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Diversity, Ecological Significance and Bioprospecting Potential of Lichens in the Western Ghats, India: A Comprehensive Review

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Abstract

Lichens are obligate, composite organisms formed by a mutualistic symbiosis between a fungal partner (mycobiont) and one or more photosynthetic partners (phycobiont—either green algae or cyanobacteria). These cryptogamic organisms occupy a wide spectrum of terrestrial substrates, orchestrating fundamental biogeochemical cycles and early pedogenesis. The Western Ghats of India, designated as one of the world's 36 global biodiversity hotspots, provides unique heterogeneous microclimates, sharp altitudinal clines, and substantial precipitation gradients that foster a remarkably rich lichen biota.

This review provides a comprehensive synthesis of the floristic diversity, substrate affinities, altitudinal zonations, functional ecology, bio-monitoring utility, and bio-prospecting frontiers of lichens across the Western Ghats. Region-specific inventories document approximately 1,096 lichen species distributed across 188 genera and 50 families, harboring a notable 257 endemic species (~23.4% endemism). Crustose and leprose microlichens dominate the taxonomic landscape (719 taxa), followed by foliose/squamulose (324 taxa) and fruticose (71 taxa) forms. Parmeliaceae stands as the dominant family (137 species), and Graphis represents the most specious genus (49 species). Corticolous lichens form the dominant substrate guild (953 taxa), with notable occurrences of saxicolous (230 taxa), terricolous (73 taxa), and foliicolous forms (56 taxa, including 48 obligate phyllosphere dwellers).

Ecologically, lichens serve as sensitive, non-destructive biomonitors of air quality and heavy metal deposition. Furthermore, secondary metabolites derived from acetate-polymalonate, mevalonate, and shikimic acid pathways exhibit potent antimicrobial, antioxidant, antitumour, enzyme-inhibitory, and allelopathic properties, alongside extensive ethnobotanical applications (e.g., spice mixtures known as Chharila, natural dye precursors, and perfumery fixatives). Nevertheless, anthropogenically induced habitat fragmentation, land-use conversion, air pollution, and unregulated commercial harvesting impose severe conservation challenges. Mitigating these pressures necessitates systematic high-resolution spatial mapping, molecular barcoding, in situ lichen reserves, and scalable axenic culture techniques to balance conservation and sustainable bioresource utilization.

Keywords: Lichens, Western Ghats, Biodiversity hotspot, Parmeliaceae, *Graphis*, Bioindicators, Bio-prospecting, Endemism, Conservation.

1. Introduction

Lichens represent self-sustaining, obligate symbiotic partnerships comprising a heterotrophic fungal partner (the mycobiont, predominantly Ascomycota and rarely Basidiomycota) and an autotrophic photosynthetic partner (the phycobiont, belonging to Chlorophyta or Cyanobacteria). Recent microscopic and metagenomic investigations have broadened this classical dual concept, revealing that lichen thalli can also host complex microbiomes, including specialized endolichenic bacteria, basidiomycete yeasts, and non-obligate endolichenic fungi. Morphologically, lichens manifest in three principal growth forms:

Crustose & Leprose (Microlichens): Tightly appressed to or embedded within the substrate, lacking a lower cortex.

Foliose & Squamulose (Macrolichens): Dorsoventrally flattened, leaf-like thalli possessing distinct upper and lower cortices, typically anchored by rhizines.

Fruticose (Macrolichens): Radially symmetrical, shrubby, pendant, or hair-like thalli attached via a basal disc.

Globally, approximately 18,500 to 20,000 lichen species have been circumscribed. The Indian subcontinent represents a key repository of cryptogamic biodiversity, harboring upwards of 2,300 to 2,900 recognized species spanning tropical, subtropical, temperate, and alpine biogeographic zones. Among India's recognized lichen geographical zones, the Western Ghats mountain range is distinguished by its high species richness and remarkable degree of regional endemism. Extending roughly 1,600 km along peninsular India's western flank, this mountain chain serves as a crucial orographic barrier that intercepts the southwest monsoon, driving extraordinary climatic and ecological diversity.

Despite their profound roles in primary succession, nitrogen fixation, nutrient recycling, and microfaunal habitat provisioning, lower cryptogamic taxa have historically

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received far less conservation emphasis than sympatric angiosperms and vertebrate fauna. Systematically consolidating regional inventories, ecological interactions, and chemical profiles is essential to guide modern bioprospecting and habitat management.

Fig 1: Epiphytic corticolous lichens on bark. Source: Barbara Gabay

2. Review Objectives

This review evaluates the state of lichenological research in the Western Ghats by focusing on six core objectives:

i). Synthesizing the documented taxonomic diversity, floristic composition, and endemism of Western Ghats lichens.
ii). Evaluating substrate preferences, microhabitat stratification, and altitudinal zonations.
iii). Elucidating the functional ecological roles of lichens, with focus on heavy metal and atmospheric bioindication.
iv). Reviewing bioprospecting avenues, focusing on secondary metabolite biosyntheses, pharmacological activities, and traditional ethnobotanical uses.
v). Identifying major anthropogenic threats and land-use pressures on regional lichen communities.
vi). Proposing actionable, multi-tiered conservation frameworks, molecular taxonomic frontiers, and biotechnological pathways.

3. Geographic and Ecological Profile of the Western Ghats

The Western Ghats (Sahyadri Range) constitutes an unbroken mountain chain spanning an area of roughly 160,000 km², traversing six Indian states: Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu, and Kerala.

Parameter	Regional Characteristic
Geographic Span	~1,600km (8°N to21°N latitude)
Area Covered	~160,000km²across 6 states
Elevation Range	Near sea level to2,695m (Anaimudi Peak)
Annual Rainfall Gradient	1,000 mm (eastern rain-shadow)to >6,000mm
Primary Vegetation Zones	Tropical wet evergreen, semi-evergreen, moist deciduous, dry deciduous, montane shola-grasslands, scrub

This orographic architecture establishes distinct microhabitats. Windward western slopes experience high rainfall, perpetual cloud immersion, and sustained relative humidity, whereas leeward eastern slopes grade into dry deciduous forests and rain-shadow scrub. In upper montane belts (>1,500 m), stunted high-elevation evergreen forests (*sholas*) interspersed with montane grasslands create isolated sky-island refugia characterized by cooler temperatures and dense epiphytic communities.

4. Lichen Diversity, Taxonomic Structure, and Endemism

The Western Ghats supports approximately 1,096 documented lichen species belonging to 188 genera across 50 families. This represents nearly half of India's total documented lichen biota. Notably, approximately 257 species (~23.4%) are strictly endemic to the Western Ghats, underscoring its role as an evolutionary and ecological refugium.

4.1. Taxonomic Composition and Morphological Breakdowns

Micro lichens dominate the regional assemblage, forming the primary crustose matrix on bark, rocks, and leaf surfaces, while macro lichens form prominent canopy layers in mid-to-high elevations.

Total Documented Species: 1,096

- **Micro lichens (Crustose / Leprose):** 719 taxa (65.6%)
- **Macro lichens:** 377 taxa (34.4%)
  - **Foliose & Squamulose:** 324 taxa (29.6%)
  - **Fruticose:** 71 taxa (6.5%)

Table 1: Floristic and Taxonomic Metrics of Western Ghats Lichens.

Metric/Parameter	Documented Regional Value	Ecological& Taxonomic Context
Total Recorded Species	~1,096	~45–48% of total known Indian lichen taxa
Total Genera	188	Broad representation of tropical and montane lineages
Total Families	50	High phylogenetic breadth
Endemic Species	~257	~23.4% endemism rate within the hotspot
Micro lichens	719taxa	Dominated by Graphidaceae, Thelotremataceae, Arthoniaceae
Foliose & Squamulose	324taxa	Dominated by Parmeliaceae, Physciaceae, Lobariaceae
Fruticose	71taxa	Dominated by Usneaceae/Parmeliaceae (*Usnea, Ramalina*)
Dominant Family	Parmeliaceae (137 spp.)	22 genera;
Dominant Genus	*Graphis* (49spp.)	Script lichens adapted to humid forest canopies and bark

At the state level, Tamil Nadu exhibits the highest reported species richness, largely reflecting historical and intensive collections across the Nilgiri and Palni Hills, followed by Karnataka, Kerala, and Maharashtra. Pyrenocarpous (perithecioid) lichens, graphidaceous taxa (lirellate script lichens), and thelotremataceous species show exceptional

representation in the moist evergreen tracts.

5. Substrate Preferences and Distributional Guilds

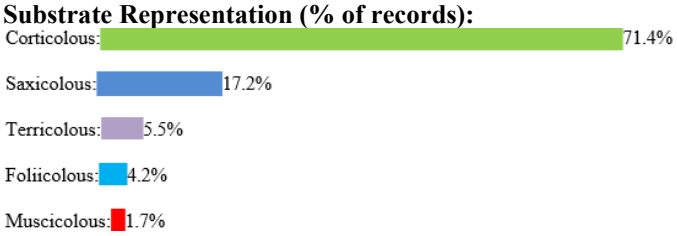
Substrate availability, moisture retention, surface pH, texture, and canopy light penetration drive lichen community assembly across the Western Ghats.

Table 2: Substrate Guilds and Taxa Frequencies in the Western Ghats

Substrate Guild	Substrate Description	Documented Taxa Count	Ecological Notes& Typical Genera
Corticolous	Tree bark (trunk, branches, twigs)	953	Dominant guild; favored by dense canopies; *Graphis*, *Parmotrema*, *Pyxine*, *Lecanora*
Saxicolous	Exposed and shaded rock surfaces	230	Lithic colonizers; *Xanthoparmelia* , *Buellia*, *Pertusaria*, *Caloplaca*
Terricolous	Soil, humic banks, road cuts	73	Soil stabilization; *Cladonia*, *Peltigera*, *Stereocaulon*
Foliicolous	Living leaf surfaces (epiphyllous)	56	Specialized phyllosphere dwellers (48 obligate); *Porina*, *Strigula*, *Trichothelium*
Muscicolous	Overgrowing moss cushions	22	Bryophilic associations in wet montane *sholas*; *Lobaria*, *Leptogium*

Note: *The cumulative taxa across substrate types exceeds 1,096 because select generalist species exhibit facultative affinities across multiple substrate categories (e.g., corticolous-saxicolous generalists).*

Substrate Representation (% of records):



Foliicolous lichens represent an ecologically sensitive group: of the 56 documented foliicolous taxa, 48 are obligate leaf-dwellers. These microlichens require uninterrupted ambient humidity and stable understory conditions, primarily occurring in wet evergreen forests of the Nilgiri and Palni Hills.

6. Altitudinal Stratification and Microclimatic Clines

Elevation strongly modulates temperature, atmospheric pressure, cloud cover, and rainfall distribution, driving marked altitudinal zonation across the Western Ghats:

Elevation	
2,600m	**Upper Montane Zone(>2,000–2,600m):** Montane Shola-Grasslands; high fog condensation. *Usnea, Ramalina, Lobaria, Sticta, Peltigera, Cladonia.*
1,000–2,000m	**Mid-to-High Elevation Zone(1,000–2,000m):** Optimum Lichen Diversity (Wet Evergreen& Sholas). Peak richness of *Parmeliaceae, Graphidaceae, Physciaceae.*
<1,000m	**Foot hill& Sub Montane Zone(<1,000m):** Deciduous, semi-evergreen, dry scrub. *Pyrenula, Arthonia, Graphis, Dirinaria, Pyxine.*

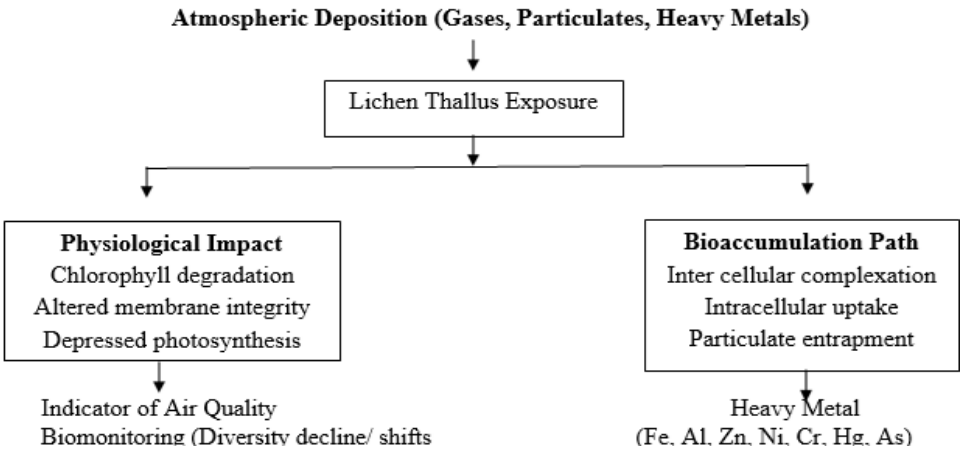
Foothill and Lowland Belt (<1,000 m): Characterized by deciduous and semi-evergreen forests. The lichen flora is dominated by drought-tolerant, photophilous crustose taxa (Arthonia, Pyrenula, Graphis, Dirinaria, and Pyxine).

Montane Belt (1,000–2,400 m): Represents the peak of lichen diversity and structural complexity. Sustained cloud immersion, high relative humidity (often >80%), and diverse host phorophytes support lush communities of both foliose/fruticose macrolichens (*Parmotrema, Everniastrum, Usnea, Heterodermia, Lobaria*) and microlichens (*Thelotrema, Graphis*).

Upper Subalpine/Grassland Crests (>2,400 m): Open rocky outcrops and stunted ericaceous vegetation harbor specialized saxicolous and terricolous communities, including cold-adapted *Cladonia, Umbilicaria*, and *Xanthoparmelia* species.

7. Ecological Significance and Biomonitoring Utility

Lichens lack roots, stomata, and protective cuticles, depending entirely on atmospheric wet and dry deposition for moisture and mineral nutrients. This physiological architecture makes them exceptionally sensitive to atmospheric dynamics.



7.1. Primary Pedogenesis and Nitrogen Dynamics

Lichen hyphae penetrate rock fissures, producing respiratory carbon dioxide and chelating lichen acids (such as oxalates and polycarboxylic acids) that drive biochemical and physical weathering of lithic surfaces. Cyanolichens (containing *Nostoc*, *Scytonema*, or *Stigonema* photobionts, such as

Lobaria, *Peltigera*, and *Leptogium*) fix atmospheric nitrogen through heterocysts, releasing bioavailable nitrogenous compounds into surrounding forest soils.

7.2. Atmospheric Biomonitoring and Heavy Metal Accumulation

Because of their high surface-area-to-volume ratio and uniform ion-exchange capacity across seasons, lichens serve as standard biomonitors:

- **Urban and Industrial Trace Elements:** *Pyxine cocoes*, a widespread foliose corticolous species, reliably accumulates metals including Fe, Al, Zn, Ni, and Cr along vehicular and industrial corridors in peninsular India.
- **Point-Source Mercury Biomonitoring:** Lichen bioassays near Kodaikanal (Palni Hills) detected elevated mercury concentrations associated with past industrial discharges from a clinical thermometer manufacturing plant.
- **Arsenic and Mineral Signatures:** Epilithic and corticolous taxa near mining tracts systematically accumulate As, Mn, and Cu, providing spatial resolution of airborne particulate plumes without requiring power-dependent sampling equipment.

8. Bioprospecting and Pharmacological Potential

Lichens synthesize over 1,000 distinct secondary metabolites (often termed "lichen substances"). These compounds are primarily deposited as extracellular crystallites on the medullary and cortical hyphae, typically constituting 0.1% to 10% (and occasionally >20%) of the thallus dry weight.

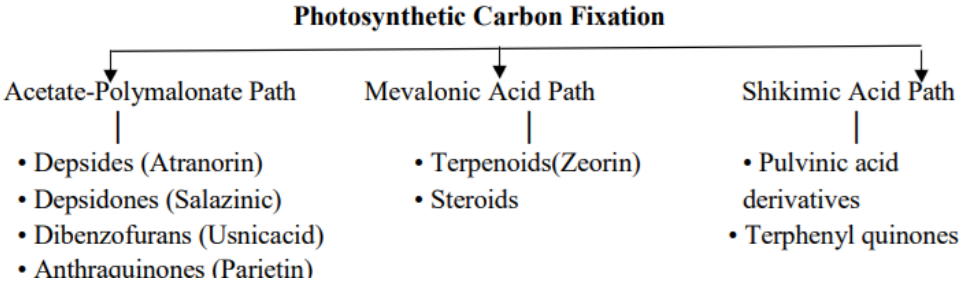


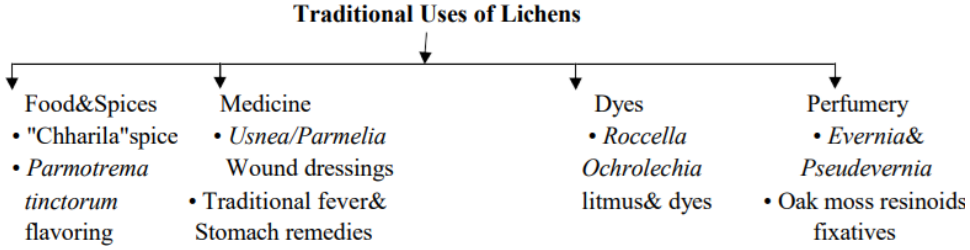
Table 3: Major Lichen Bioactive Classes and Pharmacological Activities

MetabolicClass	Representative Compounds	Typical Source Genera	Demonstrated Biological Activities
Dibenzofurans	Usnic acid	*Usnea*, *Alectoria*	Broad-spectrum antibacterial (Gram-positive), antineoplastic, wound-healing, UV-photoprotective
Depsides	Atranorin, Gyrophoric acid, Lecanoric acid	*Parmotrema*, *Everniastrum*, *Lecanora*	Antioxidant, anti-inflammatory, analgesic, fungal germination inhibition
Depsidones	Salazinic acid, Physodic acid, Norstictic acid	*Parmotrema*, *Heterodermia*, *Usnea*	Antiviral, enzyme-inhibitory(e.g., α-glucosidase, tyrosinase), cytotoxic against human cancer
Anthraquinones	Parietin, Emodin	*Xanthoria*, *Caloplaca*, *Pyxine*	Photosensitizing, antimicrobial, protein kinase inhibitory
Pulvinic Acid Derivs.	Vulpinic acid	*Pseudevernia*, *Candelariella*	Radical scavenging, anti feedant, selective cytotoxic agent
Anthraquinones	Parietin, Emodin	*Xanthoria*, *Caloplaca*, *Pyxine*	Photosensitizing, antimicrobial, protein kinase inhibitory
Pulvinic Acid Derivs.	Vulpinic acid	*Pseudevernia*, *Candelariella*	Radical scavenging, anti feedant, selective cytotoxic agent

Despite this potential, bioprospecting remains constrained by slow radial growth rates (typically 0.5–5 mm per year for crustose taxa; 1–10 mm for foliose forms) and recalcitrance to high-yield synthetic laboratory cultivation.

9. Ethnobotanical and Commercial Utilization

Traditional communities across the Western Ghats utilize lichens for culinary, medicinal, and commercial purposes:



9.1. Spice and Culinary Preparations (*Chharila*)

In Indian markets, dry macrolichen mixtures sold under vernacular names like *Chharila*, *Patthar ke Phool*, or *Kalpasi* contain parmelioid lichens (chiefly *Parmotrema tinctorum*, *Everniastrum cirrhatum*, and *P. reticulatum*). These lichens are integral ingredients in traditional spice formulations (e.g., *Garam Masala*, *Goda Masala*, and regional meat gravies), prized for their earthy aroma, umami depth, and antioxidant preservative properties.

9.2. Traditional Ethnomedicine

Genera including *Usnea*, *Parmelia*, *Lobaria*, *Heterodermia*, and *Sticta* are used in indigenous systems (Ayurveda, Unani, and Siddha). They serve as topical astringents, hemostatic agents for open wounds, and remedies for pulmonary ailments and digestive disorders.

Pigments, Dyes, and Industrial Aromatic Fixatives

- **Natural Colorants:** Genera such as *Roccella*, *Ochrolechia*, and *Parmotrema* yield phenolic orcinol derivatives that convert via ammoniacal fermentation into purple, crimson, and brown wool dyes, as well as classic litmus indicators.
- **Perfumery Resins:** While *Evernia prunastri* (oakmoss) and *Pseudevernia furfuracea* (treemoss) are historically European industrial standards, related Western Ghats parmelioid taxa contain similar aromatic resinoids that function as fixatives in heavy oriental fragrances and cosmetics.

10. Threats and Conservation Challenges

Lichen communities face mounting anthropogenic and environmental pressures across the Western Ghats:

Threat Factor	Direct Mechanism of Impacton Lichen Biota	Ecological Vulnerability
Deforestation & Monoculture Expansion	Clear-felling of native wet evergreen forests for tea, coffee, rubber, and teak plantations removes mature phorophyte canopies.	Eliminates long-established, slow-dispersing corticolous climax communities.
Habitat Fragmentation	Creation of artificial forest edges alters microclimatic temperature, light, and relative humidity regimes.	Desiccates and derstory foliicolous and muscicolous species.
Atmospheric Pollution	Atmospheric SO_2, NO_x, ozone, and ammonia degrade phycobiont chlorophyll pigments and acidify tree bark. This may be due to lack of epidermis, where pollutants directly enter the thallus through fungal mycelia	Induces"lichen deserts"in urban-industrial corridors.
Unregulated Commercial Harvesting	Destructive stripping of *Chharila* species from tree trunks and rock faces for spice and perfume markets.	Exceeds natural regeneration rates; causes local population collapses.
Forest Fires	Surface and canopy fires in dry deciduous and grassland-shola ecotones destroy saxicolous and corticolous biomass.	Long recovery times (>15–30 years) for slow-growingt halli.
Climate Change	Rising temperatures and shifting monsoon schedules force montane species to shift upward.	Squeezes high-elevation sky-island taxa (*sholas*) out of viable thermal envelopes.

11. Conservation Strategies and Policy Directives

To ensure the persistence of lichen diversity and protect endemic germplasm, conservation actions should combine multiple targeted approaches:

i). **Systematic Inventories and High-Resolution Mapping:** Expand standardized cryptogamic surveys into underexplored tracts (such as the Agasthyamalai Biosphere Reserve, Sharavathi Valley, and northern Sahyadri ranges in Maharashtra) using geographic information systems (GIS).

ii). **Establishment of Cryptogamic Sanctuaries:** Designate micro-reserves and specialized "Lichen Sanctuaries" in high-diversity, high-endemism zones (modeled after India's first cryptogamic garden in Dehradun, Uttarakhand) within protected areas like Nilgiri Biosphere Reserve and Kudremukh National Park.

iii). **Regulation of Commercial Harvesting:** Enforce sustainable harvesting guidelines, seasonal harvesting moratoria, and minimum size quotas for non-timber forest product (NTFP) collectors targeting *Chharila*, while preventing harvest within primary core conservation zones.

iv). **Permanent Biomonitoring Networks:** Integrate epiphytic lichen monitoring plots into National Clean Air Programmes (NCAP) and forest department monitoring programs to track baseline air quality and ecosystem health.

v). **Biotechnological Approaches (*Ex Situ* Culture):** Support axenic culturing of isolated mycobionts and photobionts, whole-thallus tissue culture, and heterologous expression of lichen polyketide synthase (PKS) genes in microbial hosts to generate secondary metabolites without harvesting wild biomass.

vi). **Capacity Building and Community Engagement:** Train forest staff, taxonomists, and students in non-flowering plant identification, while educating indigenous forest-dwelling communities on sustainable non-destructive harvesting methods.

12. Research Gaps and Future Perspectives

Substantial knowledge gaps remain across the Western Ghats lichen landscape. Addressing them requires integrating contemporary tools with classical taxonomy:

- **Integrative Molecular Phylogenetics:** Most Western Ghats taxa are described purely on morpho-anatomical and spot-test/thin-layer chromatography (TLC) characteristics. Integrating high-throughput DNA barcoding (ITS, nrLSU, *RPB1*, *RPB2*, *EF-1α*) is critical to delineate cryptic species complexes within species-rich groups like *Graphis*, *Parmotrema*, *Usnea*, and *Pyrenula*.
- **Microbiome Metagenomics:** Investigating the functional roles of endolichenic bacteria and basidiomycete yeasts in nutrient exchange, secondary metabolite diversification, and drought adaptation.
- **Quantitative Gradient Ecology:** Establishing permanent, elevation-stratified transects across the Western Ghats to model climate-induced upward shifts in lichen taxa using predictive ecological niche modeling (ENM/MaxEnt).
- **Targeted Pharmacological Characterization:** Moving beyond crude extract antimicrobial screens toward mechanistic cellular studies, identifying specific protein targets, pharmacokinetic profiles, and structural activity relationships (SAR) of isolated pure compounds.
- **Cultivation and Fermentation Technology:** Optimizing photobiont-mycobiont re-synthesis in bioreactors and eliciting silent metabolic gene clusters using epigenetic modifiers to unlock pharmaceutical precursors.

13. Conclusion

The Western Ghats harbors one of the richest and most diverse lichen biotas in tropical Asia, supporting roughly 1,096 recognized species, with nearly one-quarter endemic to the range. These organisms play vital roles in forest nutrient cycling, soil generation, microhabitat provisioning, and environmental bioindication, while offering substantial bioprospecting opportunities across medicine, cuisine, and

industry.

However, rapid land-use changes, climate variability, and commercial overexploitation threaten these slow-growing cryptogams. Safeguarding the lichen heritage of the Western Ghats requires elevating cryptogamic conservation alongside vascular flora and vertebrate fauna. Combining molecular systematics, ecosystem-level habitat protection, standardized air-quality biomonitoring, and sustainable biotechnological production of active metabolites will ensure that both the evolutionary integrity and the economic potential of these organisms are preserved for the future.

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