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DIVERSITY, CONSERVATION, AND UTILIZATION OF FUNGI FROM INDIA

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Fungi form an important component of biotic communities to be dealt with scientific accuracy and utmost care. India is one of the important geographic areas, where in which tropical and temperate climatic conditions prevail with 23% of forest. In view of this it is the cradle for fungal diversity as it harbours 5% of global fungal population. Approximately, 29000 fungal species are reported from India representing diversified fungal genera and species under Chromista and Eumycota . Out of 2.1-3.8 million of fungal estimate, only a fraction of fungal wealth has been identified and more than 95% remains to be explored. In order to identify and classify the fungi, the morphotaxonomic knowledge along with molecular techniques is essential. The conservation of fungi has become essential as many of the fungi have become biotechnologically important and some of the fungi have become extinct and many are facing threats. Fungi have become important in day to day human life besides their role in agriculture, industries, pharmaceuticals, environment, plant protection, health, food industry, and fermentation.

Key Words: Biotechnology, Fungi, Diversity, Conservation, Genera, Species.

The estimate of fungi being 2.1 to 3.8 million, (Hawksworth and Lucking 2017). However, the global biodiversity of fungi has been extensively studied and their species has been estimated. The development of molecular phylogeny has revealed an unexpected fungal diversity and utilization of culture independent approaches including high throughput amplicon sequencing which has dramatically increased the number of fungal operational taxonomic units. Many of the cryptic species were also identified based on molecular phylogeny. Recently, developed and generated data from culture dependent and independent survey, the fungal estimate on the earth has gone to 13.2 million compared to 2.2-3.8 million species that has been estimated earlier (Bing Wu *et al.* 2019)

Out of this only 1,20,000-1,40,000 fungal species have been identified based on critical study. Around 29000 fungal species are reported from India. The true fungi belong to kingdom Eumycota and Chromista with around 5000 genera. The eighth edition of Dictionary of the Fungi has recognized eleven Phyla. The Deuteromycotina is not accepted as a formal taxonomic category (Hawksworth 1997), due to their perfect states being represented either in Ascomycotina and Basidiomycotina,respectively. Manoharachary *et al.* (2005, 2009) have presented exhaustive reviews on fungal diversity. Fungi are cosmopolitian and occur in fresh waters, oceans, estuaries, litter, air, soil, wood, dung, as pathogens on plants and animals, on hair, in seed, in soil, rhizosphere, leaf surface, fruit surface, nectaries, pollen grains, and several other habitats.

The lower fungi which mostly occur in water are represented by Oomycota while in Oceans and estuaries along with members of Ascomycota and Conidial fungi may occur commonly. Mucoraceous fungi reproduce asexually by aplanospores and are dispersed either violently or passively by wind, rain, or animals. Mostly they are found in soil and dung and few are parasitic. Trichomycetous fungi live in the guts or arthropods and only two fungi are reported from India. The members of Zygomycotina have been reported from India in the form of more than 1000 species. Members of this group are important in industry and in understanding physiology, biochemistry, genetics and phototropisms of fungi. *Saksenia vasiformis*, an indigenous fungus has found special attention in medial mycology. Ascomyceteous fungi posses a wide variety of fungal species that differ in their

morphology, development, organization, and nature of ascospores besides being differing in ultra structure, reserved food materials and substrate relationship. Ascomycotina is represented by more than 2700 genera and 30,000 species all over the world. Yeasts are the common fungi in this group and are found in moist and sugar rich substrates and are also prevalent in soil and fresh water/marine water bodies

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Yeasts are important in industrial fermentation like brewing and baking. Members of *Chaetomium, Xylaria, Neurospora, Sordaria, Penicillium, Aspergillus, Ascobolous* and others are common fungi occurring in soil, plant and animal remains. Fungi like *Lulwortha* and others are common in estuaries. All such fungi are important in degradation of cellulose, lignin, and other plant polymers. Truffles form Ectomycorrhiza on forest trees as symbionts and the fruit bodies of fungi like Tuber are highly delicious. Species of *Arthroderma* and *Nannazia* parasitize humans and cause skin diseases. Species of *Ceratocystis, Claviceps, Erysiphae, Phyllactinia, Sphaerotheca, Taphrina* and others parasitize plants and cause huge losses. (Manoharachary *et al.* 1994).

Based on the available literature (Manocharachary *et al. 2009),* it is estimated that Ascomyceteous fungi approximately account for 40% of the total fungi and this kind of proportion is true for Indian record also. Basidiomycotina comprises fleshy fungi which includes toadstools, bracket fungi, airy clubs, puff balls, stinkhorns, earth stars, birds nest fungi and jelly fungi. These fungi live as saprophytes, however some fungi like *Polyporus* are known as wood decay fungi and some fungi like *Ganoderma* are medicinally important. Some fungi of this group form mycorrhiza with trees helping in the transporting several nutrients to the plants. *Armillaria mellea*, the honey fungus destroys a wide range of woody plants. Some fleshy fungi like Amanita are notorious in being poisonous, however, most of them are edible and some are medicinal. Mushrooms occur in various shapes, sizes, and color and have attracted the attention of scientists and are thus prized as paintings, sculptures besides being edible. In nature, mushrooms grow wild in almost all types of soils, on organic matter, on wooden stumps, and others. They appear in all seasons, however, monsoon favour rapid growth when organic matter is available in plenty. More than 2500 species of edible mushrooms are reported in the literature from different parts of the world. Singer (1985) had reported 1320 species belonging to 129 genera of Agaricales.

Rusts are the largest group of plant parasitic fungi that cause severe diseases on crops like wheat, corn, cereals, legumes, and grasses. They are obligate in nature and produce more than one spore forms in their lifecycle. More than 170 genera of rusts have been recorded and out of which 46 are monotypic comprising 7000 species world over. Geographically, rusts are distributed all over the world except in Antartcica. The greatest number of species occurs in temperate and near temperate regions. The most widely distributed species of economic significance is *Puccinia graminis*. This is an important pathogen which is found around the globe and other being *Puccinia polyspora*. Most rust fungi occur on dicots and also on monocots.

Besides the above, several smuts in nature also cause considerable economic loss to crops. Smut fungi are plant parasites and no smut has been reported on plants belonging to Orchids. Smuts are represented by 1500 species distributed in 77 genera parasitizing around 4100 host plants. About 800 species are smut fungi are pathogenic to grasses. Deuteromycetes whose perfect stages are in Ascomyctonia and Basidomycotina are represented by 1700 genera covering around 20000 species. They occur in air, litter, soil, and other habitats and contribute extensively towards biodegradation, recycling of organic matter, industry, medicine, agriculture, food and some fungi being parasitic

on plants and humans. About 8000 Deuteromycetes are reported from India. Besides this some fungi numbering around 40 to 60 are associated as endophytes in plant tissues and form important group in medical industry and other activities. Mycorrhizal fungi can contribute up to 25 to 30% of root biomass of forests, crop plants and they form structural component of the forest ecosystem besides being helpful as symbionts in the management strategies of plants at community level, in agriculture, horticulture, floriculture and other such activities as plant nutrient mobilizers and biofertilizers. Mycorrhizal fungi also help in soil fertility, soil binding capacity and also in the improvement of plant growth and uptake of phosphorus, zinc, iron, other elements, production of plant growth promoting substances, in enhancing plant resistance to diseases and pests, bearing water stress, synergistic interaction with beneficial soil microbes. (Manoharachary 2004). An interesting ecological group of fungi captures and grows parasitically on nematodes, their cysts and eggs are known as nematophagous fungi are represented by 150 species. These are represented by *Catenaria, Dactylella, Harposporium, Monacrosporium, Nematophtora, Rhopalomycis*, and *Stylopage*. These fungi are good trapping agents and help in the biological control of nematodes which cause plant diseases.

Keratinaceous fungi colonize human hair, skin, nails, feathers, hooves, and horns. Several of these fungi cause human and animal diseases. Soil is the main reservoir of many fungi belonging to lower and higher fungi. Rhizosphere is an important ecological niche harbouring a number of fungi including useful microbes.

Though 1/3 of global fungal diversity occurs in India, still it requires extensive surveys of hidden wealth of fungi and sufficient number of mycologists to identify them. It is pertinent to mention here that unlike good olden days the number of mycologists have dwindled very fast and there are less than 15 mycologists available in India to identify the fungi.

Fig - 1

Fungal Germplasm Maintenance

- 1. Lypholization/Freeze drying
- 2. Mineral Oil Storage
- 3. Water Storage
- 4. Soil Storage
- 5. Silica Gel Storage
- 6. Deposition of cultures at National & International Culture Collection Centers
- 7. Preservation of fungal Herbarium and their deposition

Conservation of fungi

Threats of fungi throughout the globe are of great concern since they are not only beautiful but also play a significant role in human welfare through their bioproducts. Moore *et al* (2001) have suggested that fungal conservation includes (Fig 1)

1. Conservation of habitats
2. In-situ conservation of non-mycological reserves and ecological niches.
3.Ex-situ conservation particularly for saprophytic fungi growing in culture. Fungi are very seldom legally protected, however, in Slovakia, 52 fungal species have a special legal status, enabling managers to prevent damage to their habitat. Fungi are known to colonize diversified habitats besides multiplying and surviving on them. Fungi are ubiquitus and cosmopolitan in distribution covering tropics to South and North poles and mountain tops to the deep oceans. Many of the described fungal species are known only as herbarium material and only around 5 to 7% of species are isolated in pure cultures. Geographic location, climatic conditions, micro-habitat, substrate type, distribution of fauna and flora are important factors contributing to fungal distribution around the world. Fungal flora of United Kingdom, South Korea, Cuba and other countries have been well exploited for fungal species and for their biotechnology. However, in India still lacunae exists in this sphere of activity.

Unlike prokaryotes, automated isolated techniques for fungi are not yet possible because of their extreme diversity in morphology, survival and reproduction. Studies on fungal distribution and their mapping are challenging tasks due to lack of sufficient data, knowledge and lack of mycologists around the world. Fungal taxonomists have become endangered species and taxonomy has become a taxing subject to the students who have no keen interest.

Diversity

Diversity means number of fungal species at a particular site/ecological niche or substrate, the variability among living organisms from all sources including inter-alia, terrestrial, marine and other aquatic ecosystems and ecological complexes of which they are a part. It is a basic resource that sustains the human race and also includes diversity within species, between species and ecosystem, gene pool, biochemical variation, metabolites, and also between genera. Biodiversity is the most significant global and national asset and is the enduring resource for supporting the sustained existence of human race. The term biodiversity embraces genetic diversity, species diversity, ecosystem diversity and agrodiversity. 5 to 50 millions of species of living organisms exist on the globe and of which 2.1 to 3.8 millions are fungi. The vast numbers of fungi that are identified are only 1,40,000(Hawksworth 1997, Manoharachary *et al.* 2009). In order to establish the identity of remaining fungal species of 2.1 to 3.8 millions, it may take more than 4000 years. India is located in South Asia between latitudes 6^0 and 30^0 N and longitudes 69^0 and 97^0 E. The total geographic area with a land mass of 3100 million hectares with Himalayas in the North, the Bay of Bengal in the East, the Arabian Sea in the West, and Indian Sea in the South as boundaries. The richness of diversity is due to richness of forest vegetation, climatic variations, altitudinal conditions and soil types besides the seasonal variations.

The number of fungi recorded in India is around 29000 species, recorded after insects (Manoharachary *et al.* 2005). The true fungi belong to Kingdom Eukaryota which has 4 phyla, 16 classes, 110 orders, 411 families and 5100 genera (Kirk *et al.* 2001). The four phyla accepted in the ninth edition of Ainsworth and Bisby's Dictionary of the Fungi (Kirk *et al.* 2001) are Ascomycota, Basidiomycota, Chytridiomycota, and Zygomycota. However, Oomycota has been included under Chromista. The anamorphic fungi are represented as conidial states whose perfect states fall under Ascomycota and Basidiomycota. Fungi are true nucleated organisms are without palastids with absorbitive nutrition, never phagotrophic without an amoeboid state, cell walls mostly containing chitin and glucans, mitochondria with flattened cristae and peroxisomes nearly always present. Golgi bodies or cisternae are present and thallus is either unicellular or filamentos and consisting of multicellular coenocytic haploid hyphae, mostly non flagellate, if flagella present always lacking mastigonemes, reproducing sexually or asexually, the diploid stage generally short-lived and saprobic, mutualistic or parasitic. One third of global fungal diversity exists in India.

Table- 1: the number of fungal genera reported from the world and India.

Kingdom/Phyla	World		India	
	Genera	Species	Genera	Species
Chromista	111	879	78	401
Ascomycota	3,409	32,739	817	12,010
Basidiomycota	1,353	29,914	731	7,563
Chytridiomycota	123	914	57	167
Zygomycota	181	1,090	101	398
Anamorphic fungi	2,828	16,200	435	6,800
Protozoa	97	892	72	661
Total	8,102	82,628	2,291	28,000

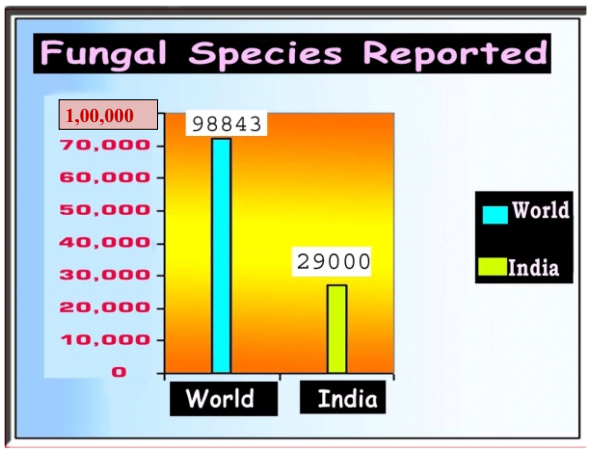

Figure 2

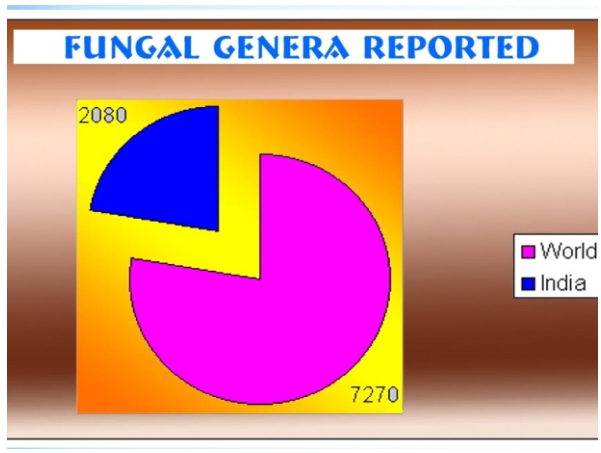

Figure 3

The number of fungal genera and species reported in the world and from India are shown in Table 1.(Fig 2 & Fig 3)

The Taxonomy and identification of fungi are based on morphology, karyology, biochemistry, histochemistry, electron microscopy, development, immunology, serology, reproduction and other criteria. Adaptation of molecular techniques such as use of DNA and RNA probes and other such kind of tools are important for further identification in case of complexity. Ecological factors are also helpful in the identification of specialized niches and helps in searching for new fungi. It also includes extremes of salinity, atmospheric pressure, temperature, pH and pollution. The presence of fossil fungi indicates their evolutionary significance besides helping in solving their Phylogenetic complexities.

Holomorph

Taxonomy is the mother of all sciences. Identification should be scientifically accurate and should be devoid of misdeterminations of fungi. Anamorph is nothing but an asexual stage and the Teleomorph denotes perfect stage of the fungus. According to ICBN Article 59, the fungus in question and new one or known one must have been described as whole fungus (Holomorph), which includes the description of asexual stage and its perfect stage, respectively. Taxonomic treatise and classifications have been developed for teleomorphic fungi. Consequently researchers have developed competence to deal with anamorph and teleomorph of the given taxon need to be studied together. In the absence of teleomorph its establishment is based on the anamorph of a given fungus (Manoharachary and Kunwar 2001).

The homothallic fungi have asexual and sexual phases while hetrothallic fungi fail to produce teleomorph due to lack of innate capacity to produce the perfect stage or due to non-availability of required nutrients/ecological factors.

Biotechnology of fungi

Saprophytic, parasitic and endophytic fungi living in the forest ecosystem and on several habitats contribute significantly to the species diversity. It has been shown recently that tropical fungi colonizing diversified habitats posses micro and macro fungi in abundance (Manoharachary *et al.* 2005). Realizing this Rossman (1994) and Hawksworth (1997) have advocated complete and urgent recovery, inventory and investigation of fungi by mycologists from forests, extreme habitats and other localities of tropical belt world over, since these areas of the world are presently under stress. Manoharachary (2001) has elaborated the various aspects of fungal biotechnology. The conversion of carbohydrates of cellular material and other useful products has become important and interest in cell mass production. Yeast plays significant role in the formation of biomass by

growing on carbohydrates, 20 amino acids were found to be components of protein in yeast and on average yeast contains 10.8% of nucleic acids, lipid content 8% and lipids also include sterols. The filamentous fungi contain many species capable of hydrocarbon oxidation. The fungi have been studied extensively with hydrocarbons as feed stock. *Cladosporium resinae*, is an important fungus in the field of petroleum product contamination.

Fungi have also been used to produce different types of metabolites from alkane media. *Mucor Aspergillus, Fusarium, Paecilomyces* and others are reported to contain hydrocarbon assimilating species. *Hansenula capsulate* and others are selected as methylotrophic. More than half of the total production of plant residues remain unused, mainly straw and leaves and often from domestic waste and agriculture waste, forest and industrial production processes. These materials are burnt or disposed off on land for soil amelioration after being composted.

By suitable treatment they can be converted into useful substrates for the cultivation of edible mushrooms. The domestic and agricultural wastes can be reintegrated after decomposition by way of natural process into the ecosystem which results in the mobilization of elements and other minerals. Edible fungi represent a well characterized biomass which is generally accepted by the consumer. Mushrooms like *Agaricus bisporus, Lentinula edodes, Volvariella volvacea*, and *Pleurotus spp* species have also been produced commercially as edible fungi and is of multidollar market in Europe and other countries.

Mushrooms are cultivated worldwide under varied climatic conditions. In the last two decades Taiwan has become third largest producer of mushrooms in the world followed by China and France. India needs to take lead in this direction so as to support food security and nutritional security. Mushrooms are considered more nutritious than many other vegetables and fruits. The protein content of mushroom is nearly equal to that of milk and is more than vegetables and fruits. The edible mushrooms are known to contain all the essential amino acids, less carbohydrates, more fibre, vitamins, unsaturated fatty acids with mineral content exceeding that of fish and meat and twice that of most vegetables. Further mushrooms are known to increase immunity and also some of them are found anticancerous. Fruiting bodies of mushrooms in general, on dry weight basis contain about 32% of protein, 2% of fat, and rest in the form of ash containing minerals. More than 2000 edible mushrooms are reported in the world and around 150 species belonging to 30 genera are regarded as prime edible mushrooms. Over 60 species are cultivated commercially and have reached an industrial scale in many countries. However, India is lacking in the commercial production and marketing of mushrooms. Mushrooms are in great demand in food industry because of flavours associated with mushrooms besides being having medicinal and tonic properties. They are in much use in China, Japan and other countries. A number of medicinal mushrooms posses alkaloids that are of pharmaceutical importance. Mushrooms like *Ganoderma, Polyprous, Lentinus*, and *Pleurotus* have been used as ornamentals also. Species of *Ganoderma* and others have been employed in cosmetic industry and also in antitumor drug production. *Morchella* is the most priced mushroom, but suitable technology has not been developed to grow it commercially. Besides these spent mushroom compos consisting of degraded cellulose, hemicelluloses, and lignin serve as an effective fertilizer and conditioner. It is also used as a source of saccharifying enzymes and production of single cell protein. Spent substrate is a rich source of biogas production. Exploitation of many mushrooms is essential for mankind. Molecular tools, protoplast fusion and other methods will be used for identification and development of new strains of edible mushrooms.

Soil fungi influences plant growth and health of the plant. Mycorrhiza, the plant root – fungus symbiotic associations plays a key role in the effective uptake of phosphorus by mycorrihizal roots besides enhancing plant growth (Manoharachary 2004). Entomogenous fungi are found in all groups of fungi and contain many useful species. *Verticillium lecanii* is parasitic on aphids and white flies. *Hirsutilla thompsonii* is the pathogen of eriophyid mites, *Beauvaria bassiana* and *Metarrhizium anisopiliae* have received utmost consideration as they control coffee berry borer and mosquitoes, respectively and are commercialized.

Role of fungi is well established in fermentation technology and using this process many metabolites are commercially exploited for their antibiotic properties.

Cephalosporin, penicillin and griseofulvin are the antibiotics derived from fungi. Yeast forms an important fungus in fermentation industry and alcohol production which is a major income yielding industry. Many fungi are involved in the production of food materials namely bread, fermented milk drinks, yoghurt, cheese, and various yeast preparations. There are many foods used in Asia and Oriental regions, for example Tofu, Tempeh, and Miso whose production is dependent on fungi.

Many different industrial organic acids are produced by many fungi. These include citric acid by *Aspergillus, Mucor* and *Pencillium*; Fumaric acid and Lactic acid by *Rhizopus* , Gluconic, Itaconic acids by *Aspergillus*. Rennin is produced by *Rhizomucor*, Riboflavin by *Eremothecium* and various other fungi are employed in steroid conversions. Production of mycelial paper, packing materials involves the addition of mycelium of many fungi along with wood pulp. Today three fungi namely *Neurospora, Emericella*, and Yeast are employed as model system in genetics. Transformation systems are available for all three species and it is easy to isolate their DNA. Fungi are good candidates for employing them in degradation. Fungi like *Aspergillius* are regarded as safe by the food and drug administration. Many fungi also secrete several hydrolytic enzymes that digest several substrates. Around 20 standard amino acids are produced commercially using fungi. Several vitamins including vitamin B12, biotin, folic acid, riboflavin and others are the products of fungi. *Blakeslea trispora* is extremely rich in beta-carotene. Industrial enzymes are used in food processing. The solubilisation of insoluble phosphorus and other minerals by the fungi is the vital process in soil which helps in the growth of the plants. The most efficient "P" solublizing fungi include species of *Aspergillus* and *Penicillium*. Fungal toxins play an important role in the health of humans and animals. Aflatoxins elaborated by *Aspergillus flavus* is commonly found associated with animal feed and some food stuffs. These toxins are highly health hazardous. The patulin, the mycotoxin has been found clinically to be carcinogenic.

Around 20 fungi have been identified to cause mycotoxicoses in animals. Ergot fungus is known to elaborate at least seven alkaloids including LSD. Ergot itself has got a respectable place pharmacopia. Some fungi are known to cause diseases in tropics among humans and animals. Coccidiodimycosis, blastomycosis, histoplasmosis, aspergillosis, and candidiasis have been well recognized as they affect the humans and cause loss of immunity.

Cryptococcosis has got worldwide distribution and is found to be prevalent in India and shaken recently the whole world. It has been found mostly in the patients suffering from AIDS and Diabetics. Fungal biomass such as bisol is used as cattle feed. The same fungus is also used as biosorbant which enables the extraction of uranium and radium from atomic industrial waste waters. Cyclosporin-A, the most often used powerful immunosuppressant has created revolution in organ transplantation. Several fungal genera are used as biocontrol agents to control pathogenic fungal diseases and also

other diseases. The most powerful biocontrol agent of mostly soil-borne, root-borne and some foliar diseases is *Trichoderma*. Several bio-herbicides are extracted from the fungal species. Plant diseases such as blights, wilts, rusts, smuts, cankers, leaf spots, blasts and others which occur on number of crop plants and forest plants have become important as they cause huge losses and thus dwindle contry's economy. Biodeterioration is a biological process that contributes deterioration and destruction of materials resulting in economic loss. Biodegradation is the biological breakdown of undesirable materials to harmless products. A vast range of materials used by man from food, feed, fibre, wood, agriculture waste and other materials including sewage, coalmine, waste from paper industries, sugar and oil refineries, effluents, pesticides, detergents and others is caused by fungi and thus fungi are second to none in their armory of enzymes and abilities to degrade all kinds of substrates into simpler compounds. However, the IT wastage and plastics need greater consideration as there are very few microbes or no organisms that can degrade these materials. Application of mycoherbicides to control unwanted plants such as weeds has been an age old practice through classical methods in which plant pathogens are released to control weeds by natural spread.

For example, control of skeleton weed by *Puccina condrillina* in Australia and *Cercospora rodamanii* for the control of water hyacinth and others clearly indicate the biopotential of fungal pathogens. Thermophilic fungi have been playing an important role as they have the ability to degrade organic matter acting as biodeteriorators elobarating many enzymes, amino acids, antibiotics, phenolic substances, polysaccharids and sterols during the degradation process and these fungi occur at high temperatures. They are also known to be involved in the production of high protein containing feeds. *Chaetomium spp* are known to produce tons of cellulase enzymes which are used in textile industry and in pharmacopia.

Fungi are also known to produce around 120 dyes that are used in textile and others. The fungus *Coprinus* has been considered as an Indian ink pod. Fungi are also used in converting polluted soils into fertile soils by degrading the pollutants. Waste recycling is an important process and many fungi are involved in this process and this helps in cycling of elements in nature. Plant disease epidemics have become important as they cause huge losses. Inorder to make agriculture sustainable, it is desirable that we should resort to IDM which will help to control the diseases besides growing disease resistant crop varieties. Many fungi are involved in the bio deterioration of paintings and sculptures including that of Ajanta Caves. Nearly 25 fungal species have been reported as responsible for the damage of paintings in Ajanta Caves. Therefore, study of degradation of heritage buildings and archaeological materials is important. Thus fungi are known to play significant role in the human welfare. No fungi, no life.

Substrate relationship in fungi

Soil Fungi

Soil is a natural medium in which plants live, multiply and die and they provide a perennial source of organic matter which could be recycled for plant nutrition.

A variety of fungi occur in soil which range from lower (Chytrids) to higher (Agarics) fungi: saprophytes to pathogens and predaceous to mycorrhizal fungi. Fungi occur in soil as hyphae, rhizomorphs, rhizomorphs, chlamydospores, sclerotia, asexual spores such as zoospores and conidia, and sexual ones such as zygospores, ascospores and basidiospores and entire fructifications belonging to Tuberales and Gasteromycetes. Representatives of all fungal groups occur in the soil. Most frequently isolated members of the Fungi belong to the genera *Aspergillus, Penicillium*, and *Trichoderma*.

The zone of soil surrounding plant roots which is influenced biologically and chemically by

the roots is designated as "Rhizosphere". The microorganisms are found to bee more abundant in rhizosphere soil when compared with non-rhizophere soil. A variety of organic substances (carbohydrates, aminoacids, vitamins, organic acids, enzymes etc.) are excreted by roots in the form of exudates resulting in greater microbiological activity. The root surface, referred to as "Rhizoplane" also supports growth of fungi which are mostly dark mycelia forms.

Phylloplane and Litter Fungi

A great diversity of fungi occur in terrestrial environments on a variety of substrates such as green leaves, bark and decomposing plant litter on soil surface. Spores belonging to all groups of fungi are encountered in the atmosphere. Green mature leaves form suitable substrates for many fungi (Phylloplane fungi) and leaves act as spore traps. As any leaf unfolds it is a relatively clean sheet which immediately provides landing sites for airborne particles including fungal spores. Spore trapping by leaves is a natural phenomenon of nature. The most ubiquitous and by far the most numerous phylloplane fungi are members of Sporobolomycetaceae, the shadow yeasts. The conidia of *Aureobasidium pullulans* and several species of *Cladosporium* are common on leaf surfaces. A great variety of substances leak out of leaves and these are utilized by phylloplane fungi.

While some of the phylloplane fungi grow and multiply on the surfaces of green leaves (residential) many remain as dormant spores until the onset of senescence. Apart from phylloplane fungi, many microfungi are found in living tissues of plants without producing any apparent symptoms or negative effects. These are known as "Endophytes". Tropical plants are supposed to contain a high diversity of endophytes. Some of the common endophytes belong to the genera *Phyllosticta* and *Colletotrichum*.

Eventually when the leaf senesces and falls on the surface of soil some of the phylloplane fungi such as *Aureobasidium, Alternaria, Curvularia, Cladosporium* colonise the leaf litter. As decomposition progresses, typical litter fungi such as *Beltrania, Beltraniella, Stachybotrys, Memnoniella, Torula, Tetraploa* colonise the litter and as decomposition progresses, some of these disappear and new ones appear. In the final stages of decomposition the fungal flora becomes dominated by typical soil inhabiting fungi. Plant litter is composed of six main categories of chemical constituents i.e., cellulose, hemicelluloses, lignin, water soluble sugars, ether and alcohol soluble constituents and proteins. The breakdown of these constituents is affected in a sequence of specific reactions with the enzyme system of specific organisms. Thus fungi which are capable of utililzing simple sugars appear (sugar fungi) initially followed by cellulose degrading fungi (cellulolytic fungi) and finally by lignin decomposers (lignolytic fungi)

Seed-Borne Fungi

Seeds as they develop in the field and particularly after mature, but before being harvested become colonized by field fungi. These include *Cladosporium, Aureobasidium, Epicoccum* and *Alternaria sp*. and also other fungi, such as Fusarium and *Helminthosporium sp*., which are seed-borne pathogens. The longer the grains are exposed to the weather, the more profusely they develop. A distinction can be made between fungi present as spore contaminants on the surface of the seeds and fungi whose spores have germinated and penetrated into the pericarp.

By comparing the fungi which grow on culture media inoculated with surface sterilized grain with those inoculated with normal grain. After harvest cereal grains are usually commercially stored at below 70% humidity and at this level the field fungi can no longer grow. Spores of the storage fungi will be present on the grains as casual inhabitants.

Members of the *Aspergillus glaucus* and *A. restrictus* groups are abundant as they do not invade the grain to any extent before harvest. As a result of all their activities, the percentage germination of the grains falls. It becomes discoloured and biochemical changes occur in the endosperm so that it is not fit for consumptions. Toxins may be produced in sufficient quantities to constitute a health hazard, if consumed. Finally it leads to complete spoilage.

Aquatic Fungi

The aquatic environments are very rich in a wide variety of different types of organic matter including decaying tree leaves and wood. A great diversity of fungi are found on decomposing leaves in fresh water streams, drift and interidal wood in oceans and mangrove substrates in estuaries. In fresh water streams, two major groups of fungi occur, the zoosporic "water molds" mostly belonging to saprolegniales and the conglomerate of conidial fungi called "water-borne conidial fungi" (ingoldian fungi). Water molds occur on dead animal and plant remains, particularly on dead insects, seeds and fruits. Ingoldian fungi are found in well aerated lakes growing on leaves and twigs and forming conidia which are released into water and are readily trapped in foam. The conidia are much elongated or curved (sigmoid) or often branched (tri or tetra radiate eg. *Tetrachaetum, Lemonniera, Tricladium*). The aero-aquatic fungi occur on deciduous tree leaves which have fallen into stagnant water and are capable of vegetative growth on submerged leaves or woody substrates. They sporulate only when the substrate is exposed to air (eg. *Helicodendron, Helicoon*)

Coprophilous Fungi

Dung is a specialised and highly complex substrate and favourable for fungal growth. It contains appreciable quantities of readily available carbohydrates and also high nitrogen content, rich in water soluble vitamins, growth factors and mineral ions. Representatives of most of the major groups of fungi except the Mastigomycotina grow on dung (Coprophilous fungi).

The coprophilous fungi include obligate dung fungi such as *Pilobolous Ascobolus, Lasiobolus, Saccobolus* and also facultative fungi commonly found on other substrates also. The coprophilous fungi demonstrate a successional pattern in their occurrence. Coprogen has been identified as growth promoter. Dung on decomposition results in the formation of soil fertilizing factor.

Entomogenous Fungi

A large number of fungi are parasitic on insetcts and other small arthropods. Insect parasitic fungi include some chytrids, almost all members of Entomophthorales, numerous Ascomycetes and Fungi Imperfecti, and some infections cause discomfort (such as Laboulbeniales) to their hosts, and others are lethal. The genera *Entomophthora, Massospora, Cordyceps* and *Beauveria* cause infections on insects.

Predaceous Fungi

Several fungi obtain their livelihood by capturing animals (amoebae and nematodes) in a specialized trap and then feed on them after their death. They are common in soil, dung and rotting wood. The order Zoopagales include exclusively the predaceous fungi. Although predaceous fungi occur in diverse taxonomic groups, the Hyphomytcetes present the majority of predaceous fungi (*Dactylaria, Monacrosporium*).

Keratinophillic Fungi

These are highly specialized group of fungi which colonize substrates rich in keratin such as human hair, skin, nail, feathers, hooves and horns. They are abundant in soils of the animals houses and farm soils visited frequently by cattle. Species belonging to genera *Arthorderma, Chrysosporium, Epidermophyton, Microsporium* and *Trichophyton* belong to this category.

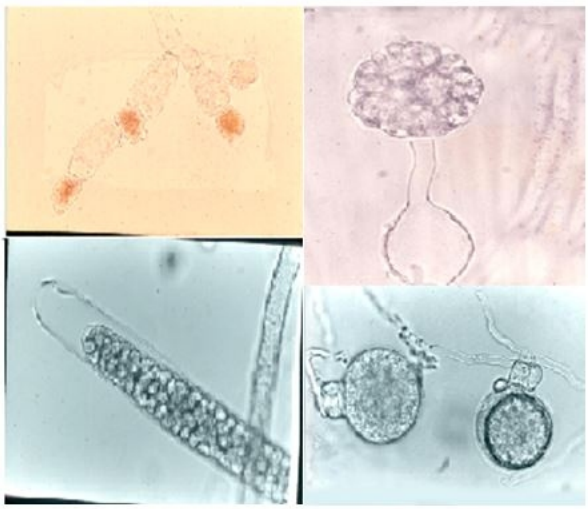

Figure-4: (10 x 45x) *Allomyces arbuscula, Pythium* sp, *Saprolegnia* sp, Oospore of Phytophthora (450X)

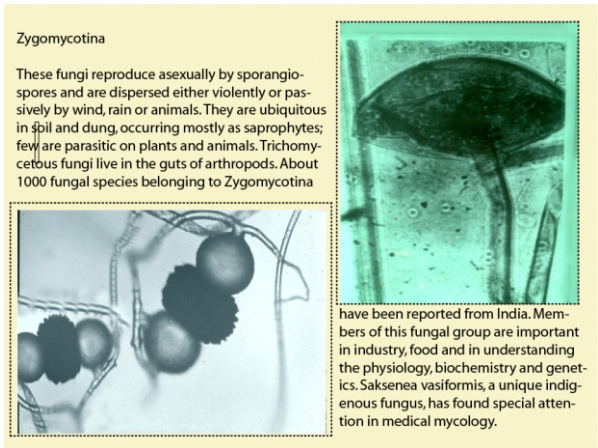

Figure-6: (10 x 100x) *Rhizopus sexualis*, sporangium with columella, zygospore (1000X)

Figure-8: *Polyporus, Dictyophora, Odumansia*

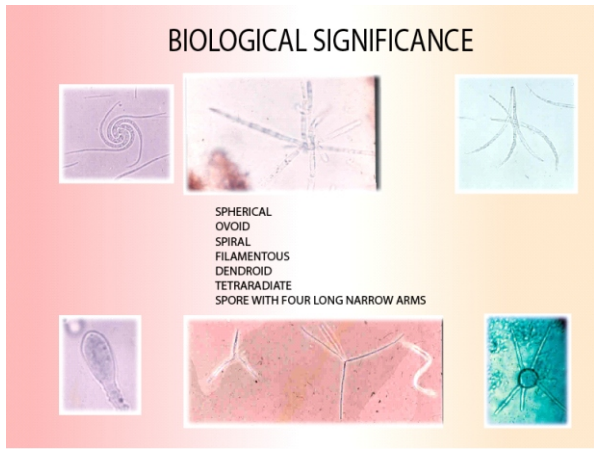

Figure-5: Conidial Fungi of water ecosystem (10 x 100x) Water-borne conidial fungi: *Geofyrella* sp, *Dendrospora erecta, Lunulospora curvula, Triscelophorus monosporus,* Sigmoidspore, *Anguillospora, Dactylella, Actinospora megalospora* (450X)

Figure-7:(10 x 45x) *Chaetomium* sp, *Ophiostoma* sp, *Neurospora crassa, Peziza* (400X)

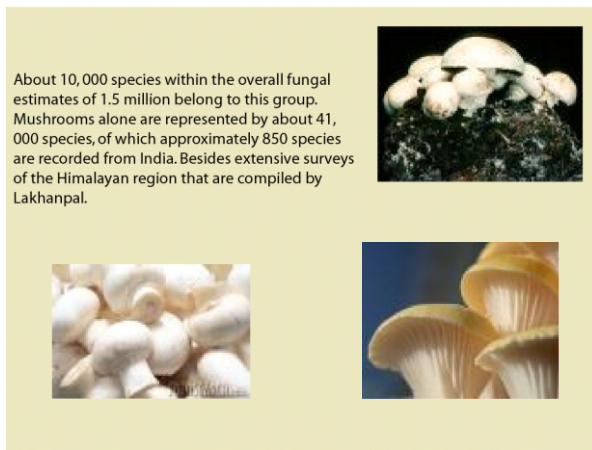

Figure-9: *Agaricus biosporus*

Figure-10: *Coprinus cinereus, Tremetes*

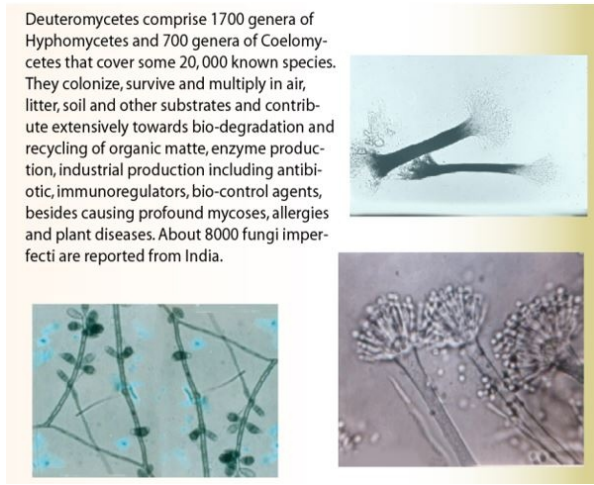

Figure-11: *Graphium* sp, *Curvularia* sp, *Aspergillus* sp (450X)

Fungi in extreme environments

Temperature is one of the cardinal factors which determines the distribution of many fungi. Depending on the range of temperature at which they grow, they are classified as psychrophiles, mesophiles and thermophiles. Psychrophiles and thermophiles constitute the group of extremophiles.

Thermophilous Fungi

A thermophilous organism is defined as one that grows as temperatures above those considered to be the maximum limits for most forms of life. The most widely used definition of the thermophilous fungus is one whose minimum for growth is at 20^0 C or above and maximum for growth at 50^0 C or above. Such fungi have optima around 40-50^0 C. There are number of fungi which grow well in temperatures below 20^0 C and which may grow in temperatures of up to 50^0 C these are regarded as thermotolerant mesophiles rather than as true thermophiles. Some 30 species of thermophilous fungi have so far been described and among them Mucor pusillus, *Thermoascus aurantiacus, Chaetomium thermophile, Thermomyces lanuginosus* and *Torula thermophila* are most common. A similar number of fungi are thermotolerant (*Aspergillus fumigatus*). The thermophilic fungi occur in self-heating garden and mushroom compost, hay, municipal waste, piles of wood chips, and coal spoil trips etc. They also occur in natural habitats where geothermal heat, sun heating, microbial metabolism or body heat of warm blooded animals provide the elevated temperature necessary for their growth.

Psychrophilous Fungi

Psychrophilous fungi are those which are cold loving and which grow best at low temperatures. Both polar regions support many psychrophiles. Although many fungi grow on freezed foodstuffs stored at -10 to 5^0 C and these are mostly considered as cold-tolerant mesophiles rather than true psychrophiles. They are present in survival state rather than in actively growing state.

Halophilic Fungi

Halophiles require Sodium chloride for their growth and most of these fungi occur in oceans and salt marshes. Extreme halophiles grow in concentrates of brine. Fungi are cosmopolitan in oceans and estuaries and occur as plant and animal parasites, live in lichen like association and also as saprophytes on organic material of plant, animal and anthropogenic origin. Marine habitats include the oceans and their shores and sediments; estuaries and salt marshes. Representatives of all fungal groups except Basidiomycetes have been found on

marine algae (algicolous fungi). Marine fungi occur on prop roots, pneumatophores, twigs, and drift wood in the intertidal region of mangrove strands (manglicolous fungi). So far about 600 species are known from marine environment, the largest group being Ascomycotina and majority of them belonging to two groups- Halosphaeriales and the Pleosporales. Species belonging to genera *Halosphaeria, Pleospora, Lulworthia, Didymosphaeria, Leptosphaeria* among Ascomycetes; *Halocyphina villosa* among Basidiomycetes; species of *Periconia, Dendryphella, Cirrenalia, Asteromyces* and *Zalerion* among Deuteromycetes are commonly found in decomposing substrates in oceans. The spores of many ascomycetes possess appendages which vary in shape (thorn, spine, tube, cap, veil or fiber-like). Several obligate ascomycetes (species of *Corollospora*) are found in intertidal beaches where their fruit bodies occur attached firmly to sand grains (arenicolous fungi). Spores of lignicolous marine fungi are found in sea foam.

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