BHARATHIDASAN UNIVERSITY
Tiruchirappalli- 620024, Tamil Nadu, India

Programme: M.Sc., Biotechnology(Environment)

Course Title :Environmental Biotechnology
Course Code : CCO8

Unit-III

Role of microorganism in Bioremediation

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Bioremediation is the process of using microorganisms such as bacteria and fungi to degrade, transform, or detoxify environmental pollutants into less harmful or non-toxic forms. These microorganisms are naturally equipped with metabolic pathways and enzymatic systems that allow them to break down a wide variety of contaminants.

Role of Bacteria in Bioremediation

- Bacteria are among the most commonly used microorganisms for bioremediation due to their adaptability, diverse metabolic capabilities, and rapid growth.

Mechanisms of Bioremediation by Bacteria

- Enzymatic Degradation: Bacteria produce enzymes like oxygenases, dehalogenases, and hydrolases that help break down organic pollutants.
- Biotransformation: Some bacteria transform pollutants into less harmful forms through processes such as oxidation, reduction, or hydrolysis.
- Bioaccumulation/Biosorption: Certain bacteria can absorb or adsorb heavy metals and other contaminants, storing them within their biomass.

- ***Examples of Bacteria in Bioremediation***
  - *Pseudomonas putida:* Known for degrading hydrocarbons, phenols, and pesticides.
  - *Alcanivorax borkumensis:* Specialized in breaking down oil spills in marine environments.
  - *Rhodococcus sp.:* Effective in degrading aromatic hydrocarbons and complex organic compounds.
  - *Deinococcus radiodurans:* Capable of remediating radioactive waste due to its extreme resistance to radiation.
- ***Applications of Bacteria***

1. Oil Spill Cleanup: Hydrocarbon-degrading bacteria are used to treat petroleum contamination in marine and terrestrial environments.
2. Heavy Metal Detoxification: Certain bacteria can immobilize or precipitate heavy metals such as lead, mercury, and cadmium.
3. Wastewater Treatment: Bacteria degrade organic waste and remove nitrates, phosphates, and toxic chemicals.
4. Plastic Biodegradation: Some bacteria can degrade synthetic plastics like polyethylene and polystyrene.

Advantages of Using Bacteria

1. High growth rates and metabolic activity.
2. Ability to target specific pollutants.
3. Can be genetically engineered for enhanced efficiency.
4. Operate under diverse environmental conditions.

- ***Limitations***

1. May require optimal environmental conditions (pH, temperature, nutrients) for effective activity.
2. Limited efficacy on highly recalcitrant or complex pollutants.
3. Risk of bacterial overgrowth disrupting ecosystems.

Role of Fungi in Bioremediation

- Fungi, particularly filamentous fungi and white rot fungi, are valuable in bioremediation because of their ability to degrade complex organic compounds and survive in harsh environments.
- ***Mechanisms of Bioremediation by Fungi***

1. Lignin Degradation: Fungi like white rot fungi produce extracellular enzymes (e.g., lignin peroxidase, manganese peroxidase, and laccase) that break down lignin and similar recalcitrant pollutants.
2. Mycoremediation: The use of fungal mycelium to adsorb or degrade pollutants.
3. Enzymatic Biodegradation: Fungi can degrade hydrocarbons, pesticides, and dyes through oxidative enzymes.

Examples of Fungi in Bioremediation

1. *Phanerochaete chrysosporium:* Known for degrading polycyclic aromatic hydrocarbons (PAHs) and industrial dyes.
2. *Trametes versicolor:* Used to treat soil and water contaminated with pesticides and heavy metals.
3. *Aspergillus niger:* Effective in biosorption of heavy metals like lead and cadmium.

Applications of Fungi

1. Soil Bioremediation: Degradation of persistent organic pollutants such as pesticides, herbicides, and hydrocarbons.
2. Industrial Effluent Treatment: Removal of synthetic dyes and toxic chemicals from textile and paper mill effluents.
3. Heavy Metal Removal: Mycoremediation of lead, mercury, arsenic, and chromium from contaminated sites.
4. Degradation of Synthetic Polymers: Some fungi can degrade plastics and other synthetic materials.

Advantages of Using Fungi

1. Broad substrate range and ability to degrade recalcitrant pollutants.
2. Function effectively under harsh environmental conditions.
3. Use extracellular enzymes, which allows for degradation of pollutants without direct contact.

- ***Limitations***

1. Slow growth and degradation rates compared to bacteria.
2. Dependence on specific environmental conditions for optimal enzyme activity.
3. Limited knowledge of fungal metabolism and genetics compared to bacteria.

Comparison of Bacteria and Fungi in Bioremediation

Aspect	Bacteria	Fungi
Growth Rate	Rapid	Slower
Substrate Range	Limited	Broad
Enzyme Systems	Intracellular and extracellular	Mainly extracellular
Target Pollutants	Hydrocarbons, metals, organic waste	Persistent organics, lignin-like compounds
Environmental Suitability	Diverse, including anaerobic	Prefer aerobic environments
Adaptability	High	Moderate

Integrated Bioremediation Approach

- An integrated approach combining bacteria and fungi often yields better results, as their complementary abilities can address a broader range of pollutants. For instance:

1. Bacteria can rapidly degrade simple hydrocarbons, while fungi break down more complex and recalcitrant compounds.
2. Co-cultivation of bacteria and fungi can enhance the efficiency of processes like soil and wastewater treatment.

White Rot Fungi

- ***Characteristics***
- White rot fungi are basidiomycetes that are primarily known for their ability to degrade lignin, a complex and recalcitrant component of wood. They produce extracellular oxidative enzymes that allow them to break down not only lignin but also a variety of environmental pollutants.
- ***Examples***
- *Phanerochaete chrysosporium*
- *Trametes versicolor*
- *Pleurotus ostreatus*

Mechanism of Action

- Extracellular Enzymes:
  - Lignin peroxidase (LiP)
  - Manganese peroxidase (MnP)
  - Laccase
    These enzymes generate free radicals that can oxidize and break down lignin-like structures and other complex organic pollutants.

- ***Uses***

1. Degradation of Persistent Organic Pollutants (POPs):
   - Effective in breaking down polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins.
2. Textile Industry Effluent Treatment:
   - Degradation of synthetic dyes and other industrial chemicals.
3. Bioremediation of Soils:
   - Used to treat contaminated soils with pesticides, hydrocarbons, and explosives like TNT.
4. Wood and Pulp Industry:
   - Breakdown of lignin during paper production.

- ***Advantages***

1. Broad Substrate Range: Can degrade a variety of complex organic pollutants.
2. Enzymatic Flexibility: Capable of degrading recalcitrant compounds that other organisms cannot.
3. Eco-friendly: Utilizes natural processes without introducing harmful by-products.

- ***Disadvantages***

1. Slow Growth: Compared to bacteria, fungi grow and act more slowly.
2. Environmental Sensitivity: Require specific conditions (e.g., pH, moisture, oxygen) for optimal activity.
3. Nutritional Requirements: Depend on organic substrates for growth, which may limit their application in nutrient-poor environments.

Specialized Degrading Bacteria

- ***Characteristics***
- Bacteria are highly diverse microorganisms that can metabolize various pollutants. Specialized degrading bacteria have evolved to utilize specific pollutants as their primary energy or carbon source.
- ***Examples***

1. *Pseudomonas putida:* Degrades aromatic hydrocarbons, phenols, and pesticides.
2. *Alcanivorax borkumensis:* Breaks down hydrocarbons in oil spills.
3. *Rhodococcus sp.:* Handles aromatic and aliphatic hydrocarbons, nitriles, and chlorinated compounds.
4. *Deinococcus radiodurans:* Degrades radioactive contaminants.

- ***Mechanism of Action***

1. Intracellular Enzymes:
    1. Oxygenases (monooxygenases and dioxygenases)
    2. Hydrolases
    3. Dehalogenases
    These enzymes facilitate the breakdown of pollutants into less harmful intermediates or complete mineralization to CO2_2 and water.

- ***Uses***

1. Oil Spill Cleanup:
    1. Hydrocarbon-degrading bacteria are widely used to remediate oil spills in marine and terrestrial ecosystems.
2. Heavy Metal Detoxification:
    1. Bacteria can immobilize or bioaccumulate heavy metals, reducing their bioavailability.
3. Pesticide Degradation:
    1. Effective in breaking down organophosphates, carbamates, and chlorinated pesticides.
4. Radioactive Waste Treatment:
    1. Capable of surviving and degrading pollutants in highly radioactive environments.

- ***Advantages***

1. Fast Growth and Activity: Rapidly degrade simple and moderately complex pollutants.
2. Specificity: Can target particular pollutants with high efficiency.
3. Genetic Modifiability: Easily engineered to enhance biodegradation capabilities.
4. Operates in Diverse Conditions: Functions well in both aerobic and anaerobic environments.

- ***Disadvantages***

1. Limited Substrate Range: Cannot handle highly complex pollutants like lignin effectively.
2. Nutritional Dependency: May require external nutrients to support their growth.
3. Competition with Native Microorganisms: Effectiveness can be reduced in complex microbial ecosystems.

Comparison Table

Aspect	White Rot Fungi	Specialized Degrading Bacteria
Target Pollutants	Persistent organic pollutants (POPs), lignin-like compounds	Hydrocarbons, heavy metals, radioactive waste
Degradation Speed	Slow	Fast
Substrate Range	Broad	Limited
Enzyme Systems	Extracellular enzymes (e.g., laccase)	Intracellular enzymes (e.g., oxygenases)
Environmental Conditions	**Requires specific conditions (e.g., moisture, pH)**	**Adaptable to various environments**
Cost-effectiveness	Moderate	High
Applications	Organic pollutant degradation	Hydrocarbons, pesticides, and metals
Adaptability	Moderate	High

Integration of White Rot Fungi and Bacteria

- Combining white rot fungi and specialized degrading bacteria can create a synergistic effect:

1. Fungi can break down complex pollutants into simpler intermediates, which are then further degraded by bacteria.
2. Co-cultivation enhances the overall biodegradation efficiency and expands the range of pollutants that can be treated.

Phytoremediation: Fundamentals and Major Methods of Application

- Phytoremediation is an eco-friendly, cost-effective technology that uses plants to clean up contaminated environments, particularly soils, water, and air. Plants naturally have the ability to absorb, accumulate, and detoxify pollutants from their surroundings. This process leverages various plant mechanisms, such as uptake through roots, transpiration, and the enzymatic breakdown of pollutants. Phytoremediation offers a sustainable alternative to traditional remediation methods, which are often costly and disruptive.

Fundamentals of Phytoremediation

- Phytoremediation is based on the concept that certain plants can take up contaminants from the environment and either store them in their biomass or convert them into less harmful forms. These plants use their root systems, leaves, and other tissues to interact with pollutants in soil, water, and air. Phytoremediation can be used for a wide range of contaminants, including heavy metals, organic pollutants, and radionuclides.
- Key mechanisms involved in phytoremediation include:
- Uptake: The absorption of contaminants through the plant's root system from the soil or water.
- Translocation: The movement of contaminants from the roots to the stem and leaves.
- Storage: The accumulation of contaminants in the plant's tissues.
- Transformation: The conversion of pollutants into less harmful or inert compounds.
- Volatilization: The release of contaminants into the atmosphere, especially volatile organic compounds (VOCs).
- Phytoremediation can be applied to contaminated sites with a variety of pollutants, including heavy metals, petroleum hydrocarbons, pesticides, and solvents. The success of phytoremediation depends on plant species, pollutant type, and environmental conditions.

Major Methods of Phytoremediation Application

- Phytoremediation can be categorized into several methods, each targeting different types of pollutants and employing different plant mechanisms.
- ***1. Phytoaccumulation (Phytoextraction)***
- Description: Phytoaccumulation is the process where plants absorb pollutants from the soil or water and accumulate them in their tissues, primarily in the roots, stems, or leaves. This method is particularly effective for removing heavy metals and other inorganic contaminants from the environment.
- Mechanism: Plants take up contaminants through their roots and transport them to above-ground parts. These pollutants are stored in vacuoles or bound to cell walls in the plant tissues.
- Target Pollutants: Heavy metals (e.g., lead, cadmium, arsenic, mercury), radioactive materials, and some organic contaminants.

- Examples:
  - *Brassica juncea* (mustard plant) for uptake of cadmium, lead, and zinc.
  - *Helianthus annuus* (sunflower) for uranium and heavy metals.
  - *Thlaspi caerulescens* for zinc and cadmium.
- Applications:
  - Heavy Metal Removal: Phytoaccumulation is widely used for the remediation of soils contaminated with heavy metals, particularly in mining areas.
  - Polluted Water: Certain plants can also accumulate heavy metals from contaminated water bodies, making this method suitable for remediation of aquatic environments.

- Advantages:
  - Can remove a wide range of heavy metals and pollutants.
  - Non-destructive and environmentally friendly.
  - Plants can be harvested for disposal or recycling of metals.
- Disadvantages:
  - Limited by the plant's ability to accumulate large amounts of contaminants.
  - High accumulation might lead to the death of the plant if concentrations exceed tolerable limits.
  - Requires subsequent disposal or recycling of the contaminated plant biomass.

Phytovolatilization

- Description: Phytovolatilization is the process by which plants absorb contaminants from the soil or water and release them into the atmosphere in a transformed, often less toxic, volatile form. This method is particularly useful for removing volatile organic compounds (VOCs) and certain metals.

1. Mechanism: Plants take up pollutants through their roots, transport them to their leaves, and release the contaminants into the atmosphere through transpiration. In some cases, the pollutants are chemically transformed into less harmful forms before being volatilized.

2. Target Pollutants: Volatile organic compounds (e.g., benzene, trichloroethylene), mercury, selenium, and some pesticides.

3. Examples:
   - *Populus* species (poplar trees) for mercury and selenium volatilization.
   - *Phragmites australis* (common reed) for volatile organic compounds.

4. Applications:
   - Volatile Organic Compound (VOC) Remediation: Used to treat contaminated air, especially in industrial sites or landfills where VOCs are prevalent.
   - Mercury and Selenium: Plants like poplars have been used to reduce mercury and selenium contamination from soil or water.

- ***Advantages:***
  - Effective in treating volatile contaminants without requiring soil disturbance.
  - Plants can degrade or detoxify some pollutants before releasing them.
  - Relatively low cost and can be done in situ.

1. Disadvantages:
   - Only effective for volatile contaminants.
   - Potential risk of releasing harmful pollutants into the atmosphere.
   - Limited by the plant species' ability to transform and volatilize contaminants.

Rhizofiltration

- Description: Rhizofiltration is the process in which plants remove pollutants from water through their roots. The contaminants are either absorbed into the root tissues or adsorbed onto the root surface.

1. Mechanism: Water is filtered through the root zone, where contaminants are either absorbed or adsorbed. This method is typically used in the treatment of polluted groundwater or surface water.
2. Target Pollutants: Heavy metals (e.g., lead, mercury, chromium), pesticides, radionuclides, and other organic pollutants.
3. Examples:
   1. *Eichhornia crassipes* (water hyacinth) for removal of heavy metals like lead, mercury, and arsenic.
   2. *Salvinia molesta* (giant water fern) for removal of organic compounds and metals.

1. Applications:
   1. Wastewater Treatment: Rhizofiltration is especially useful for cleaning up industrial effluents, stormwater runoff, and contaminated groundwater.
   2. Heavy Metal Removal from Water: Effective for removing heavy metals from aquatic environments, such as lakes and rivers contaminated by industrial discharge.
2. Advantages:
   1. Highly effective for treating aquatic environments.
   2. Can be used to remove a wide range of contaminants.
   3. Non-toxic and environmentally friendly.
3. Disadvantages:
   1. Only applicable to water bodies, not soils.
   2. Requires continuous management to prevent the spread of invasive aquatic plants.
   3. Pollutant concentration in the plant tissues may eventually reach levels that could harm the plant.

. Phytostabilization

- Description: Phytostabilization is the process in which plants reduce the mobility and bioavailability of contaminants in the soil. The pollutants are not removed from the site but are immobilized in the soil, reducing their potential to spread into the environment.

1. Mechanism: Plants uptake contaminants and either store them in their tissues or precipitate them in the root zone. This process stabilizes the pollutants, preventing them from leaching into groundwater or being taken up by other organisms.
2. Target Pollutants: Heavy metals (e.g., lead, arsenic, zinc), radioactive materials, and some organic pollutants.
3. Examples:
   1. *Vetiveria zizanioides* (vetiver grass) for stabilization of heavy metals like lead and cadmium.
   2. *Alnus glutinosa* (black alder) for stabilization of arsenic.

Applications:

1. Mine Tailings: Phytostabilization is used to stabilize contaminated soils in mining areas, preventing heavy metal leaching.
2. Erosion Control: Plants are used to stabilize contaminated soils and prevent erosion, thereby reducing the spread of pollutants.

1. Advantages:
    1. Prevents the spread of contaminants in the environment.
    2. Low maintenance and cost-effective.
    3. Suitable for long-term management of contaminated sites.
2. Disadvantages:
    1. Does not remove contaminants from the site, only immobilizes them.
    2. May not be effective for highly mobile or volatile contaminants.
    3. May require long-term monitoring to ensure stabilization is maintained.

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