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Role of Fungi in Biodegradation

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Pollution of the environment due to plastics, metals, glass, paper etc. has been one of the largest concerns to science and the general public in the last few decades. Nowadays, the industrialized world is confronted with the contamination of soils, water sources and air with hazardous and toxic xenobiotics. The industrialization of agriculture, rapid growth in the chemical industry and the need to generate cheap forms of energy have all caused the continuous release of very organic chemicals into the biosphere. For example, in the United States alone an enormous amount waste is produced annually. In fact, approximately 300 million metric tons of hazardous wastes are produced each year. Biodegradation and Bioremediation of the above mentioned pollutants are the great idea to resolve this problem.

What is Biodegradation and Bioremediation?

Biodegradation can be defined as the decomposition of materials mainly by fungi or bacteria, is a natural process that acts on substances such as leaves, grass, and food scraps. Also, biodegradation is the decay or breakdown of materials that occurs, when microorganisms use an organic substance as a source of carbon and energy. The technique of biodegradation has been extended to break down artificial products, mainly plastics such as aliphatic polyesters, aromatic co-polyesters, and polyethene. Bioremediation is a process by which living organisms degrade or transform hazardous organic contaminants to less toxic compounds.

Table 1: Difference between Biodegradation and Bioremediation

Biodegradation	Bioremediation
The decomposition of organic materials in the environment through microbial action then it is called as Biodegradation.	It is one of the methodologies of waste management technique in which biological agents are uses to remove contaminations from the environment.
It is natural process	It is artificial process
It is slow process	It is faster process
It is arbiter by the nature	It is totally engineered process of human. So it is controlled by the human.
It can be helpful or harmful	It has beneficial effects
It does not require expert	It requires expert for the designing and implementation of the process

Mechanism involves in biodegradation

Fungi have numerous enzyme system and occur under the various climatic condition on a variety of substrates, the mode of nutritious in fungi is always heterotrophic, therefore being a heterotrophic organism they obtain their nutrition either through parasitic or saprotrophic mode and to do so, they employ a series of enzyme reaction on the substrate they grow since the biomass (dead bodies of plants and animals) are complex in chemical composition they are made available to fungi nutrition by converting it to the simpler form. Following enzymes which are produced by fungi are involved in biodegradation.

1) Cutinases- are a subclass of esterase enzyme which is identifed by their ability to hydrolyze polyesters with high molar mass. Cutinases are produced by *Fusarium solani, Penicillium citrinum, Pichia pastoris, Aspergillus oryzae, Humicola insolens*. *Fusarium solani* pisi cutinase (FsC) and *Humicola insolens* cutinase (HiC) are capable of degrading low crystallinity PET flm with 97% weight loss being observed within 96 hrs.

2) Lipases- are enzymes that catalyze the hydrolysis of lipids. Some fungal species that are well known to produce lipases and are involved in the degradation of plastics, i.e., Rhizopus delemer, Candida antarctica, *Termomyces lanuginosus, Candida rugosa* can degrade poly (butylene succinate-cohexamethylene succinate) copolymer. *Rhizopus delemer* produces lipase which can degrade 53% of the polyester type-polyurethanes (ES-PU) film after 24 hrs reaction.

3) Proteases- are enzymes that break the long peptide chain into short peptides or break down proteins to polypeptide chains by hydrolysis, this process is known as proteolysis. *Aspergillus, Trichoderma, Paecelomyces, Penicillium, Alternaria, Phaenarochete, Pestalotiopsis, Rhizopus, Mucor, Humicola, Termoascus, Termomyces* are some of the important fungal species which are producing proteases to degrade plastics.

Other enzymes like Esterases, Peroxidases, Laccase, Pro-oxidant ions etc also play important role in biodegradation.

Fungal biodegradation of Chemical pollutants

The development of resources, industries even agriculture has practices produced more chemicals and compounds which has consequently increased the number of compounds identified as being potential environmental threats to living organisms. These pollutants vary greatly in their form and mechanism of action. Thus, the identification and evaluation of these compounds from the environmental matrixes have provided a unique challenge. For example *Aspergillus niger, Aspergillus flavus*, and *Aspergillus oryzae* can use for biodegradation of LDPE (low density polyethylene) under laboratory conditions. Sangale *et al.*, 2019 reported that *Aspergillus terreus* strain MANGF1/WL and *Aspergillus sydowii* strain PNPF15/TS are the most efficient polythene deteriorating fungal isolates among various strain. Another examples are, biodegradation of monomeric styrene by *Phanerochaete chrysosporium* KFRI 20742, *Trametes versicolor* KFRI 20251, and *Daldinia concentrica* KFRI 40-1 giving metabolites including 2-phenyl ethanol, benzoic acid, cyclohexadiene-1,4-dione, butanol and succinic acid.

Fungi are capable of mineralizing a wide variety of toxic xenobiotics due to the non-specific nature of their extracellular enzymes. For instance, anaerobically digested molasses spent wash (DMSW) is a dark-brown-coloured recalcitrant effluent which has a high chemical oxygen demand (COD) and high pollution potential. Fungi such as *Aspergillus, Rhizopus* and *Fusarium* are able to effectively degrade DMSW. fungi belonging to genus Aspergillus, Trichoderma, *Phanerochaete* and *Coprinus* are known to decompose agriculture straws like paddy straw, corn straw, wheat straw and horticultural wastes, whereas *Pleurotus sajor-caju, P. platypus* and *P. citrinopileatus* are known to colonize coir fibre, cotton stalks and sorghum stover. These fungi may be specific for each substrate and can be used as an effective tool for in situ degradation of lignin residues.

Table 2: Economically beneficial examples of fungal degradation

Process	Substrate	Species
Composting	Straw, manure, agricultural waste, bark	Consortia of bacteria and fungi, usually uncharacterized
Mushroom cultivation	Lignocellulose, animal manure Straw, Saw dust Wood logs	*Agaricus bisporus* *Pleurotus ostreatus* (oyster mushroom) *Lentinus odoides* (shiitake mushroom)
Single-cell protein production	Alkanes, Brewery wastes, molasses Sulfite waste liquid	Yeasts, *e.g.*, *Candida tropicalis* *Saccharomyces cerevisiae, S. carlsbergensis* *Candida utilis*, *Paecilomyces varioti*
Solid-waste treatrnent	Sludge/sewage Pulp and paper mill effluent	Consortia of bacteria and fungi, usually uncharacterized *Coriolus versicolor*, *Phanerochaete chrysosporium*
Waste water treatment	Distillery waste Kraft bleaching effluent Tannery effluent	Yeasts, especially *Candida utilis* *Phanerochaete chrysosporium* *Aspergillus*, *Penicillium*

Agricultural chemicals (pesticides) also degraded by different fungal species. *Chaetosartorya stromatoides, Aspergillus terricola,* and *A. terreus* can degrade pesticides very effectively. *Laetoporeus sulfureus, Gloephyllum trabeum,* and *Ganoderma austral* easily degrade fungicides.

Table 3: Fungal degradation of pesticides

Compound	Fungi	Ref.
Phenylurea herbicides	*Rhizoctonia solani*	(Weinberger and Bollag, 1972)
Diuron, Linuron, Monolinuron, Monuron & Buturon	*Cunninghamella echinulata*	(Tillmanns *et al*., 1978)
Diuron	*Beauveria bassina* *Cunninghamella elegans* *Aspergillus niger* *Mortierella isabellina*	(Tixier *et al*., 2001)
Isoproturon	*Mortierella* sp. *Mucor* sp. *Alternaria* sp. *Phoma* sp. Basidiomycete strain Gr177	(Ronhede *et al*., 2005)
Diuron, Metalaxyl, Atrazine & Terbuthylazine	*Coriolus versicolor*	(Bending *et al*., 2002)

Strategies for Bioremediation

For the successful biodegradation / bioremediation of a given contaminant following strategies are usefull:

a) Passive/ intrinsic Bioremediation: It is the natural bioremediation of contaminant by the indigenous microorganisms and the rate of degradation is very slow.

b) Bioventing: Process/way of Biostimulation by which gas stimulants like oxygen and methane are added or forced into soil to stimulate microbial activity.

c) Bioaugmentation: It is the inoculation/introduction of microorganisms in the contaminated site/soil to facilitate biodegradation.

d) Biostimulation: Practice of addition of nitrogen and phosphorus to stimulate indigenous microorganisms in soil.

e) Composting: Piles of contaminated soils are constructed and treated with aerobic thermophilic microorganisms to degrade contaminants. Periodic physical mixing and moistening of piles are done to promote microbial activity.

f) Phytoremediation: Can be achieved directly by planting plants which hyper accumulate heavy metals or indirectly by plants stimulating microorganisms in the rhizosphere.

g) Bioremediation: Process of detoxification of toxic/unwanted chemicals / contaminants in the soil and other environment by using microorganisms.

h) Mineralization: Complete conversion of an organic contaminant to its inorganic constituent by a species or group of microorganisms.

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