an urban tropical dry deciduous forest of central India - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/publication/348795131_Phytosociological_observations_on_tree_species_diversity_of_an_urban_tropical_dry_deciduous_forest_of_central_India
21. (PDF) Creating Forest from Wasteland - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/publication/347932352_Creating_Forest_from_Wasteland
22. PHYTOCHEMICAL STUDIES, FTIR AND GC-MS ANALYSIS OF HARDWICKIA BINATA ROXB. (FABACEAE / CAESALPINIACEAE) | INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES AND RESEARCH, accessed August 1, 2025, https://ijpsr.com/bft-article/phytochemical-studies-ftir-and-gc-ms-analysis-of-hardwickia-binata-roxb-fabaceae-caesalpiniaceae/
23. Anti bacterial and antifungal activity of various leaves extracts of Hardwickia binata - International Journal of ChemTech Research, accessed August 1, 2025, https://sphinxsai.com/Oct_dec_2010_vol2_no.4/PharmTech_vol2_no.4_1_pdf/PT=09%20(2183-2187).pdf

24. evaluation of antioxidant activity and phytochemical analysis of hardwikia binata (roxb.), accessed August 1, 2025, https://www.researchgate.net/publication/351541225_EVALUATION_OF_ANTIOXIDANT_ACTIVITY_AND_PHYTOCHEMICAL_ANALYSIS_OF_HARDWIKIA_BINATA_ROXB
25. Components identified in the root bark exudates of Hardwickia binata Roxb. - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/figure/Components-identified-in-the-root-bark-exudates-of-Hardwickia-binata-Roxb_tbl1_274385628
26. In vitro Cytotoxicity Evaluation of Hardwickia binata Roxbs against Human Breast Cancer Cell Line MCF-7 and Human Cervical Cancer Cell Line HeLa - Pharmacognosy Research, accessed August 1, 2025, https://www.phcogres.com/article/2025/17/2/105530pres20252098-0
27. Hardwickia binata - Forrest-ecology, accessed August 1, 2025, https://forrest-ecology.org/2023/11/hardwiki-bipinnata/
28. Anjan - Anandvan Foundation, accessed August 1, 2025, https://anandvanfoundation.org/flora/anjan/
29. ANTIMICROBIAL AND ANTIFUNGAL ACTIVITY OF BARK OF HARDWICKIA BINATA ROXB (FABACEAE / CAESALPINIACEAE) | INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES AND RESEARCH, accessed August 1, 2025, https://ijpsr.com/bft-article/antimicrobial-and-antifungal-activity-of-bark-of-hardwickia-binata-roxb-fabaceae-caesalpiniaceae/
30. Original Research Paper Varsha D. Hutke* Botany Vaishali Rathod, accessed August 1, 2025, https://www.worldwidejournals.com/global-journal-for-research-analysis-GJRA/recent_issues_pdf/2021/April/evaluation-of-antioxidant-activity-and-phytochemical-analysis-of-hardwikia-binata-roxb_April_2021_8684111691_8017128.pdf
31. Nutritive value of anjan tree leaves on performance of heifers - International Journal of Chemical Studies, accessed August 1, 2025, https://www.chemijournal.com/archives/2019/vol7issue6/PartAP/7-6-472-191.pdf
32. Productivity of grasses in association with Hardwickia binata under rainfed conditions - UKnowledge, accessed August 1, 2025, https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1893&context=igc
33. Different Silvi-pastoral systems for improving livestock production in ..., accessed August 1, 2025, https://www.veterinarypaper.com/pdf/2024/vol9issue3/PartI/9-3-106-457.pdf
34. Characterization of New Cellulosic Fiber from the bark of Hardwickia ..., accessed August 1, 2025, https://www.ripublication.com/ijaer18/ijaerv13n2_22.pdf
35. Forestry :: Minor Forest Products - TNAU Agritech Portal, accessed August 1, 2025, https://agritech.tnau.ac.in/forestry/ntfp_hardwickia_binata.html
36. The Oleo-Resin from Hardwickia Pinnata. Hrtrclwiclcia, Pimwta (Tamil-Kolavu, Madeyan, Sam- pirani; Malayalam-Shurali, Kiyavu, Ko, accessed August 1, 2025, https://journal.iisc.ac.in/index.php/iisc/article/download/1585/4645
37. Forage productivity and carbon storage from Hardwickia binata based silvopasture systems in semi-arid rainfed conditions | Range Management and Agroforestry, accessed August 1, 2025, https://publications.rmsi.in/index.php/rma/article/view/1020?articlesBySimilarityPage=5
38. Forage productivity and carbon storage from Hardwickia binata based silvopasture systems in semi-arid rainfed conditions | Range Management and Agroforestry, accessed August 1, 2025, https://publications.rmsi.in/index.php/rma/article/view/1020?articlesBySimilarityPage=26
39. Understory pasture, top feed and fire wood productivity of anjan tree (Hardwickia binata) based silvopasture systems under moisture conservation practices and grasses - Indian Agricultural Research Journals, accessed August 1, 2025, https://epubs.icar.org.in/index.php/IJA/article/view/119687
40. Complete protocol for in vitro plant propagation of H. binata - ResearchGate, accessed August 1, 2025, https://www.researchgate.net/figure/Complete-protocol-for-in-vitro-plant-propagation-of-H-binata_fig3_275965279
41. Tree-Canopy Management and Soil Quality Index of Hardwickia binata Roxb. based Agroforestry System in Bundelkhand, Central India | Indian Forester, accessed August 1, 2025, http://indianforester.co.in/index.php/indianforester/article/view/147131
42. Growth of Tree and Yield of Intercrop as Influenced by Tree Densities under Hardwickia binata Based Agrisilviculture System in Semi-arid Conditions of India, accessed August 1, 2025, https://epubs.icar.org.in/index.php/IJA/article/view/102656
43. Impact of Long-Term Agroforestry Systems on Carbon Pools and ..., accessed August 1, 2025, https://www.mdpi.com/1999-4907/16/6/946
44. Effect of moisture conservation practices on performance of Anjan (Hardwickia binata) tree based silvipasture systems | Range Management and Agroforestry, accessed August 1, 2025, https://publications.rmsi.in/index.php/rma/article/view/305
45. Hardwickia binata Roxb. - World Flora Online, accessed August 1, 2025, https://test.worldfloraonline.org/taxon/wfo-0000203549;jsessionid=8CD80461243CDEE84988DA213DEFB113
46. Hardwickia binata Roxb. - GBIF, accessed August 1, 2025, https://www.gbif.org/species/5350021
47. Bihar: Survey soon to find out reason for disappearance of two trees - Times of India, accessed August 1, 2025, https://timesofindia.indiatimes.com/city/patna/survey-soon-to-find-out-reasonfor-disappearance-of-two-trees/articleshow/91479113.cms