Indian J. mycol. Res., 25(2), 101-111 (1987)
Printed in India

FIRST S. N. BANERJEE MEMORIAL LECTURE

FUNGI AS DECOMPOSERS IN THE ECOSYSTEM

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I am extermely grateful to the *Indian Mycological Society* for inviting me to deliver First Prof. S. N. Banerjee Memorial Lecture. I consider it a great honour and avail this occasion to pay my homage to the great mycologist and founder of this society.

Fungi are the most important biodegraders and bioconverters in ecosystems. Vegetable matter is their main target of attack. In grass land and crop ecosystems they decompose the grass and crop residues ; in forests the litter decomposition is mostly accomplished by fungi while in aquatic ecosystems the fungi disintegrate all such plant materials which get added to the system from time to time. Fungi also parastize a large number of plants and animals in different ecosystems. A broder look shows that the nature of fungi responsible for decomposition varies with the system, season, environment and the substrate. Vittal (1976) found that each plant harbours a characteristic mycoflora in its litter and depending on the frequency, the fungi could be catagorized as dominant, common, frequent, occasional and rare etc. The fungal decomposers maintain a regular order of succession on the same substrate till it is completely fragmented and mineralized. The primary colonizers on all the accumulated plant materials are the so called "sugar fungi" which can use only simple sugars and are unable to utilize complex materials like cellulose or lignin.

Being ubiquitous, the fungi occupy practically all such spaces in the eco-niche which have even a trace of organic matter and which are normally beyond the reach of other organisms. Decomposition of leaves, grasses and wood in the forests/grass lands or that of dead plant and animal tissues in various other systems is accomplished by a variety of fungi. Fungi as inhabitants of extreme environment can grow in a very wide range of pH and temperature. They are known to disintegrate proteins, starch, sugars, cellulose, hemicellulose, fats, pectins, lignin and chitin etc. They are more important than bacteria in causing disintegration of recalcitrant materials like lignin. The main carbon substrate

in forests is leaf litter and its counter part in agricultural fields is crop residue. Sugar fungi specially the members of Mucorales and some conidial Hyphomycetes are the first to colonize the plant matter. They consume the simple soluble sugar components including the pentoses, hexoses and disaccharides. The secondary colonizers are endowed with degradative enzymes and they are capable of metabolizing more complex carbohydrates like hemicellulose, cellulose and other oligo-and polysaccharides. Tertiary colonizers have the capacity to use highly complex polymers like lignins. Lignin is the most resistant fraction of the woody plants left after the metabolization of cellulose and hemicellulose.

Leaf as Spore Traps

Out of all the plant parts the leaves are the best "trappers" of fungal spores. Along with its unfolding the leaf functions as landing site for all sorts of particles, bacteria, yeast cells, spores and pollens. Leaf morphology, orientation and leachates play an important part in phylloplane dynamics. If we take leaf impressions, we shall find a very large variety of fungal spores. Many of these even germinate and die. In addition to saprotrophs, a variety of leaf parasites also invade the foliar tissues and elicit various types of chemicals on leaf surface making the phylloplane system more dynamic, lively and competitive. The number of phylloplane inhabitants increase with the age of the leaf. Their numbers are very high on the leaves affected by parasitic fungi like rusts and mildews. This is obviously because of change in permeability of more nutrients on the surface. Pollens add to the energy budget by providing various types of nutrients for the competitors. This pertially "exhausted" but chemically more enriched leaf, harbouring a variety of organisms ultimately becomes a part of terrestrial or aquatic ecosystem by falling in fragments or in full. Before joining the new system the leaf may have three types of organisms i.e. parasites, saprotrophs and parasites turned necrotrops Members of Sporobolomycetaceae constitute a major segment of phylloplane microflora. They produce air borne spores which are very small. Nutrients liberated from pollen help in pathogenicity of *Cochliobolus* on rye leaf. *Aureobasidium pullulans*, *Alternaria alternata*, *Nigrospora sphaerica* and *Curvularia lunata* add to the list of primary colonizers.

Role of Soil Fungi

Subsequent colonizers are usually the soil inhabitants, they grow from the soil via the continuum of organic debris. Species from several common genera of soil inhabiting fungi including *Mortierella*, *Penicillium* and *Trichoderma* have the ability to cause the break down of highly resistant materials including the exoskeletons of insets and chitinous remains of other microfungi. Activity of such fungi represents the final stage of minaralization of primary and secondary

organic materials in soil. After reaching the medium of soil/water, the organisms which join the system along with the leaf or other plant fragments have to compete with the "resident" species for food and survival. In the new environment, the casuals may either be eliminated in time and space or may grow and reproduce in the challenging conditions. Recovery of high percentage of leaf spot and twig fungi from the litter, crop residue and those of extra aquatic fungi from aquatic ecosystem reflects that a large number of casuals can grow, thrive and survive as decomposers in different ecosystems. They may have limited or extensive role in decomposition. Those which are unable to compete get consumed as food by other organisms. Liberation of antifungal substances, specially the phenolics by leaves may inhibit the growth of many leaf dwellers. The situation poses difficulty in correctly assessing the role of additional nutrients and that of nitrogen fixing bacteria on the phylloplane.

Decomposition of Grasses

Very few studies have been made on the micro-organisms mediating decomposition in tropical grass lands (Dwivedi, 1979). The genera of fungi that first appear on the species of grasses (*Cyhodon dactylon, Dicanthium annulatum, Setaria glauca, Saccharum munja*) are *Alternaria, Curvularia, Helminthosporium, Nigrospora, Phoma, Pyrenochaeta* and *Stemphylium.* The dominant genera that follow primary colonization are *Bispora, Annellophora, Tetraploa, Volutella, Cladosporium, Melanospora, Periconia, Humicola, Myrothecium* and *Stachybotrys.* They are followed by the third series of fungi, of which dominant genera are *Hormiscium, Lacellina, Papulospora, Spondylocladium, Fumago , Pithomyces, Leptothyrium* and *Hendersonia.* The rate of decomposition in the grass lands is usually slow during the dry season. Sharma and Dwivedi (1975) reported that the pattern of fungi on standing and cut down shoots of *Setaria glauca* was almost identical.

Decomposition of Leaf Litter

Leaf litter is the main carbon substrate for the saprophytes in the forest ecosystems In forests, there is a close interaction between the soil fungi, litter fungi, and wood fungi. Water is a potential factor in colonization of buried plant parts *Pythium* and *Mortierella* prefer wet conditions while *Mucor, Aspergillus* and *Penicillium* prefer dry conditions Species of *Trichoderma, Fusarium* and *Gliocladium* are not much affected by the moisture level.

Many fungi which cause degradation of oligo-and polysaccharides posses the capacity to simultaneously synthesize transient oligo-saccharides, the simpler sugars are kept in a "self locked" system and can be utilized by such fungi only which have the capacity to degrade their complex polymers (Bilgrami, 1964).

Decomposition of forest organic matter proceeds in stages and involves a variety of soil organisms. In acid forest soils the role of fungi is perhaps much more important than that of bacteria. Species of *Aspergillus*, *Chaetomium*, *Fusarium*, *Gliomastix*, *Memnoniella*, *Penicillium*, *Stachybotrys* and *Trichoderma* are specially important. Practically under all the forest covers the fungal biomass is 3-5 times greater than the bacterial biomas. The role of fungi is much more important in the tropical forests than in the temperate ones. Fungi cause very heavy and rapid loss of forest litter. When the litter is fresh, the biological activity is maximum. Subsequently the michrobial activity declines (Singh, 1969). Toky and Rama Krishnan (1984) reported that in forests of North East India, the weight loss of the leaf litter decreased with the age of the fallow but the rate of nutrient release showed a reverse trend which was largely dependent on the micro-environmental changes during secondary succession. Shukla *et al.* (1978) reported that fungal activity on leaf litter of sal (*Shorea robusta*) declined during summers. Their population was highest in early season.

Cellulose Degradation

Cellulose is the most prominent carbonaceous constituent of the higher plants. It is most abundant and well distributed organic compound in the forest, grass land crop ecosystems. Decomposition of this complex carbohydrate has a special significance in biological cycle of carbon because large part of vegetation which gets added to the soil every year is cellulosic in nature,

The cellulose utilizing population includes aerobic and anaerobic mesophilic bacteria, filamentous fungi, basidiomycetes, thermophic bacteria, actinomycetes and certain protozoa. Out of these, the fungi play the most significant role in cellulose decomposition in the humid soils. Cellulolytic basidiomycetes are specially important in the degradation of forest litter and wood. A diverse group of fungi utilizes cellulose for its carbon and energy requirement. The species of *Aspergillus*, *Chaetomium*, *Curvularia*, *Fusarium*, *Memnoniella*, *Phoma*, *Thielavia* and *Trichoderma* are strongly cellulolytic in nature. In addition *Alternaria*, *Coprinus*, *Fomes*, *Myrothecium*, *Penicillium*, *Polyporus*, *Rhizoctonia*, *Trametes*, *Trichothecium* and *Verticillium* are also good cellulose degraders. Two groups of enzymes designated as C_1 and Cx are involved in cellulose decomposition. C_1 enzyme is an enigma and its *modus operandi* is not fully understood. It is a large molecule inducible enzyme. It loosens the cellulose fibrils of crystalline areas. Cx group of enzymes hydrolyse the cleavage of 1-4 glycosidic linkages but a prior modifying action of C_1 is essential for the action of Cx. Two theories i.e. unienzyme theory (Whittakar, 1957) and multienzyme theory (Reese. 1959) have been proposed for cellulose dogradation,

Hemicellulose Degradation

Hemicelluloses, the non-cellulosic cell wall polysaccharides constitute important source of energy and nutrients for the microflora. These are present in the spaces between cellulose microflbrils. Chemically they are complex formed by linear union of smaller sugar chains like xylans, arabans, mannans & galactans etc. Fungi from all the major groups have the capacity to degrade hemicellulose. Some of the fungal genera and their relative preference for hemi. cellulosic components are as follows :

Fungi	Preference fer Hemicellulosic substrate
Alternaria, Fusarium & Trichothecium	Hemp Polyuronide
Rhizopus, Zygorhychus & Aspergillus	Galactan, Mannan and Xylan
Chaetomium, Penicillium & Helminthosporium	Wheat pentosan
Coriolus, Fomes & Polyporus	Araban, galactan and mannan

Wood decay is mostly caused by members of Basidiomycotina & few Ascomycotina. Chemically there are three major components in the wood i.e. cellulose, hemicellulose and lignin. These constituents may be disintegrated by the same organism to degrade the entire cell wall. Under natural conditions a series of organisms are involved in wood decay exhibiting various types of synergistic and antagonistic interactions.

Wood Decomposition

Primary moulds are not capable of degrading the wood. They utilise sugars, starch and lipids. Primary degraders are mostly from the Deuteromycotina or their sexual stages.

Secondary moulds (*Trichoderma* and *Gliocladium*) appear after the main decay is accomplished. They also generally not utilise lignin and cellulose but they use the byproducts of other organisms, such as the dead hyphae or soluble carbon released due to extracellular enzymes of true wood decomposers.

The main timber decay fungi are Basidiomycetes and Ascomycetes and their imperfect stages cause soft rots, usually in converted timber. There are many genera reported but common ones are *Chaetomium, Xylaria, Peziza* and *Phialophora.* The hyphae occur in the ray parenchyma, than in the secondary walls of the tracheid and vessel, forming cavities with pointed ends which often run round the cell following the alignment of the cellulose fibrils. In transverse section these appear as holes in the wall with hypha in the centre of each. Evetually the holes enlarge and meet to form a large cavity.

Lignin Degradation

Degradation of wood caused by members of Basidiomycotina has received considerable attention. There are basically two types of basidiomycete rots, brown-rot and white-rot. Brown-rot fungi cause degradation of cellulose and hemicellulose ; the lignin is left more or less unaltered and the wood turns brown. Since the lignin is left, the walls retain their structural integrity till the last phase of decay. The attack is main'y on the S_2 and S_1 walls, the primary wall and the middle lamella are not affected. The most noted change in lignin on attack by brown rot fungi is a decrease in the methoxyl content. Loss of methoxyl in the lignin of spruce wood is linearly related to the weight loss during attack by *Lenzites saepiaria* (Grohn and Dector, 1959). Many saprophytic basidiomycotina including species of *Clavaria, Collybia, Marasmius* and *Mycena* are able to decompose lignin found in the leaves and twigs that comprise forest litter (Linderberg, 1955). Some of the soil fungi like species of *Penicillium* and *Fusarium* have the capacity to destroy upto 20% of lignin present in wheat straw (Gulya, 1967). Lignin degrading enzymes are reported from some wood rotting fungi. Wood rotting "white rot fungi" produce an enzyme transmethylase which modify lignin for further degradation by cellulolytic enzymes. Transmethylase remove the methoxyl group exposing cellulose microfibrils to enzymatic attack by cellulases.

White-rot can degrade lignin, and other phenolic compounds as well as the polysaccharide. The whole cell wall substance is removed including the middle lamella in cases. *Polyporus versicolor* can destroy about 97% of lignin from the wood suffering with white rot (Cowling, 1961).

Lignin decomposes very slowly. Many of the Basidiomycetes are capable of degrading lignin, but the reaction is very slow. The microflora functioning in aerobic lignin decomposition at moderate temperatures consist largely of the higher fungi. Species of *Agaricus, Armillaria, Coprinus, Coriolellus, Fomes, Ganoderma, Lenzites, Marasmius, Panus, Pleurotus, Polyporus, Polystictus, Poria, Trametes* and *Ustulina* are active lignin degraders.

Degradation of Starch

Cellulose and hemicellulose together with lignin comprise the bulk of the crop debris that undergo decay. Besides these, several other polyaccharides are found in plant tissues and their decomposition occupies a degree of prominancc in soil.

Starch is the major reserve carbohydrate of green plants. Fungi, bacteria and actinomycetes have the capacity to hydrolyse starch. Some of the fungal genera

that utilize starch are *Aspergillus*, *Fomes*, *Fusarium*, *Polyporus* and *Rhizopus*. Leaf-spot fungi like species of *Phyllosticta* have been found to be good degraders of starch (Bilgrami, 1959).

Degradation of Pectic Substances

Pectic substances are found abundantly in the middle lamella, a tissue constituent located between individual cells.

Pectic substances are readily decomposed by microorganisms in soil. A variety of saprophytic and pathogenic fungi are capable of hydrolyzing pectin, protopectin and pectic acid, using these substances as carbon and energy sources.

Pathogenicity and the decay of vegetables and fruits are often associated with the hydrolysis of pectic material. Some pathogens solubilize the middle lamella by means of their pectic enzymes and thereby separate individual plant cells from one another. The loosened cells then either autolyse or are killed by pathogens or the secondary invaders

Chitin Degradation

Chitin is the most common polysaccharide in nature whose basic unit is an amino sugar (N-acetylglucosamine).

Chitin is found in the skeletons of a number of invertebrate animals and in the cell walls of most fungi Chitin decomposition is a characteristic common to species of *Streptomyces* and some fungi(*Fusarium*, *Mucor*, *Mortierella*, *Trichoderma*, *Aspergillus*, *Penicillium*, *Gliocladium*, *Thamnidium*, *Absidia* and several Basidiomycetes).

Coprophilous Fungi and Dung Degradation

Dung of herbivores which is very rich organically is habitat of large variety of fungi. Zygomycete Mucorales like *Mucor*, *Pilaira* & *Pilobolus* are the first to appear. After about a fortnight, parasitic Mucorales like *Chaetomium* and *Piptocephalis* may grow on them. Some apothecial and perithecial fungi like *Chaetomium* and *Podospora* may appear earlier in order of succession. The spores of most of the coprophilous fungi are discharged with force. Dung contains appreciable quantity of readily available carbohydrates ; nitrogen content may be as high as 4% Dung is also rich in water soluble vitamins, growth factors and mineral ions. Dung has the capacity to retain moisture for a long period. The order of decomposition of substrates from dung is on same pattern as of other sources. Simple soluble sugars, starches and proteins are first to disappear, followed by hemicellulose, cellulose, and lignin. In order of succession, therefore, the Mucorales are followed by Ascomycotina (cellulose decomposers)

followed by Basidiomycotina (lignin decomposers). Under natural conditions, however, the succession is not very compartmentalized because a number of coprophilous Agaricales are known to utilize both cellulose and lignin. Moisture contents of dung and the speed of spore germination of fungi of different groups are the important decisive factors. After degradation of cellulose the "sugar fungi" may reappear because the spore remain in the same niche. Apparently it appears that there is running down of nutrients but in effect the situation is quite complex because dung is just not a substrate for fungi alone. It supports vast populations of bacteria, protozoa, nematodes, annelides, insects and the like. The other microorganisms compete with fungi but actually they have little effeet on the order of fungal succession.

Majority of the coprophilous fungi are cosmopolitan and do not have specificity. Some, however, like *Basidiobolus ranarum* occur in dung of frog (amphibia) only. This zygomycete Entomophthorales is phototropic like *Pilobolus*. Why do the coprophilous fungi liberate their spores with force or the spore bearing structures show inclination towards light need thorough investigation.

Aquatic Ecosystem

The role of fungi in aquatic ecosystems is very little understood. Hardly 20% fungi are aquatic in nature. Aquatic environments are often very rich organically with a very rich variety of matter including decaying wood, twigs and leaves. Fungi, being aerobes prefer such waters in which diffusion rate of oxygen is very high. Open sea is almost like a fungal desert with only yeasts or lower fungi attached to pelagic animal. The environment is fairly stable. Wood, sea-weeds and small animals are the main habitats of fungi. Fungal parasites on fishes are quite common.

Fresh water fungi constitute two main groups i.e., (i) Zoosporic water moulds and (ii) Conidial Hyphomycetes. Saprolegniales are the most predominant water moulds. They occur on plant remains and animal tissues. *Saprolegnia*, *Achlya*, *Aphanomyces*, *Dictyuchus*, *Leptolegnia*, *Allomyces* and *Rhizophydium* are some of the common fungi to be encountered in the fresh waters. *Cryptococcus* is the most common aquatic yeast.

Some of the Chytridiales and Saprolegniales are strongly cellulolytic and play a significant role in decomposition of plant matter. Aquatic Hyphomycetes are undoubtedly much more common and abundant (in terms of spore number) in the free flowing water than in the stagnant ones. Many aquatic Hyphomycetes are introduced with allochthonous material. The marginal soils also contribute a significant fraction of fungal flora (geofungi) in streams and other fresh water bodies. Bilgrami and Datta Munshi (1985) reported ten Hyphomycetes from Ganga system in Bihar.

List prepared by them shows that fungi belongin to all the important gronps occur in water.

Fungi reported from River Ganga (Bilgrami and Datta Munshi, 1985)

Oomycetes
Saprolegniales
Achlya prolifers, Isoachlya anisospora var. *indica, Saprolegnia ferax.*

Peronosporales
Pythium butleri, P.carolinianum

Zygomycetes
Mucorales
Absidia spinosa, Actinomucor sp., *Circinella simplex, Mucor mucedo, Syncephalastrum racemosum*

Pyrenomycetes
Sphaeriales
Chaetomium funicola, C. perpulchrum, Diaportho sp., *Podospora nannapodalis.*

Discomycetes
Pezizales
Ascobolus sp.

Loculoascomycetes
Pleosporales
Leptosphaeria aquatica, Leptospora rubella, Ophiobolus herpotrichus, O. spirosporus, Thyridium sp.

Coelomycetes
Sphaeropsidales
Phoma nebulosa

Hyphomycetes
Moniliales

Alternaria gomphrenae, Aspergillus fumigatus, Aspergillus, japonicus, A. phoenicis, Drechslera, australiensis Nigrospora oryzae, Penicillium citrinum, P. hergquei, P. pinophilum. P. spiculisporum.

Most of the extra-aquatic Hyphomycetes are efficient cellulose decomposers. About one hundred extra aquatic fungi have been reported from water systems. The leaves of deciduous trees and twigs are metabolized by a variety of aquatic and extra-aquatic fungi.

The distribution of fungi in aquatic ecosystems to a great extent depends upon the presence of such plants and animals which they parasitize or consume when dead. In aquatic systems the fungi are important in maintaining the energy flow in two main ways : First through assimilation of dissolved organic compounds, they make themselves available to the organisms higher in the food chain. Secondly they can mineralize complex organic compounds, thereby releasing the inorganic substrates which can then be used by the phototrophs. This mineralization is crucial to the primary productivity and thus to maintenance of energy flow in the aquatic ecosystem.

REFERENCES

Bilgrami, K. S. (1959) The utilization of starch by two species of *Phyllosticta. Curr. Sci.* **27**, 24-27.

Bilgrami, K. S. (1964). Studies on formation and role of synthetic oligosaccharides during utilization of some complex carbohydrates by some pathogenic species of *Phyllosticta Flora* (BD). **154**, 81-88.

Bilgrami, K. S. and Datta Munshi, J. S. (1985). Ecology of river Ganges : Impact of human activities and conservation of Aquatic biota (Patna to Farakka). *Final Tech. Report.* D.O. En. Govt. of India.

Cowling, E. B. (1961). Comparative biochemistry of the decay of sweetgum sap wood by white-rot and brown-rot fungi. USDA. Tech. Bull. 1258, 79 pp.

Dwivedi, R. S. (1979). Micro-organisms in In Grass land ecosystems of the world. Edt. R. T. Coupland, Cambridge University Press pp. 227-230.

Grohn, H. and Detor, W. (1959). Uber den Abbau Von Fichtenholz durch *Lenzites saepiaria. Holzforschung* **13**, 8-12.

Gulya, S. F. (1967). On the role played by several soil fungi in the microbiological decomposition of lignin. *Agrokem. Tekjtan* **16**, 137-150.

Linderberg, G. (1955). Ligninabbauund Phenoloxydasbildung der Hyphomycetes. *Z. Pflanzen ernatr. Dung. Bodenk.* **69**, 142-150.

Reese, E. J. (1959). Cellulosic decomposition : Fungi in *Marine Boring* [illegible] *Fouling Organisms.* pp. 265-291 D. L. Ray, Friday Horbor (eds.), Symposium Univ. of Washington Press, Seatle.

Sharma, P. D. and Dwivedi, R. S. (1975). Mycoflora colonizing the down shoots of *Setaria glauca* Beav. *Tropical Ecology* **16**, 96-103

Shukla, A. N., Tandon, R. N. and Gupta, R. C. (1978). *Phyllosphere* mycoflora colonizing the leaf litter of Sal (*Shorea robusta* Caertn.) in relation to some of the environmental factors. *Tropical Ecology* **19**, 1-6.

Singh, K. P. (1969). Studies on decomposition of leaf litter of important trees of deciduous forests at Varanasi. *Tropical Ecology*, **10**, 292-311.

Toky, O. P. and Rama Krishnan, P. S. (1984). Litter related to secondary succession and species type under slash and burn agriculture (Jhum) in North-Eastern India. *Proc. Indian natl. Sci. Acad.* **50B**, 57-65.

Vittal, B. P. R. (1976). Studies on litter fungi. *Proc. Indian Acad. Sci.* **83B**, 133-138.

Whittiker, D.R.(1957). The mechanism of degradation of cellulose by *Myrothecium verrucariae. Can. J. Biochem. & Physiol.* **35**.