Biodegradation of environmental pollutants by microorganism

Introduction

- Biodegradation is defined as the biologically catalyzed reduction in complexity of chemical compounds.
- Indeed, biodegradation is the process by which organic substances are broken down into smaller compounds by living microbial organisms
- . When biodegradation is complete, the process is called "mineralization".
- However, in most cases the term biodegradation is generally used to describe almost any biologically mediated change in a substrate.

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- Understanding the process of biodegradation requires an understanding of the microorganisms that make the process work.
- The microbial organisms transform the substance through metabolic or enzymatic processes.
- It is based on two processes: **growth and cometabolism**.
- In **growth**, an organic pollutant is used as sole source of carbon and energy. This process results in a complete degradation (mineralization) of organic pollutants.
- **Cometabolism** is defined as the metabolism of an organic compound in the presence of a growth substrate that is used as the primary carbon and energy source.

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- Several microorganisms, including fungi, bacteria and yeasts are involved in biodegradation process.
- Algae and protozoa reports are scanty regarding their involvement in biodegradation.
- Biodegradation processes vary greatly, but frequently the final product of the degradation is carbon dioxide
- Organic material can be degraded aerobically, with oxygen, or anaerobically, without oxygen

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- Biodegradable matter is generally organic material such as plant and animal matter and other substances originating from living organisms, or artificial materials that are similar enough to plant and animal matter to be put to use by microorganisms.
- Some microorganisms have the astonishing, naturally occurring, microbial catabolic diversity to degrade, transform or accumulate a huge range of compounds including hydrocarbons (e.g. oil), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), radionuclides and metals.

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- The term biodegradation is often used in relation to ecology, waste management and mostly associated with environmental remediation(bioremediation)
- Bioremediation process can be divided into **three** phases or levels.
- **First,** through natural attenuation, contaminants are reduced by native microorganisms without any human augmentation.
- **Second**, biostimulation is employed where nutrients and oxygen are applied to the systems to improve their effectiveness and to accelerate biodegradation.

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- **Finally,** during bioaugmentation, microorganisms are added to the systems.
- These supplemental organisms should be more efficient than native flora to degrade the target contaminant.
- A feasible remedial technology requires microorganisms being capable of quick adaptation and efficient uses of pollutants of interest in a particular case in a reasonable period of time.

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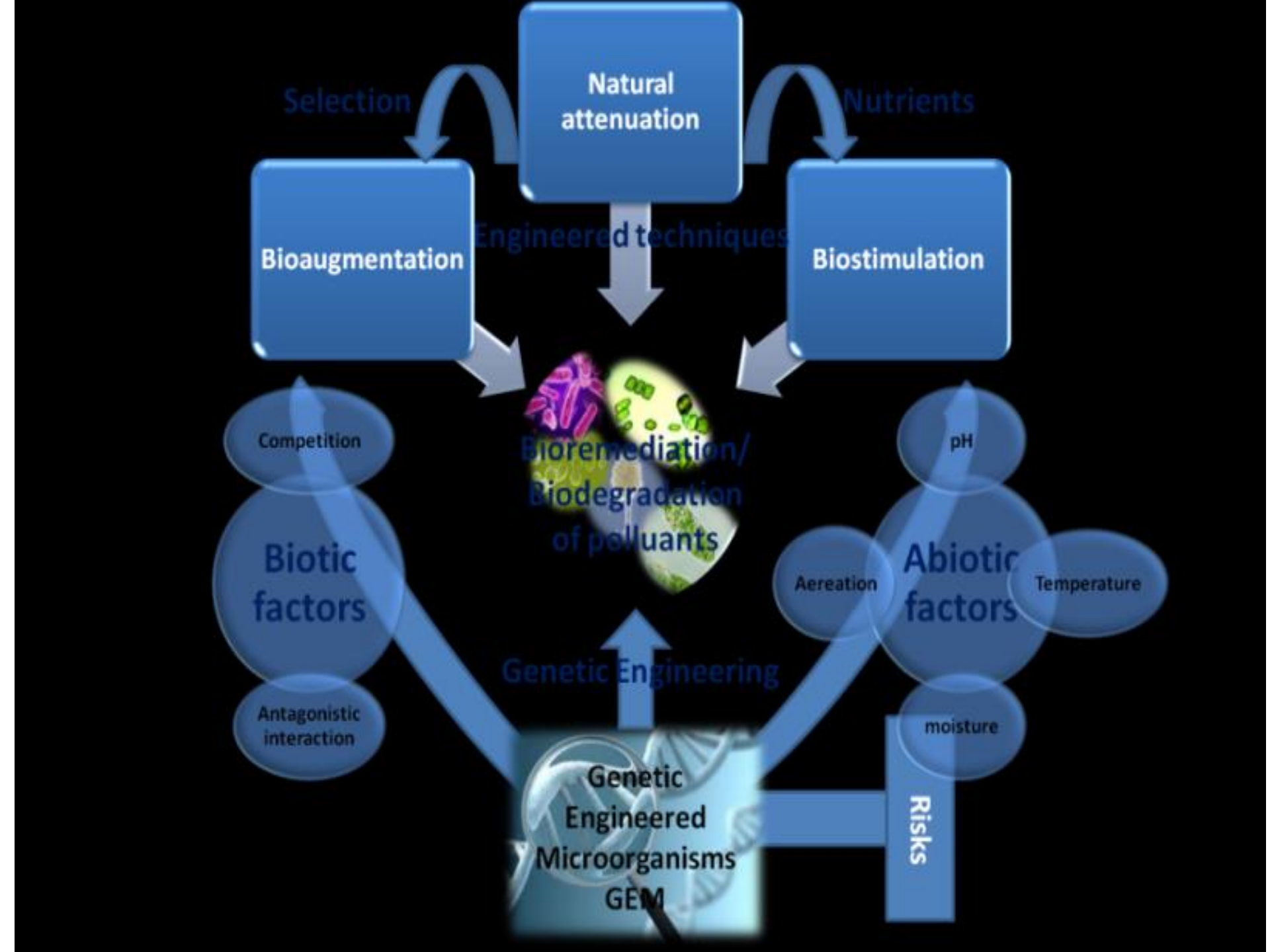
- Many factors influence microorganisms to use pollutants as substrates or cometabolize them, like, the genetic potential and certain environmental factors such as temperature, pH, and available nitrogen and phosphorus sources, then, seem to determine the rate and the extent of degradation.
- Therefore, applications of genetically engineered microorganisms (GEM) in bioremediation have received a great deal of attention.
- These GEM have higher degradative capacity and have been demonstrated successfully for the degradation of various pollutants under defined conditions.
- However, ecological and environmental concerns and regulatory constraints are major obstacles for testing GEM in the field

- Bioremediation of polluants utilizing biodegradation abilities of microorganisms include the natural attenuation, although it may be enhanced by engineered techniques, either by addition of selected microorganisms (bioaugmentation) or by biostimulation, where nutrients are added.
- Genetic engineering is also used to improve the biodegradation capabilities of microorganisms by GEM.
- Nevertheless, there are many factors affecting the efficiency of this process and risks associated to the use of GEM in the field


Natural attenuation
Selection
Nutrients
Bioaugmentation
Engineered techniques
Biostimulation
Competition
Bioremediation/ Biodegradation of polluants
pH
Biotic factors
Abiotic factors
Aereation
Temperature
Genetic Engineering
Antagonistic interaction
moisture
Genetic Engineered Microorganisms GEM
Risks

Role of microorganisms in biodegradation of pollutants

- Bioremediation and biotransformation methods endeavour to harness the astonishing, naturally occurring, microbial catabolic diversity to degrade, transform or accumulate a huge range of compounds including:
- hydrocarbons (e.g. oil),
- polychlorinated biphenyls (PCBs),
- polyaromatic hydrocarbons (PAHs),
- radionuclides and metals

Some biodegradable pollutants

- In the last few decades, highly toxic organic compounds have been synthesized and released into the environment for direct or indirect application over a long period of time.
- Fuels, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides and dyes are some of these types of compounds .
- Some other synthetic chemicals like radionuclides and metals are extremely resistant to biodegradation by native flora compared with the naturally occurring organic compounds that are readily degraded upon introduction into the environment.

- **Hydrocarbons:** are organic compounds whose structures consist of hydrogen and carbon.
- Hydrocarbons can be seen as linear linked, branched or cyclic molecules.
- They are observed as aromatic or aliphatic hydrocarbons. The first one has benzene (C6H6) in its structure, while the aliphatic one is seen in three forms: alkanes, alkenes and alkynes
- **Polycyclic aromatic hydrocarbons (PAHs):** are important pollutants class of hydrophobic organic contaminants (HOCs) widely found in air, soil and sediments.
- The major source of PAH pollution is industrial production
- The use of microorganisms for bioremediation of PAH-contaminated environments seems to be an attractive technology for restoration of polluted sites.

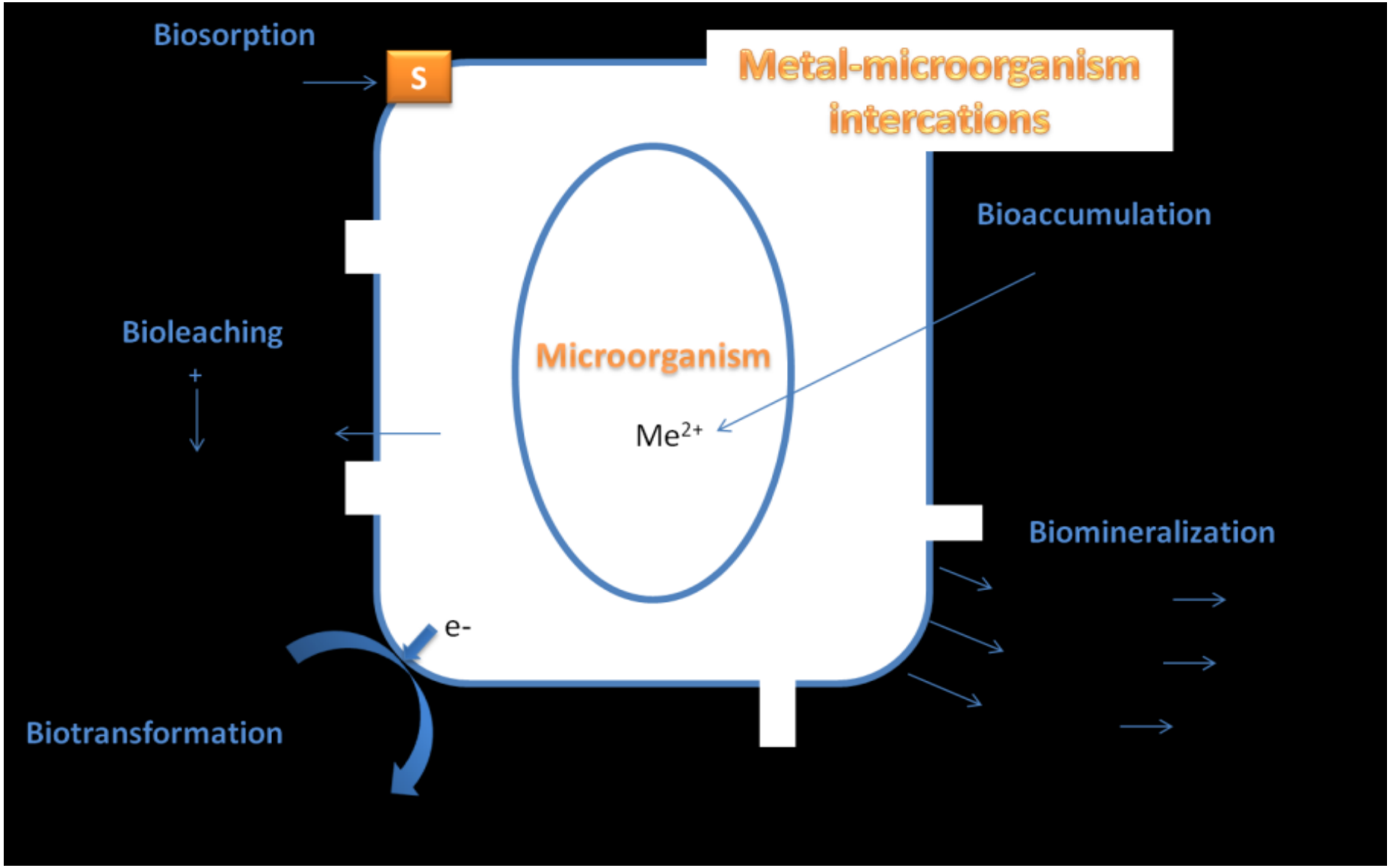
- **Polychlorinated biphenyls (PCBs):** are mixtures of synthetic organic chemicals.
- Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications.

- **Pesticides:** are substances or mixture of substances intended for preventing, destroying, repelling or mitigating any pest.
- Pesticides which are rapidly degraded are called nonpersistent while those which resist degradation are termed persistent.
- The most common type of degradation is carried out in the soil by microorganisms, especially fungi and bacteria that use pesticides as food source.
- **Dyes:** are widely used in the textile, rubber product, paper, printing, color photography, pharmaceuticals, cosetics and many other industries.
- Azo dyes, which are aromatic compounds with one or more (–N=N–) groups, are the most important and largest class of synthetic dyes used in commercial applications

- These dyes are poorly biodegrabale because of their structures and treatment of wastewater containing dyes usually involves physical and / or chemical methods such as adsorption, coagulation-flocculation, oxidation, filtration and electrochemical methods.
- The success of a biological process for color removal from a given effluent depends in part on the utilization of microorganisms that effectively decolorize synthetic dyes of different chemical structures.
- **Radionuclides**: a radionuclide is an atom with an unstable nucleus, characterized by excess energy available to be imparted either to a newly created radiation particle within the nucleus or via internal conversion.
- During this process, the radionuclide is said to undergo radioactive decay, resulting in the emission of gamma ray(s) and/or subatomic **particles such as alpha or beta particles**

Heavy metals: unlike organic contaminants, the metals cannot be destroyed, but must either be converted to a stable form or removed. Bioremediation of metals is achieved through biotransformation.

Microbial processes used in bioremediation technologies modified from Lloyd and Lovley [21].



Bacterial degradation

- There are many reports on the degradation of environmental pollutants by different bacteria.
- Several bacteria are even known to feed exclusively on hydrocarbons [22].
- Bacteria with the ability to degrade hydrocarbons are named hydrocarbon-degrading bacteria.
- Biodegradation of hydrocarbons can occur under aerobic and anaerobic conditions, it is the case for the nitrate reducing bacterial strains Pseudomonas sp. and Brevibacillus sp. isolated from petroleum contaminated soil
- Furthermore, among 80 bacterial strains isolated by Kafilzadeh et al. which belonged to 10 genus as follows: Bacillus, Corynebacterium, Staphylococcus, Streptococcus, Shigella, Alcaligenes, Acinetobacter, Escherichia, Klebsiella and Enterobacter, Bacillus was the best hydrocarbon degrading bacteria.

- Although many bacteria are able to metabolize organic pollutants, a single bacterium does not possess the enzymatic capability to degrade all or even most of the organic compounds in a polluted soil.
- Mixed microbial communities have the most powerful biodegradative potential because the genetic information of more than one organism is necessary to degrade the complex mixtures of organic compounds present in contaminated areas.
- Both, anaerobic and aerobic bacteria are capable of biotransforming PCBs.
- Higher chlorinated PCBs are subjected to reductive dehalogenation by anaerobic microorganisms.
- Lower chlorinated biphenyls are oxidized by aerobic bacteria .
- Aerobic catabolic pathway for PCB degradation seems to be very similar for most of the bacteria and comprises **four** steps catalysed by the enzymes, biphenyl dioxygenase (BphA), dihydrodiol dehydrogenase (BphB), 2, 3-dihydroxybihenyl dioxygenase (DHBD) (BphC) and hydrolase (BphD).

Microfungi and mycorrhiza degradation

- Microfungi are described as a group of organisms that constitute an extremely important and interesting group of eukaryotic, aerobic microbes ranging from the unicellular yeasts to the extensively mycelial molds.
- Yeasts preferentially grow as single cells or form pseudomycelia, whereas molds typically grow as mycelia-forming real hyphae.
- Fungi are an important part of degrading microbiota because, like bacteria, they metabolize dissolved organic matter; they are principal organisms responsible for the decomposition of carbon in the biosphere
- But, fungi, unlike bacteria, can grow in low moisture areas and in low pH solutions, which aids them in the breakdown of organic matter

- Mycorrhiza is a symbiotic association between a fungus and the roots of a vascular plant. In a mycorrhizal association, the fungus colonizes the host plant's roots, either intracellularly as in arbuscular mycorrhizal fungi (AMF), or extracellularly as in ectomycorrhizal fungi.
- They are also an important component of soil life and soil chemistry.
- Bioremediation using mycorrhiza is named mycorrhizoremediation.