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Review Paper

Fungal Biodiversity : Evolution & Distribution- A Review

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Abstract:

Fungal species are especially important component of biodiversity on earth. Several studies have focused on enumerating the world's fungal diversity. There are over 1.5 million reported fungal species distributed widely throughout the globe. India has been the hub for such fungi. Fungi play a significant role in the day to day life, besides their utilization in industry, agriculture, medicine, food industry, textiles, bioremediation, biogeochemical cycling, as bio-fertilizers, bio-pesticides and many other ways. Only a fraction of total fungal wealth has been subjected to scientific scrutiny and mycologists need to unravel the unexplored and hidden wealth. In this review we describe unique fungal niches (air, water, soil), harboring many taxa of well known fungal species, thus highlighting the extent and distribution of fungal biodiversity. Fungal biotechnology has grown as an integral part of the human welfare. In the present review, the occurrence and distribution of fungi in different regions of India has been studied to highlight the extent of their diversity and uniqueness of their habitats.

Key Words - Biodiversity, Conservation, Phylogenetic, Deuteromycotina

I. INTRODUCTION

Fungi are important components of the ecosystem typically constituting more of the biomass than bacteria, especially in soil, depending on growth and nutrient conditions. Fungi have been considered the largest biotic community after insects [1]. Evolution of fungi has been reported 1800 million years ago. That makes them four times older than plants and half as old as bacteria. Fungi belong to super kingdom Eukaryota. Out of 1.5 million fungi around the globe [2], only 50% have been characterized until now and one third of total fungal diversity of the globe exists in India, the number of fungi recorded in India exceeding 27,000 species [3, 4]. The variety of fungi not only occupies prime position in biodiversity but play indispensable roles in industry, agriculture, medicine, biogeochemical cycles [5,6] and many other ways, besides their utilization in industry, agriculture, medicine [5], food industry, textiles, bioremediation, biogeochemical cycling, in recycling nutrients and decomposing the dead organic matter [7,8,9] in soil [10], as biofertilizers and many other ways. Fungal biotechnology has become an integral part of the human welfare [4]. But only 100 thousand species have been collected, identified, named and catalogued despite four centuries of research. These are classified in four phyla, 103 orders, 484 families and 4979 genera (Table 1).

Table 1 Fungal genera

Phyla	India
Myxomycotina	380
Mastigomycotina	205
Zygomycotina	50
Ascomycotina	745
Basidiomycotina	232
Deuteromycotina	468
Total	2080

In this review we describe unique fungal niches, harboring many taxa of well known fungal species, thus highlighting the extent and distribution of fungal biodiversity.

Evolutionary History

Cladogram

A cladogram depicts the phylogenetic relationships between several groups of organisms in a tree-like diagram. The current classification of Kingdom Fungi recognizes seven phyla, two of which—the Ascomycota and the Basidiomycota—are contained within a branch representing subkingdom Dikarya.

Taxonomicgroups

The major divisions (phyla) of fungi have been classified based mainly on the characteristics of their sexual reproductive structures. Currently, seven fungal divisions are proposed:

Chytridiomycota

The Chytridiomycota are commonly known as chytrids. These fungi are ubiquitous with a worldwide distribution. Chytrids produce zoospores that are capable of active movement through aqueous phases with a single flagellum, leading some early taxonomists to classify them as protists.

Blastocladiomycota

Recent molecular data and ultrastructural characteristics, place the Blastocladiomycota as a sister clade to the Zygomycota, Glomeromycota, and Dikarya (Ascomycota and Basiomycota). The blastocladiomycetes are fungi that are saprotrophs and parasites of all eukaryotic groups and undergo sporic meiosis unlike their close relatives, the chytrids, which mostly exhibit zygotic meiosis.

Neocallimastigomycota

The Neocallimastigomycota were earlier placed in the phylum Chytridomycota. Members of this small phylum are anaerobic organisms, living in the digestive system of larger herbivorous mammals and possibly in other terrestrial and aquatic environments. They lack mitochondria but contain hydrogenosomes of mitochondrial origin.

Zygomycota

The Zygomycota contain the taxa, Zygomycetes and Trichomycetes, and reproduce sexually with meiospores called zygospores and asexually with sporangiospores. Black bread mold (*Rhizopus stolonifer*) is a common species that belongs to this group; another is *Pilobolus*, which is capable of ejecting spores several meters through the air.

Glomeromycota

Members of the Glomeromycota are fungi forming arbuscular mycorrhizae with higher plants. Only one species has been observed forming zygospores; all other species solely reproduce asexually. The symbiotic association between the Glomeromycota and plants is ancient, with evidence dating to 400 million years ago.

Ascomycota

The Ascomycota, commonly known as sac fungi or ascomycetes, constitute the largest taxonomic group within the Eumycota. These fungi form meiotic spores called ascospores, which are enclosed in a special sac-like structure called an ascus. This division includes morels, a few mushrooms and truffles, single-celled yeasts (e.g., of the genera *Saccharomyces, Kluyveromyces, Pichia, and Candida*), and many filamentous fungi living as saprotrophs, parasites, and mutualistic symbionts.

Prominent and important genera of filamentous ascomycetes include *Aspergillus, Penicillium, Fusarium,* and *Claviceps.*

Basidiomycota

Members of the Basidiomycota, commonly known as the club fungi or basidiomycetes, produce meiospores called basidiospores on club-like stalks called basidia. Most common mushrooms belong to this group, as well as rust and smut fungi, which are major pathogens of grains. Other important Basidiomycetes include the maize pathogen *Ustilago maydis,* human commensal species of the genus *Malassezia,* and the opportunistic human pathogen, *Cryptococcus neoformans*

The Potential Role of Fungi

Fungi play vital roles in the biosphere. They are essential for recycling nutrients in all terrestrial habitats thus acting as decomposers of the complex organic components in soil ecosystem. As opportunistic heterotrophs, they penetrate solid substrates, and spores for long-range dispersal. They act as disease causing agents of plants and animals, but have established mutualistic association with a diverse groups of organisms: cyanobacteria and green algae (in lichens), bryophytes, pteridophytes, gymnosperms and angiosperms (in mycorrhizae), and coleopteran, dipteran, homopteran, hymenopteran and isopteran insects. As parasites they penetrate host organisms, liberate spores that will effectively transmit them from one host to the next, and produce toxic compounds (mycotoxins), thus affecting human health in numerous ways. Fungi are also instrumental in producing numerous fermented foods. Also, cholesterol lowering drugs (the statins), major immunosuppressant drugs (cyclosporins), the cancer drug Taxol, and penicillins some of the important fungal products. The most efficient way of converting recalcitrant lignocellulosic materials used in industries, is through fungal enzymes [11]. Climate change will lead to increase in stress on agricultural productivity, and hence as a solution, fungi will be brought to use as a new generation of agricultural inoculants (e.g. mycorrhizas, endophytes, biocontrol agents) in order to provide more nutrient efficient and drought-tolerant crops. Fungi also play a vital role in decomposition of waste. Along with bacteria, worms and other invertebrates, fungi break down wood, leaves and dung thus releasing the nutrients back into the soil. Few organisms other than fungi have the enzymes able to decompose such tough materials as lignin and keratin [12].

Fungal Habitats

Fungi are cosmopolitan, occurring in all aerobic ecosystems. They colonize a wide range of substrates and perform a diverse functions. Many species of fungi are cosmopolitan but some are specialists found only in restricted substrates or habitats. The habitats which fungi can occupy are extraordinarily diverse. This is evident from the studies of [13], who compiled information on the methods used for the inventorying of fungi in different habitats. Well known and most common niches harboring numerous fungal taxa are Air, Water and Soil. Unexplored and unusual habitats might be considered as detrimental to fungal growth. But, surprisingly, numerous species are found to grow and survive in such habitats.

Airborne fungi

The air-spore flora constitutes a constantly changing population of fungal spores [14]. Studies performed by [15] revealed a marked seasonal fluctuation in the fungal flora in India and found that Alternaria showed summer maxima, although *Aspergilli* were most frequently isolated. *Alternaria* and *Fusarium* were found in abundance during summer [16]. Malika (1975) [17] observed during study of summer air-spora over Lahore that *Curvularia, Helminthosporium* showed maximum growth during two months (July, August), with *Aspergilli* showing a gradual increase in number from dry to wet months. *A. humicola, C. lunaia, C. pallenscens, P. chermesinum* were abundant during rainy season. Greater frequency of occurrence of *Aspergilli* was observed in winter and spring while *Biospora, Candida, Penicillium* were observed as winter

types and *Epicoccum, Mucor, Penicillium, Pullularia, Rhizopus* as spring types. *Aspergillus fumigatus* and *P. spicaria* were found to occur frequently during winter season while during summer *Alternaria alternata* was found to occur in abundance [18]. Maximum number of spores were also observed during summer by [19]. Lowest number of thermophilus fungi was found by Evans (1972) [20], during autumn. *Aspergillus, Curvularia* and *Helminthosporium spp* were described as autumn type's fungi. The knowledge of air microflora is instrumental in understanding of abundance and seasonal variations of air flora, and forecasting of health problems in society.

1) Freshwater fungi

Certain groups of fungi find their inhabitation in fresh water. More than 3000 species of Ascomycetes are specialized for a saprobic life style in freshwater habitats where they have enhanced growth and sporulation [21,22, 23]. Few specialized freshwater basidiomycetes also are known, several have branched conidia similar to those of the Ingoldian ascomycetes. Flagellated fungi have been known to occur in aquatic habitats, including Chytridiomycota, Blastocladiomycota, and Monoblepharomycota [24]. *Batrachochytrium dendrobatidis*, the recently described amphibian killer, is an aquatic chytrid [25].

2) Marine fungi

Marine waters provide a habitat for certain specialized fungi [26], and [27] estimated that more than 1500 species of marine fungi occur in a broad array of taxonomic groups. Many of these fungi are distinct from freshwater aquatic species, and they may be saprobic on aquatic plant substrates. An investigation of deep-sea hydrothermal ecosystems revealed not only novel species of ascomycetes and basidiomycetes, but also what may be a previously unknown lineage of chytrids [28]. Most marine fungi are ascomycetes and basidiomycetes, which include ascomycete and basidiomycete yeasts [29]. Even a few mushroom-forming basidiomycetes are restricted to marine waters [30]. Some fungi employ few marine invertebrates as hosts [31], including antibiotic producers that live in sponges [32, 33, 34].

3) Soil fungi

Soil has very rich fungal diversity [35, 36]. Soil fungi and bacteria play important roles in biogeochemical cycles [37], and their diversity is highest near roots and root exudates where organic material exists. Gams (2006) [38]estimated that 3150 species of soil fungi are known. Fungi form crusts that stabilize desert soils. Crusts usually are made up of darkly pigmented ascomycetes, lichens, and nitrogen-fixing cyanobacteria [39]. These darkly pigmented ascomycetes are members of the classes Dothideomycetes and Arthoniomycetes, but basidiomycetes and bacteria may occur in the associations [40, 41]. Yeasts are well known from American deserts in association with cacti and flies where they detoxify plant metabolites [42].

The advent of new sequencing technologies is helping to elucidate the microbial diversity in many ecosystems, but more studies are needed to document the functional role of fungi in the microbial communities thriving in these unusual environments.

Distribution of Fungal Diversity in India

Since the number of fungi present on Earth was conservatively estimated at 1.5 million species [43], alternative estimates ranging from 0.5–9.9 million have been published by other authors [44]. According to the calculation made by Schmitt & Mueller (2004) [45], there must be a minimum of 0.6 million species. Data from 25 studies in different parts of Asia, Europe and North America were analyzed statistically by Schmitt et al. (2004) [46]; the results showed that fungal species richness was much higher than that of the plants, and were consistent with the high estimates of species numbers made by Hawksworth (1991) [43].

These figures for currently known fungal species are, however, higher than that obtained by summing the figures in the eighth edition of Ainsworth &

Bisby's Dictionary of the Fungi [47] and making an allowance for subsequently described species, which gave a figure of 74 000 [44], or the 80 000 total in the ninth edition [48].

Lakhanpal (1997) [49] has recorded that in a survey conducted in the North-Western Himalayas during 1976-1987, 300 species of mushrooms and toadstools were recovered; of these, nearly 72 species in 15 fungal genera were observed to enter into mycorrhizal relationship with *Abies pindrow Royle, Betula utilis D.Don, Cedrus deodara (Roxb.) Loud, Picea smithiana (Wall.) Boiss, Pinus roxburghii Sarg, Pinus wallichiana A.B. Jackson, Rhododendron arboreum Smith, Quercus incana Roxb. and Quercus semicarpifolia Smith.* Medicinal mushrooms like species of *Ganoderma, Trametes, Daldinia, Geastrum, Scleroderma, Ramaria, Auricularia, Schizophyllum* and many other Polypores were collected in different seasons. According to a study conducted by Saravanakumar and Kaviyarasan (2010) [50] in southern India, analysis was made to investigate soil nutrients and soil mycoflora of natural soils. Soil samples were collected for microbial enumeration from Shola forests of Tamil Nadu. Out of 48 samples, 55 species belonged to 21 genera were recorded. Among these two of Ascomycotina, nine species of Zygomycotina and others belonged to Deuteromycotina. Most dominant species reported was *Aspergillus niger*. These were followed by *Penicillium simplicissimum, Rhizopus stolonifer, Syncephalastrum racemosum, Aspergillus fisheri* and *Cunninghamella echinulata*. However, sixty seven species belonged to 23 genera were recorded from second season among them six species of Zygomycotina, two of Ascomycotina, four species of Coelomycetes and remaining fifty five species are Deuteromycetes. *Penicillium spp*. are the predominant genera and followed by *Aspergillus* with twelve species. Earlier reports also indicate that *Aspergillus* and *Penicillium* were dominant in forest soils [51]. The genera of *Curvularia* (7 species), *Trichoderma* (5 species), *Fusarium* (3 species), *Cladosporium* (2 species), *Paecilomyces* (2 species) contributed more than one species and other genera were represented as single. *Aspergillus terreus* occurred in highest contribution and *Penicillium spp.* was the second dominant flora followed by *Aspergillus niger, T. areoviride, F. oxysporum* and *A. flavus. P. veruculosum, Penicillium spp., A. amstelodami, Curvularia oryzae* and *Nigrospora sphaerica* were contributed as very low.

According to an analysis by Devi et al 2012 [52], an attempt has been made to investigate soil micro-fungal community structure and phylogenetic diversity from soil from different altitudes of NE India under Eastern Himalayan range and to assess if altitude has any impact on the diversity of fungi in the range. It was observed by Devi et al (2012) [52], under Euritoiales, *Penicillium* and *Aspergillus* were the most diverse genus and were evenly distributed in the entire stretch. *Bacillus* from high altitudes of eastern Himalayan range has been reported to produce thermostable enzyme [53]. Previous study also demonstrated that the fungi isolated from soil systems of high altitudinal cold climatic zones in eastern Himalayan range were capable of synthesizing stable silver nanoparticles [52]. The study made by Panda et al (2010) [54] revealed that in this ecological context, stability of edaphic factors is one of the important factor governing the activity and diversity of fungi. Mycoflora differs in its composition from an ecological niche to the other have also been reported by Manoharachary (2008) [55]. Earlier reports have indicated that the genera *Penicillium, Aspergillus* and *Trichoderma* appeared abundantly in Indian soils dominating both in the frequency and in relative density [56, 57, 58] and had important role in decomposition of leaf litter [59, 60, 61].

Fungal Conservation

The prime concern is minimizing threats to fungi throughout the globe since they play a significant role in human welfare. Moore et al, 2001 have suggested the following steps for fungal conservation: (i) Habitat Conservation (ii) *In-situ* conservation of ecological niches, and (iii) *Ex situ* conservation especially for saprotrophic species growing in culture. The World Federation for

Culture Collections (WFCC) has formulated guidelines for maintainance of appropriate standards to help culture collections centres [43]. A suitable preservation technique for fungi depends upon use of the organism, time, facilities and resources available. One of the simplest methods of storage is Mineral oil storage that retains viability of fungi for many years but places strains under selective pressure because of the special conditions of storage. Soil storage involves inoculation of spores or mycelium suspended in sterile distilled water into sterile soil of approximately 20% moisture content. This method of storage can retain viability for 10 to 20 years. Silica gel storage methods are suitable methods for fungal spores that remain viable for periods up to and over 20 years. Freeze drying entails freezing of the organism and its desiccation by the sublimation of ice under reduced pressure. Cryopreservation is the method of storage at ultra low temperatures, which is the most successful method for retention of both the viability and characteristics of fungi.

Conclusion

These findings provide important insights that aid our understanding of the diversity of fungi in natural ecosystems since fungi comprise important component of microbial diversity in high altitudes and are considered key organisms in inland ecosystems. Information on fungal diversity and functions might provide scope for bioprospecting of new source of drugs and other industrially important biomolecules and enzymes. New technologies, particularly in nucleic acid analysis, bioinformatics, analytical chemistry, and habitat sampling and characterization place the study of microbial diversity on the cutting edge of science.

REFERENCES

[1] A.K. Sarbhoy, D.K. Agarwal and J.L.Varshney, "Fungi of India 1982-1992", CBS Publishers and Distributors, New Delhi, 1996 .

[2] D.L.Hawksworth, "Fungal diversity and its Implifications for Genetic Resource collections. Studies in Mycology", 2004, 50, 19.

[3] C.S.Manoharachary, "Biodiversity, conservation and biotechnology of fungi", Presidential Address, Section-Botany, The 89th Session of Indian Science Congress, Indian Science Congress Association, Lucknow, India, January 3-7, 2002.

[4] C.S. Manoharachary, K.R. Singh, A. Adholeya, T.S. Suryanarayanan, S. Rawat , B.N. Johri," Fungal biodiversity: distribution, conservation and prospecting of fungi from India. Curr Sci., 2005, 89(1), 59-70.

[5] A. Cowan, Fungi – Life Support for Ecosystems. Essential ARB, 2001, 4, 1-5.

[6] G.M. Gates, D.A. Ratkowsky and S.J. Grove, "A Comparision of macrofungi in young Silvicultural regeneration and mature forest at the Warra LTER siet in the southern forests of Tasmania. Tasforests", 2005, 16, 127.

[7] R. Molina, T . O'Dell, D. Luoma, M. Amaranthus, Castellano and K. Russell, "Biology, Ecology and Social aspects of Wild Edible Mushrooms in the Forests of the Pacific Northwest: A Preface of Managing Commercial Harvest", U.S. Dept. of Agriculture Forest service, Pacific Northwest Research station, United States, 1993, 45 pp

[8] G.J. Keizer, "The Complete Encyclopedia of Mushrooms". Rebo publishers, Netherland, 1998, pp. 268 .

[9] D. Pilz and R. Molina, "Commercial harvests of Edible Mushrooms from the forests of the Pacific Northewst united states: Issues, Management and Monitoring for sustainability", Forest Ecology and management, 2001, 1-14.

[10] G.A.Hunt, "Assessing Macrofungi of special concern for Conservation in Forested Ecosystems"' In: Proc Biology and management of species and habitats at risk. Vol 2, 15-19 Feb 1999, University College of the Cariboo, Kamloops, 1999 , pp 779.

[11] L. Lange, "The importance of fungi for a more sustainable future on our planet". Fungal Biology Reviews, 2010, 24, 90–92.

[12] N..J Dix and J. Webster, "Fungal ecology. London, Chapman & Hall, 1995.

[13] G.M. Mueller, G.F. Bills, M.S. Foster (eds), "Biodiversity of fungi: inventory and monitoring methods", Elsevier Academic Press, Amsterdam, 2004a.

[14] P.H. Gregory, "The Microbiology of Atmosphere". Leonard Hill, London, 1961.

[15] B.S.V. Rajan, S.A. Nigam and R.K. Shukla. "A study of atmosphere fungi at Kanpur", Proc. Insian Acad. Sci., 1952, 35: 33-37.

[16] T. Nayyera," Hyphomycetes from the air over Lahore". M.Sc. Thesis, Punjab University, Lahore, 1971.

[17] S. Malika, "The studies of air spora over Lahore". M.Sc. Thesis, Punjab University, Lahore, 1975.

[18] R. Kumar, "Studies on aeromycoflora or Dehradun city. J. Indian Bot. Soc., 1984, 63: 277-291.

[19] Mamanova IV, "Mycoflora of air and exhibits of the Hermitage Museum. Mikologiya-i- Fitopathogiya, 1988, 22: 410-412.

[20] H.C. Evan, "Thermophilous fungi isolated from the air". Trans Br. Mycol. Soc., 1972, 59: 516-519.

[21] C.A.Shearer , E.Descals , B.Kohlmeyer , J.Kohlmeyer , L.Marvanová , D. Padgett , D.Porter et al. "Fungal diversity in aquatic habitats. Biodiversity and Conservation", 2007, **16**: 49–67.

[22] P.M. Kirk , P. F. Cannon , D. W. Minter , J.A.Stalpers," Dictionary of the Fungi, 10th ed. CABI, Wallingford, UK, 2008.

[23] C.A. Shearer , H.A. Raja, "Freshwater ascomycetes database [online]", Website http://fungi.life.illinois.edu/ [accessed 30 January 2011], 2010 .

[24] T.Y.James , P.M.Letcher , J.E.Longcore , S.E.MozleyStandridge , D.Por ter , M. J. Powell , G.W. Griffith , R. Vilgalys, "A molecular phylogeny of the flagellated Fungi (Chytridiomycota) anddescription of a new phylum (Blastocladiomycota)", Mycologia, 2006, **98**: 860–871.

[25] J.E. Longcore , A.P. Pessier , D.K.Nichols, "*Batrachochytrium dendrobatidis* gen. et sp. nov., a chytrid pathogenic to amphibians", Mycologia, 1999, **91**: 219–227.

[26] J. Kohlmeyer, B. Volkmann-Kohlmeyer, "Illustrated key to the filamentous higher marine fungi". Botanica Marina, 1991, **34**: 1–61.

[27] K.D. Hyde, "Where are the missing fungi? Mycological Research, 2001, **105**: 1409–1412.

[28] T.LeCalvez ,G.Burgaud , S.Mahé , G.Barbier , P.Vandenkoornhuyse, "Fungal diversity in deep-sea hydrothermal ecosystems", Applied and Environmental Microbiology, 2009, **75**: 6415–6421.

[29] T. Nagahama, "Yeast biodiversity in freshwater, marine and deep-sea environments. *In* Rosa C., Gábor P. [eds.], Biodiversity and ecophysiology of yeasts", 2006, 241–262. Springer-Verlag, Berlin, Germany.

[30] M. Binder , D.S. Hibbett , Z. Wang , W.F.Farnham, "Evolutionary relationships of *Mycaureola dilseae* (Agaricales), a basidiomycete pathogen of a subtidal rhodophyte", American Journal of Botany, 2006 , **93**:547–556.

[31] K.Kim , C.D.Harvell, "The rise and fall of a six year coral fungal epizootic". American Naturalist, 2004, **164**: S52–S63.

[32] P. Bhadury, B.T. Mohammad, P.C. Wright , "The current status of natural products from marine fungi and their potential as anti-infective agents", Journal of Industrial Microbiology & Biotechnology, 2006, **33**:325–337.

[33] M.V. Pivkin , S.A. Aleshko, V.B. Krasokhin, V. Khudyakova Yu, " Fungal assemblages associated with sponges of the southern coast of Sakhalin Island. Russian Journal of Marine Biology, 2006, **32**:207–213.

[34] B. Wang , Y-L. Qiu , "Phylogenetic distribution and evolution of mycorrhizas in land plants". Mycorrhiza, 2006, **16**: 299–363.

[35] J.L.Kirk , L.A.Beaudette , M.Hart , P.Moutoglis , J.N.Klironomos , H.Le e , J.T. Trevors, "Methods of studying soil microbial diversity. Journal of Microbiological Methods, . 2004, **58**: 169–188.

[36] K.H. Domsch, W.Gams , T.H. Anderson , "Compendium of soil fungi", 2nd ed. IHW-Verlag and Verlagsbuchhandlung, Eching, Germany, 2007.

[37] P.Vandenkoornhuyse , S.L.Baldauf , C.Leyval , J.Straczek , J.P.W Young, Extensive fungal biodiversity in plant roots. Science, 2002, **295**: 2051.

[38] W. Gams, "Biodiversity of soil-inhabiting fungi. Biodiversity and Conservation", 2006, **16**: 69–72.

[39] J.S. States , M. Christensen, "Fungi associated with biological soil crusts in desert grasslands of Utah and Wyoming". Mycologia, 2001, **93**: 432–439.

[40] K.R.Kuhlman , W.G.Fusco , M.T.LaDuc , L.B.Allenbach , C.L.Ball , G. M. Kuhlman , R .C. Anderson et al, "Diversity of microorganisms within rock varnish in the Whipple Mountains, California.", Applied and Environmental Microbiology, . 2006, **72**: 1708–1715.

[41] C.Ruibal , C.Gueidan , L.Selbmann , A.A.Gorbushina , P.W.Crous , J. Z .Groenewald , L. Muggia et al., "Phylogeny of rock-inhabiting fungi related to Dothideomycetes". Studies in Mycology, 2009, **64**: 123–133.

[42] W.T. Starmer , V. Aberdeen , M.A. Lachance, "The biogeographic diversity of cactophilic yeasts"' *In* Rosa C., Gábor P. [eds.], Biodiversity and ecophysiology of yeasts, 2006, 486–499. Springer-Verlag, Berlin, Germany.

[43] D.L.Hawksworth, "The fungal dimension of biodiversity, its magnitude and significance", Mycol Res, 1991, 5, 441–456.

[44] D.L. Hawksworth, "The magnitude of fungal diversity: the 1.5 million species estimate revisited", Mycological Research, 2001, 105: 1422–1432.

[45] J.P. Schmitt, G.M. Mueller, "An estimate of global fungal diversity", 2004, Biodiversity and Conservation: in press.

[46] J.P. Schmitt, G.M. Mueller, Y.Huang, P.R. Leacock, J.L. Mata, Q. Wu, "Assessment of tree species richness as a surrogate for macrofungal species richness", 2004, Biological Conservation: in press

[47] D.L. Hawksworth, P.M. Kirk, B.C. Sutton, D.M.Pegler, " Ainsworth & Bisby's dictionary of the fungi". 8th edition. CAB International, Wallingford, 1995.

[48] P.M. Kirk, P.F. Cannon, J.C. David, J.A. Stalpers (eds), "Ainsworth & Bisby's dictionary of the fungi", 9th edition. CABI Publishing, Wallingford, 2001.

[49] T.N. Lakhanpal, "Diversity of mushroom mycoflora in the North-West Himalaya", In: Sati SC, Saxena J, Dubey RC (eds) Recent researches in ecology, environment and pollution. Today and Tomorrow's Printers and Publishers, New Delhi, 1997.

[50] K. Saravanakumar and V.Kaviyarasan, "Seasonal distribution of soil fungi and chemical properties of montane wet temperate forest types of Tamil Nadu". African Journal of Plant Science, 2010, Vol. 4(6), 190-196.

[51] A.H. Moubasher, S.M. El-Dohlob, "Seasonal fluctuation of Egyptian soil fungi", Trans Br Mycol Soc, 1970, 54, 45-51.

[52] L.S. Devi, S.R. Joshi, "Antimicrobial and synergistic effects ofsilver nanoparticles synthesized using soil fungi of high altitudes of eastern Himalaya". Mycobiology, 2012, 40, 27-34.

[53] S.L. Devi, P. Khaund, S.R. .Joshi, "Thermostable α-amylase from natural variants of Bacillus spp. prevalent in eastern Himalayan range", Afr J Microbiol Res, 2010, 4, 2534-42.

[54] T. Panda, P.K. Pani, N. Mishra and R.B.Mohanty, "A Comparative Account of the Diversity and Distribution of Fungi in Tropical Forest Soils and Sand Dunes of Orissa", India. J Biodiversity, 2010, 1(1), 27-41.

[55] C. Manoharchary, K.C. Mohan, I.K. Kunwar, S.V.Reddy, "Phosphate solubilizing fungi associated with Casuarina equisetifolia", J Mycol Pl Pathol, 2008, 38(3), 507-513.

[56] N. Behera, D.P. Pati, S.Basu, "Ecological study of soil micro fungi in a tropical forest soil of Orissa", India.Trop Ecol, 1991, 32(1), 136-143.

[57] S. Bhagat, S. Pan, "Cultural and phenotypic characterization of Trichoderma sp. From Andaman and Nicobar Islands". J Mycol Pl Pathol, 2010, 40(1), 145-157.

[58] S.D. Mamtaz, R.R. Mishra, "Decomposition of Maize(Zea mays) crop residues". J Ind Bot Soc 70, 1991, 135-138.

[59] K. Uma Devi, C. Manoharachary, "Studies in litter fungi from Hyderabad (Andhra Pradesh) India", Proc Nat Acad Sci India, 1987a , 57(B), 549-551.

[60] K. Uma Devi, C.Manoharachary, "Microbial decomposition of scrub jungle forest leaf litter", J Ind Bot Soc, 1991, 70, 157-162.

[61] T. Panda, S.D. Rout, N. Mishra, "Decomposition of Casuarina leaf litter in coastal sand dunes of rissa", Int J Gen Mol Biol, 2009, 1(8), 137-143.