KAVAKA 62(2): 97-108 (2026) DOI:10.36460/Kavaka/62/2/2026/97-108

Invisible Kingdom yet Indispensable: why fungal taxonomic revolutions must be central to India's conservation strategy during Viksit Bharat Mission 2047

Kunhiraman C. Rajeshkumar[1*], Garima Anand[2], M. Sudhakara Reddy[3], Rajnish K. Verma[4], Nanjian Raaman[5], Deeba Kamil[6], Ajay K. Gautam[7]

[1] *Biodiversity and Palaeobiology (Fungi) Group, MACS Agharkar Research Institute, G. G. Agarkar Road, Pune, Maharashtra 411004, India*
[2] *Department of Botany, Dyal Singh College, University of Delhi, Delhi 110003, India*
[3] *Department of Biotechnology, Thapar Institute of Engineering and Technology, Patiala 147004, India*
[4] *Department of Plant Pathology, Punjab Agricultural University Ludhiana 141004, India*
[5] *Former Professor, Centre for Advanced Studies in Botany, University of Madras, Guindy Campus, Chennai 600025, Tamil Nadu, India*
[6] *Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India*
[7] *Patanjali Herbal Research Department, Patanjali Research Foundation, Haridwar 249405, Uttarakhand, India*

**Corresponding Author Email: rajeshfungi@gmail.com*

(Submitted on 3 June, 2026; Accepted on 10 June, 2026)

ABSTRACT

India occupies approximately 2.4% of the world's land area yet harbours nearly 8% of globally recorded biodiversity, positioning it among the most biologically rich regions on Earth. Much of this diversity is concentrated in the globally recognized biodiversity hotspots such as the Himalayas (alpine ecosystems), Western Ghats (tropical forests), Indo-Burma (north-eastern region), and Sundaland (Nicobar Islands). Notwithstanding this richness, biodiversity conservation in India has traditionally focused on plants and animals, while fungi remain largely overlooked. This cryptic kingdom plays a fundamental role in ecosystem functioning by regulating nutrient cycles, sustaining soil health, supporting plant productivity, and maintaining forest resilience. Recent advances in molecular phylogenetics and genomic research have transformed fungal classification and revealed an immense, previously unrecognized diversity. However, many biodiversity inventories and conservation frameworks in India still rely on outdated taxonomic concepts, creating a gap between modern scientific knowledge and conservation practice. Ignoring these changes risks underestimating fungal diversity and overlooking ecologically important lineages. Fungi and lichens also contribute significantly to climate regulation by sequestering carbon, stabilizing soil, and restoring ecosystems. Integrating modern fungal taxonomy into biodiversity policies, inventories, and restoration programs would strengthen conservation outcomes and ecosystem resilience. This review article examines the need to align policy frameworks, scientific research, and conservation strategies with modern classification systems to strengthen biodiversity governance and facilitate the achievement of global conservation targets for Bharat. Recognizing fungi alongside flora and fauna is therefore essential to achieving a more inclusive, scientifically grounded approach to biodiversity conservation in India.

Keywords: Artificial Intelligence, Bharat, CBD, Conservation, Funga, Modern taxonomic framework

INTRODUCTION

India occupies only about 2.4% of the world's land area. Yet, it harbours nearly 8% of the global recorded biodiversity, with roughly 45,000 plant species and over 91,000 animal species, placing it among the world's most biologically diverse regions. This extraordinary diversity is concentrated across four global biodiversity

hotspots: the Himalayas, Western Ghats, Indo-Burma, and Sundaland (including the Nicobar Islands), making

India a unique global leader in biodiversity and bioresources. A rich and remarkable spectrum of fungal biodiversity thrives alongside India's biodiversity hotspots. Yet despite this richness, biodiversity conservation in India has long been shaped by visible life forms. Forest trees, flowering plants, charismatic mammals, birds, and coral reefs dominate conservation narratives, legal frameworks, and funding priorities. Yet beneath these visible layers lies a vast, largely unaccounted-for biological kingdom whose influence permeates every ecosystem in the country. Fungi regulate nutrient cycles, sustain forests, govern soil health, mediate plant productivity, and shape microbial communities. In spite of this, fungi remain marginal in India's biodiversity discourse, particularly in conservation planning and policy implementation.

Fungal taxonomy has reached a critical inflection point. The explosion of molecular phylogenetics, phylogenomics, and integrative systematics has upended long-standing species concepts, family boundaries, and higher classifications. Genera have been dismantled, redefined, or resurrected. Morphology-based groupings are now shown to reflect deep evolutionary divergences. These are not mere academic refinements but foundational changes affecting biodiversity measurement, monitoring, and protection. As multi-locus and environmental sequencing further redefine fungal diversity, traditional, morphology-based taxonomies are increasingly obsolete. The new reliance on genome-scale data and sequence-only taxa accelerates species discovery but also threatens nomenclatural stability and biological meaning. The core challenge now is not the greater production of data, but the synthesis of phenotypic, ecological, and genomic evidence into a unified, evolutionarily coherent classification system (Hibbett *et al*., 2011; Hawksworth and Lücking, 2017; Lücking *et al*., 2020; Wijayawardene *et al*., 2022).

India, as one of the world's megadiverse countries, stands at a critical juncture. While global fungal classification is rapidly evolving, national conservation frameworks remain largely static and plant and animal centric. Ignoring these taxonomic revolutions risks misrepresenting fungal diversity, misdirecting conservation priorities, and weakening ecosystem management strategies. This article

discusses that modern fungal classification is not optional knowledge for India's biodiversity agenda but an essential foundation for credible conservation. The adoption of the "One fungus=One name" principle was intended to resolve long-standing dual nomenclature in pleomorphic fungi; however, the genomic era has paradoxically introduced new layers of taxonomic instability. Rapid reclassification driven by limited sampling, incomplete loci, or conflicting phylogenomic signals has resulted in frequent name changes that challenge applied disciplines such as plant pathology, medical mycology, and biotechnology (McNeill *et al*., 2012; Schoch *et al*., 2014; Johnston *et al*., 2019; Hyde *et al*., 2023). This article contends that while genomic data are indispensable, taxonomic decisions must be guided by standardized markers, robust phylogenetic support, and community consensus mediated through curated platforms such as MycoBank and Index Fungorum. As fungal systematics transitions from single-locus barcoding to multilocus and genome-scale datasets, the criteria for species delimitation have become increasingly inconsistent across taxa and research groups. While phylogenomics promises unprecedented resolution, it also risks over-splitting lineages when separated from morphology, ecology, and reproductive biology. This article advocates for globally accepted minimum standards for sequence length, marker selection, and analytical rigor, emphasizing that taxonomic inflation may undermine long-term data comparability and biodiversity assessments (Lücking *et al*., 2020).

India's biodiversity and climate governance frameworks, though largely indirect, provide a strong foundation for conserving fungi and lichens, which remain under-represented in policy discourse. The Biological Diversity Act (2002), aligned with India's CBD commitments, establishes decentralized mechanisms via the National Biodiversity Authority, State Biodiversity Boards, and local Biodiversity Management Committees to

document, conserve, and sustainably manage all biodiversity components. In principle, this mandate covers groups such as fungi and lichens, which fall under the broader category of cryptogams, through the People's Biodiversity Registers; in practice, their inclusion is sporadic and taxonomically limited. The National Red List Assessment Initiative, led by the Ministry of Environment, Forest and Climate Change (MoEFCC), to meet CBD and Kunming-Montreal Global Biodiversity Framework targets, has focused mainly on plants and animals, leaving fungi and lichens largely unassessed. Institutions such as the Botanical Survey of India have produced baseline inventories of fungal and lichen diversity, providing a scientific base that could be integrated into national conservation planning and policy. These systematically curated datasets form a critical scientific foundation, not only for understanding the extent of microbial diversity but also for identifying conservation priorities. When effectively integrated into national conservation planning and policy frameworks, such data can guide evidence-based decision-making, support habitat protection strategies, and ensure that often-overlooked groups like fungi and lichens are meaningfully incorporated into biodiversity management and sustainability initiatives.

Fungi and lichens play a critical yet often invisible role in ecosystem functioning, with direct implications for carbon sequestration, forest productivity, and climate resilience. Mycorrhizal fungi enhance plant nutrient acquisition, improve soil aggregation, and facilitate long-term carbon stabilization in forest soils, thereby contributing substantially to terrestrial carbon sinks. Recent global studies have demonstrated that fungal biomass constitutes a significant fraction of stable soil organic carbon, underscoring the importance of conserving fungal diversity for climate mitigation strategies (Clemmensen *et al*., 2013; Liang *et al*., 2019). Lichens, as symbiotic systems, contribute to primary production, nitrogen fixation, and biogeochemical cycling, while also serving as sensitive bioindicators of forest health and air quality. Protecting fungal and lichen communities, therefore, strengthens ecosystem resilience, enhances soil carbon storage, and indirectly supports improvements in forest cover quality rather than merely quantitative tree expansion (Hawksworth and Lücking, 2017).

National flagship initiatives such as the Green India Mission, a core part of India's National Action Plan on Climate Change, aim to restore and enhance millions of hectares of forest and tree cover, increasing carbon sequestration and ecosystem services. Though the mission does not explicitly reference fungi or lichens, its ecosystem-based approach depends on healthy soil microbial and fungal networks for long-term success. Including fungal conservation and mycorrhiza-based restoration in Green India Mission activities could notably improve afforestation, carbon credit potential, and forest sustainability. India's CBD-aligned National Biodiversity Strategy and Action Plan, along with emerging mechanisms such as biodiversity credits, offers an opportunity to formally recognize fungal and lichen ecosystem services within conservation finance frameworks. Explicitly designating fungi as a third pillar of biodiversity, alongside flora and fauna, would strengthen India's compliance with global targets and further enhance carbon sequestration, forest resilience, and nature-based climate solutions, which are critical for sustainable, climate-resilient development.

While current Indian policies and projects broadly support biodiversity and climate goals, the explicit inclusion and targeted conservation of fungi and lichens would enrich conservation outcomes, enhance carbon sequestration and forest resilience, and align national strategies with global biodiversity commitments, thereby achieving a truly comprehensive approach to ecosystem stewardship. Although fungi and lichens are historically underrepresented in formal conservation programs, several national structures and initiatives indirectly support their protection and could be expanded to include targeted fungal/lichen efforts. This direction becomes especially important when we recognize that fungi are still largely absent from mainstream conservation frameworks. One way to address this gap is through the Fauna-Flora-Funga (FFF) Proposal, which advocates formally recognizing fungi as a third, distinct pillar of biodiversity alongside plants and animals. By adopting this framework, conservation policies would move

beyond a plant-animal bias and begin to explicitly include fungal diversity in assessments, funding priorities, and legal protections. This shift would also encourage more systematic documentation, red-listing, and habitat-level protection for fungi and lichenized species.

Complementing this, India could strengthen its global conservation stance by endorsing the Convention on Biological Diversity through initiatives like the Fungal Conservation Pledge, introduced by the governments of United Kingdom and Chile. This pledge calls for the explicit inclusion of fungi in national biodiversity strategies, monitoring programs, and conservation targets. It also emphasizes improving fungal data infrastructure, promoting research, and raising awareness about their ecological roles, ranging from nutrient cycling to symbiotic associations. To align effectively with these global initiatives, India could address existing policy gaps by integrating its robust baseline biodiversity datasets, such as those generated by *Cybertruffle* (http://www.cybertruffle.org.uk/robigalia/eng/) and the Botanical Survey of India, into actionable conservation and management frameworks. Such an approach would facilitate the translation of extensive taxonomic and distributional knowledge into evidence-based policy decisions, strengthening national biodiversity conservation strategies. In practice, this would mean incorporating fungal indicators into biodiversity assessments, safeguarding ecologically sensitive fungal habitats, and integrating fungi into environmental impact assessments and restoration programs. Ultimately, these steps would not only elevate the status of fungi within conservation discourse but also contribute to more holistic and ecosystem-based biodiversity management in India.

Biodiversity Governance under the Biological Diversity Act (2002)

India's Biological Diversity Act provides the legal basis for biodiversity conservation, sustainable use, and equitable benefit sharing aligned with the Convention on Biological Diversity (CBD). It established the National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs), and local Biodiversity Management Committees (BMCs) to document and conserve biodiversity, including *cryptogams* such as fungi and lichens, through biodiversity registers and management plans. This decentralized structure could serve as a platform for national fungal/lichen conservation strategies if explicitly integrated into mandates and registers (BD Act and NBA framework).

National Red List Assessment Initiative (Vision 2025 to 2030)

Launched by the MoEFCC to fulfil CBD commitments and the Kunming-Montreal Global Biodiversity Framework (GBF), this initiative aims to assess the extinction risk of thousands of Indian species across taxa. Although largely plant and animal-focused today, expanding this assessment to include fungi and lichens would help set conservation priorities and inform legal protection and action plans. The Botanical Survey of India (BSI), a central research institution under MoEFCC, maintains inventories of fungi and lichens within India's rich floral biodiversity. Detailed documentation of cryptogams is available through its online repository at - https://ivh.bsi.gov.in/cryptogams. The repository records approximately 2,981 lichen species, highlighting the significant yet still underexplored diversity of cryptogams in India. Integrating BSI inventories into conservation planning can provide baseline data for ecosystem management and species protection.

Fungi and the Architecture of Indian Ecosystems

Fungi occupy a central yet often invisible position in Indian ecosystems. From tropical rainforests of the Western Ghats to alpine meadows of the Himalaya, fungal communities regulate ecological processes that sustain plant and animal life. Mycorrhizal fungi facilitate nutrient uptake in forest trees, enhancing productivity and resilience under climatic stress, while saprotrophic fungi drive decomposition and return carbon and minerals to the soil. Endophytic fungi modulate plant health and stress tolerance, and pathogenic fungi shape population dynamics across trophic levels. Beyond forests, fungi regulate soil fertility and disease dynamics in agroecosystems, govern organic matter turnover in freshwater and mangrove systems, and contribute to bioremediation in urban and industrial landscapes. Despite this functional centrality, fungal diversity is rarely quantified in environmental impact

assessments, biodiversity inventories, or conservation action plans in India. One reason for this neglect lies in the historical limitations of fungal taxonomy. Morphology-based identification often underestimates diversity and obscures cryptic species. As a result, fungi were perceived as taxonomically intractable and ecologically diffuse. The genomic revolution has fundamentally altered this perception, revealing fungi as highly structured, diverse, and evolutionarily informative organisms.

Civil Society & Advocacy Initiatives

Organizations such as the Fungi Foundation are actively documenting traditional ecological knowledge, supporting fungal diversity surveys, and advocating for the formal inclusion of fungi in national and international conservation frameworks. Partnerships between government agencies and such groups could catalyse policies tailored to fungal and lichen conservation and public engagement. India's environmental and climate strategies provide frameworks that, if broadened to include fungi and lichens, could support their conservation while contributing to carbon sequestration and forest cover targets: Green India Mission (GIM), as one of the eight missions under the National Action Plan on Climate Change (NAPCC), the Green India Mission aims to protect, restore, and enhance forest and tree cover using ecosystem-based approaches that improve ecological services including carbon sequestration. The mission seeks to increase forest and tree cover across 5 million hectares and improve cover on an additional 5 million hectares, thereby expanding carbon sinks and supporting biodiversity. Fungal and lichen communities would benefit from healthier forest ecosystems and could be integrated into the monitoring of soil and habitat quality under this mission. Convention on Biological Diversity (CBD) Implementation: As a party to the CBD, India is responsible for developing and implementing National Biodiversity Strategy and Action Plans (NBSAPs), integrating biodiversity objectives across sectors, and meeting global biodiversity targets, such as the effective protection of 30% of terrestrial and marine areas by 2030. Incorporating fungi and lichens into CBD-aligned goals (e.g., 30 × 30 pledge) can ensure that cryptogam biodiversity is accounted for in national and subnational conservation strategies. Biodiversity Credits & Climate Finance Innovations: merging global mechanisms, such as biodiversity credits under the Kunming-Montreal GBF, offers avenues to link biodiversity conservation with financial incentives for ecosystem protection. Explicitly recognizing fungal ecosystem services in such schemes could enable funding for fungal conservation programs and habitat restoration projects that deliver measurable biodiversity and climate benefits.

1. Strategic Value & Policy Opportunities: Integrate fungal diversity into national conservation inventories and expand the National Red List Assessment and biodiversity registers to include fungi and lichens, enabling evidence-based policy and prioritization.
2. Develop fungal-driven restoration programs by piloting mycoforestry and ecosystem restoration projects that enhance carbon sequestration while increasing forest productivity and resilience, in line with Green India Mission targets.
3. Pursue legal recognition and policy inclusion by formally designating fungi as a separate conservation category alongside flora and fauna in environmental policies and protected area management plans.
4. Leverage biodiversity finance by designing credit mechanisms that value cryptogam contributions to carbon sequestration and nutrient cycles, unlocking international funding and local conservation incentives.

   Fungi and lichens contribute significantly to ecosystem functioning and climate regulation, with implications for national targets on carbon credits and sequestration. Mycorrhizal fungi form symbiotic associations with plant roots and enhance nutrient uptake, plant health, soil structure, and carbon storage, which are critical for long-term carbon sequestration and soil stability. These underground fungal networks are key to ecosystem resilience and nutrient cycling, directly influencing forest health and carbon stocks. Recent research shows that certain fungal communities play important roles in carbon stabilization in soils, especially in post-disturbance environments, suggesting that

conserving fungal diversity could amplify long-term carbon sequestration. Lichens, symbiotic partnerships between fungi and photosynthetic partners, thrive in diverse environments and contribute to biogeochemical cycles, including minor but crucial roles in carbon and nitrogen cycling. They are also important indicators of air quality and environmental health, useful for ecosystem monitoring and adaptive management.

Fungi, particularly edible mushrooms, represent an underutilized and readily available bioresource with immense potential to substitute for animal protein in India, offering a sustainable pathway to bolster national nutritional security and directly support flagship initiatives such as the Kuposhan Mukt Bharat and Viksit Bharat Missions. Mushrooms are rich in high-quality proteins, essential amino acids,

dietary fiber, vitamins, and minerals, making them an excellent alternative to conventional animal-derived proteins while also being low in fat and environmentally sustainable to cultivate. Globally, annual mushroom and truffle production exceeds 40–45 million tonnes, with the industry valued at an estimated USD 70–75 billion in 2025 and projected to reach ~USD 100 billion by 2030, reflecting their growing economic and nutritional relevance worldwide (FAOSTAT; Allied Market Research, 2026). Despite this, India contributes less than 1% of global mushroom production, with its share hovering around 0.5-0.7%, and ranks among the lower echelons of global output, despite favourable agro-climatic conditions and abundant agro-residues that could be harnessed for cultivation (Bijla and Sharma, 2023; StatLedger, 2025). In stark contrast, China dominates global production, accounting for over 90% of the total**,** underscoring the vast gap between potential and performance in the Indian context. Expanding mushroom cultivation at scale could thus generate high-value nutritional bioresources, reduce reliance on imported proteins, promote rural entrepreneurship, and augment national strategies to eradicate malnutrition and build a resilient, nutrient-rich food system for a Viksit Bharat (FAOSTAT; Allied Market Research, 2026).

India is witnessing a growing scientific and policy-level interest in documenting the biodiversity of mushrooms, driven by their ecological, nutritional, and economic significance. National coordinated programmes such as the All India Coordinated Research Project (AICRP) on Mushrooms have played a crucial role in this regard, facilitating multi-location research on the collection, characterization, and identification of mushroom diversity across the country. Alongside such structured initiatives, institutions like the Botanical Survey of India have generated extensive baseline inventories of fungal and lichen diversity, while independent research projects continue to expand region-specific datasets. Despite these efforts, much of the work remains fragmented and yet to be integrated into national biodiversity frameworks. In this context, the rising global emphasis on inclusive conservation, reflected in the Fauna-Flora-Funga framework and international commitments under the Convention on Biological Diversity, offers a timely opportunity. By aligning coordinated programmes like AICRP and existing research outputs with such global initiatives, and by engaging with efforts such as the fungal conservation pledge, India can transition from dispersed documentation to a more cohesive and policy-oriented approach. This would not only consolidate current research momentum but also ensure that mushroom biodiversity is systematically incorporated into conservation planning, ecological monitoring, and sustainable bioresource management.

India's Fungal Diversity in a Changing Taxonomic Landscape

India is estimated to harbour a substantial proportion of global fungal diversity (including lichenised fungi), yet only a fraction has been formally documented. Most national biodiversity inventories rely on outdated taxonomic concepts and morphological identification methods. As global classification systems evolve, many Indian fungal records become taxonomically ambiguous or obsolete. Species names used in plant inventories, checklists, and conservation reports may no longer correspond to valid evolutionary entities. This disconnect creates multiple problems. First, biodiversity estimates based on obsolete taxonomy underestimate true diversity and endemism. Second, conservation assessments that rely on outdated species boundaries risk

overlooking rare or threatened lineages. Third, ecological studies that use misidentified taxa compromise reproducibility and comparative analyses. Indian biodiversity hotspots, such as the Western Ghats, Eastern Himalayas, and Northeast India, are likely centres of fungal endemism. Molecular studies increasingly reveal region-specific clades adapted to local hosts, climates, and substrates. Without integrating modern taxonomic frameworks, these unique evolutionary lineages remain invisible to conservation planners.

Conservation Policy and the Problem of Taxonomic Blindness

India's conservation policies are shaped by legislative instruments such as the Wildlife Protection Act, the Biological Diversity Act, and national biodiversity action plans. These frameworks focus predominantly on plants and animals, with fungi rarely mentioned explicitly. Even when microbial diversity is acknowledged, it is often treated as a homogeneous category rather than a structured kingdom with conservation relevance. Taxonomic blindness toward fungi has several consequences. Protected area design rarely considers fungal diversity or functional roles. Environmental clearances do not account for fungal habitat loss. Climate change vulnerability assessments exclude fungal responses and feedback. Traditional knowledge systems, which often recognize fungi as food and medicine, are disconnected from formal conservation strategies. Global biodiversity targets increasingly emphasize comprehensive and inclusive conservation. The post-2020 Global Biodiversity Framework calls for protecting genetic diversity across all domains of life. Without incorporating modern fungal taxonomy, India risks falling short of these commitments in both spirit and practice.

When Names Change, Conservation Outcomes Change

Taxonomy is often perceived as a static naming exercise, yet in reality, it shapes conservation outcomes directly. Conservation status assessments depend on species boundaries, distribution ranges, and population estimates. When taxonomic revisions split a widespread species into several narrowly distributed ones, each new entity may qualify for threatened status. Conversely, synonymizing poorly defined species can more effectively redirect conservation resources. In fungi, where cryptic diversity is common, taxonomic revisions frequently reveal hidden endemism. Ignoring these changes perpetuates a false sense of security regarding fungal resilience and distribution. For India, this means that conservation priorities based on outdated taxonomy may systematically undervalue fungal vulnerability. Moreover, misapplied names hinder international data integration. Global databases such as GenBank, GBIF, and UNITE rely on current taxonomy for data harmonization. Indian fungal records that do not align with updated classification are less likely to be incorporated into global analyses, further marginalizing national biodiversity data.

The Global Taxonomic Revolution in Fungi

Over the past two decades, fungal systematics has experienced a paradigm shift. Multigene phylogenies, genome-scale datasets, and standardized DNA barcoding have reshaped classification at every taxonomic level. The introduction of the one fungus one name principle eliminated parallel sexual and asexual nomenclatures, triggering widespread name changes. Genera such as *Aspergillus*, *Colletotrichum*, *Cercospora, Cortinarius, Fusarium*, *Ganoderma*, *Lactarius, Lentinula, Penicillium*, *Pleurotus, Phoma* and *Rusulla* etc. have been restructured based on evolutionary relationships rather than phenotypic convenience. Higher-level classification has also changed dramatically. Orders and families have been redefined, new classes erected, and long-standing groupings dissolved. Environmental sequencing has uncovered vast fungal lineages with no cultured representatives, expanding the known fungal tree of life beyond classical taxonomic boundaries. These discoveries challenge existing estimates of fungal diversity and expose the inadequacy of older classification systems. Importantly, these taxonomic changes have practical consequences. Species concepts now integrate phylogenetic distinctness, ecological specialization, and geographic structure. What was once treated as a single widespread species may now represent multiple endemic lineages with restricted

distributions. For a country like India, this has profound implications for biodiversity assessment and conservation prioritization. Ultimately, integrating modern fungal systematics into national biodiversity planning will not only improve the accuracy of species assessments but also ensure that conservation policies are responsive to the true scale and structure of fungal diversity in India.

Core microbiome database and repository for Indian flora and fauna

India's biodiversity conservation strategy under Viksit Bharat Mission 2047 should expand beyond larger organisms to include the microbial aspect. This includes creating a core microbiome database and repository for Indian flora and fauna. A core microbiome, which refers to the stable and important microbial community associated with a host, plays a vital role in nutrient cycling, stress tolerance, and disease resistance. Despite global progress in metagenomics and microbial ecology, India's microbiome data is still incomplete. Projects like the Indian Soil Microbiome Project have started mapping soil microbial diversity across different agroecological zones. This work highlights the role of soil microorganisms in sustainable agriculture and ecosystem health (ICAR-NBAIM, 2023). The Indian Biological Data Centre also provides a developing national framework for combining biological datasets, including genomics and microbiome information (DBT, 2022). Fungal diversity, an important part of microbiomes, has been partly recorded through platforms like *Cybertruffle Robigalia*. This platform has catalogued over 57570 species and linked them to global databases (http://www.cybertruffle.org.uk/robigalia/eng/).

These initiatives show the huge but underexplored microbial resources in India. Bringing these datasets into a single repository would aid in ecosystem-level conservation planning by connecting host species with their related microbiota. For example, using microbiome data can lead to improved survival of forest species and strengthen agroecosystems facing climate challenges. Regional datasets like the Indian Himalayan metagenome database also show how microbial resources can contribute to both conservation and biotechnology (Khatri *et al*., 2023). The creation of a national microbiome repository would support climate-resilient agriculture, wildlife disease monitoring, and bioeconomy growth. However, issues such as the need for taxonomic expertise, scattered data systems, and limited funding need to be resolved through unified institutional efforts. Incorporating microbiome science into conservation policies will enable India to take a comprehensive, ecosystem-based approach. It will position microbial diversity as a key element of sustainable development and ecological security by 2047.

AI-Enabled Fungal Taxonomy for Biodiversity Conservation in India

Artificial Intelligence (AI) will transform the way we understand fungal taxonomy in India by 2047. The country has vast but underexplored fungal diversity across forests, agricultural areas, deserts, mangroves, and Himalayan ecosystems. Traditional fungal taxonomy often depends on morphology and microscopic observations. This approach can be slow and does not always resolve cryptic species effectively. Recent improvements in AI, machine learning, deep learning, and bioinformatics are transforming fungal identification and classification globally. AI systems can now accurately analyze fungal images, DNA barcodes, ITS sequences, and ecological data, allowing for quicker and more reliable classification. Studies like FungiLT have shown that deep learning models can classify species-level fungi using ITS sequence data, enhancing precision in fungal systematics (Liu *et al*. 2025). AI-assisted taxonomy supports image-based identification using convolutional neural networks and explainable AI models. New research on macrofungi and Discomycetes indicates that AI systems can effectively classify morphologically similar fungal species (Korkmaz *et al*. 2025; Kumru *et al*. 2025a, b; Ekinci *et al*. 2025). Together, AI-driven tools, spanning mobile imaging, remote sensing, genomics, and automated fungal databases, have the potential to transform biodiversity documentation in India. AI can also help find new species, predict evolutionary relationships, and monitor fungal pathogens that impact agriculture, forests, and public health. Under Viksit Bharat Mission 2047, AI-driven fungal taxonomy could boost biodiversity conservation, support climate-resilient agriculture, aid in forest restoration, and contribute to the

bioeconomy. Merging AI with national microbial repositories, metagenomics, and digital biodiversity databases would enable real-time monitoring and ecological forecasting of fungi. However, India still encounters challenges such as limited fungal sequence databases, a lack of trained taxonomists, and insufficient computational resources. Therefore, strengthening partnerships among mycologists, AI researchers, and biodiversity institutions will be crucial. By 2047, AI-enabled fungal taxonomy could become an essential part of India's ecological security and sustainable scientific growth.

Capacity Gaps in Indian Mycology

One of the central challenges in aligning Indian conservation with modern fungal taxonomy is limited national capacity. Molecular systematics requires infrastructure, training, curated reference collections, and sustained funding. While India has a strong tradition in classical mycology, integration with genomic approaches remains uneven. Herbaria and culture collections often lack molecular vouchers. Many historical specimens cannot be confidently linked to modern phylogenetic frameworks. Young researchers face limited opportunities for advanced training in fungal phylogenomics and bioinformatics. Without addressing these gaps, India risks becoming a passive consumer rather than a contributor to global fungal taxonomy. Investing in taxonomic capacity is not a luxury but a strategic necessity. Accurate identification is crucial for plant pathology, forest management, biosecurity, and bioprospecting. Strengthening fungal taxonomy, therefore, delivers benefits far beyond conservation alone. Addressing capacity gaps must also begin earlier in the education pipeline. Introducing fungi and lichens into the school curriculum is essential for cultivating early scientific curiosity and ecological literacy among younger generations. These organisms represent the hidden kingdom that governs nutrient cycling, climate regulation, ecosystem resilience, and human well-being, yet remains largely invisible in formal education. By embedding fungal and lichen biology in foundational curricula, students can develop a deeper appreciation of symbiosis, sustainability, and biodiversity, while gaining insight into emerging fields such as biotechnology, medicine, and climate science. International initiatives, such as the MycoKids program of the British Mycological Society, demonstrate how early engagement through hands-on learning, citizen science, and storytelling can successfully inspire children to explore fungal diversity and its societal relevance. Such exposure fosters critical thinking and environmental stewardship, correcting the long-standing neglect of fungi, often described as the orphans of the Rio framework. This empowers future citizens and scientists to recognize and protect this indispensable yet overlooked component of life on Earth.

Integrating Fungal Taxonomy into Conservation Practice

For fungal classification to meaningfully shape conservation strategies, it must be integrated at multiple levels. National biodiversity inventories should adopt updated taxonomic frameworks and require molecular validation where appropriate. Environmental impact assessments should recognize fungi as integral components of ecosystems. Protected area management plans should incorporate fungal diversity monitoring, particularly in forests and wetlands. Policy documents should explicitly acknowledge fungi as conservation targets. Funding mechanisms should support integrative taxonomic research that links systematics with ecology and biogeography. Collaboration among taxonomists, ecologists, and policymakers is essential to translate advances in classification into actionable conservation outcomes. Equally important is public engagement. Communicating the relevance of fungi in accessible language can broaden support for inclusive biodiversity conservation. Recognizing fungi as indispensable rather than obscure can reshape conservation narratives at national and regional levels.

India's Opportunity for Leadership

Fungi are now recognized as the third pillar of biodiversity, alongside flora and fauna. However, most biodiversity frameworks historically excluded fungi, making it underrepresented in conservation laws and strategies worldwide. A recent initiative, the Fungal Conservation Pledge (2024), has called for the policy recognition of fungi as an independent kingdom. Another noteworthy global effort is the Global Strategy for Fungal

Conservation, which aims to integrate fungi into climate, biodiversity, and sustainability agendas. This creates a policy vacuum and is therefore a perfect opportunity for India to lead. India is credited as a Mega-diversity hotspot with vast undocumented fungal wealth. India is uniquely positioned to lead in integrating modern fungal taxonomy with conservation. Its ecological diversity, strong academic institutions, and growing genomic capacity provide a solid foundation. By aligning national biodiversity strategies with contemporary classification systems, India can set an example for other megadiverse countries facing similar challenges. India being rich in the ethnomycological traditions, emphasizes on integration of indigenous knowledge in biodiversity policies. NGOs often serve as a bridge between science, policy, and local communities, and can play a pivotal role in conservation strategies. Organisations like Fungi Foundation work globally to promote conversation and policy inclusion. NGOs can help convert scientific knowledge into actionable policies by including lobbies for inclusion of fungi. Strategic Policy Opportunities may include National Fungal Missions for field surveys, awareness campaigns leading to community engagements and ensuring continuous field level data flow. The promotion of mycorrhizal inoculants and fungal restoration projects could serve as critical drivers of climate resilience and ecosystem restoration. Leadership in fungal conservation would also strengthen India's voice in global biodiversity governance. Contributing high-quality taxonomic data enhances international collaboration and ensures that Indian ecosystems are accurately represented in global assessments. In an era of rapid environmental change, such leadership is both timely and necessary.

The model of public engagement in fungal taxonomy pioneered by the Westerdijk Fungal Biodiversity Institute exemplifies how thoughtfully structured citizen participation can substantially accelerate the discovery and documentation of biodiversity. By actively engaging volunteers, students, and amateur naturalists in specimen collection, culturing, and preliminary identification, the institute has not only enhanced scientific productivity but also cultivated broader societal awareness of fungal diversity and published several new species. Such participatory frameworks effectively bridge the divide between professional taxonomists and the wider community, nurturing a shared ethos of scientific stewardship. In a country like India, endowed with vast yet insufficiently explored fungal wealth, the adoption of similar initiatives holds considerable promise for unlocking untapped diversity. The strategic integration of citizen science programs with national repositories and academic institutions would strengthen taxonomic research while simultaneously fostering capacity-building at the grassroots level. Consequently, embracing and adapting such inclusive models represents a compelling opportunity for India to position itself as a global leader in fungal biodiversity assessment and conservation.

CONCLUSION

Fungi form the invisible foundation of India's ecosystems, yet their conservation remains constrained by outdated taxonomic perspectives. The global revolution in fungal classification has exposed the inadequacy of traditional approaches and highlighted the urgency of integrative, evolution-based taxonomy. Ignoring these changes undermines biodiversity assessment, weakens conservation priorities, and risks overlooking irreplaceable evolutionary lineages. For India, embracing modern fungal taxonomy is not merely a scientific refinement but a conservation imperative. Aligning policy, practice, and research with contemporary classification will strengthen ecosystem management, fulfil international commitments, and ensure that the country's biodiversity conservation strategies are truly comprehensive. The invisible kingdom can no longer remain invisible in India's conservation future.

ACKNOWLEDGEMENTS

Kunhiraman C. Rajeshkumar gratefully acknowledges the financial support of the Anusandhan National Research Foundation (ANRF), Department of Science and Technology, Government of India (ANRF/ARG/2025/002281/LS), and thanks Dr. Prashant K. Dhakephalkar, Director, MACS-ARI, for guidance and laboratory facilities.

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