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Biodegradation of xenobiotic compounds

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Abstract
Environmental pollution with organic xenobiotics (pesticides, pharmaceuticals, petroleum compounds, *polycyclic aromatic hydrocarbons* (PAH) and *polychlorinated biphenyls* (*PCB*) *etc*.) is a global problem and the development of inventive remediation technologies for the decontamination of impacted soils are of paramount importance. Physical, chemical and biological methods can be used for the remediation of contaminated soils. However, biodegradation has long been recognized as a cost effective method for the decontamination of soil and water resources. A variety of pollutant attenuation mechanisms are possessed by living organisms which makes remediation of contaminated land and water more feasible than physical and chemical remediation. Biodegradation is expected to be the major mechanism of removal of most of chemicals released into the environment by biological activity. The most important organisms in biodegradation are fungi, bacteria and algae. Biodegradable materials degrade into biomass, carbon dioxide and methane.

Keywords: Bioremediation, xenobiotics

Introduction

Xenobiotic (greek "xenos" = strange, foreign, foreigner) are chemically synthesized compounds found within an organism/Biosphere that is not naturally produced by or expected to be present within and thus are 'foreign to the biosphere'. Xenobiotic compound have been produced artificially by chemical synthesis for industrial or agricultural purposes, e.g. Halogenated H.C., aromatics, pesticides, PAH. Natural substances can also become xenobiotic if they are taken by other organisms such as natural human hormones by fish found downstream of sewage treatment, plant outfalls or chemical defenses produced by some organisms against predators.

Origin of different types of chemical compounds in the environment

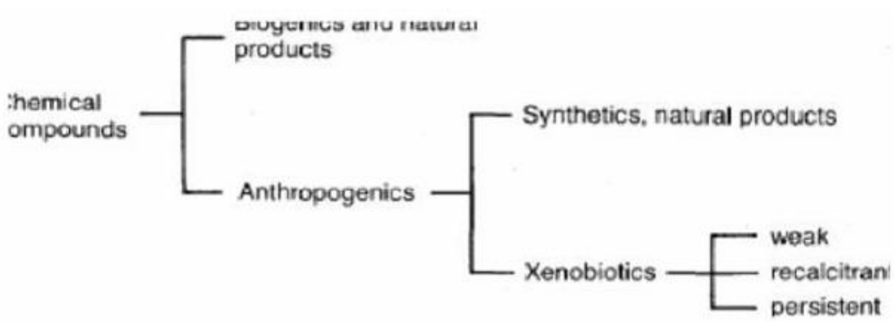

Fig 1: Origin of different types of chemical compounds in the environment

Romi singh during 2017 studied on Origin of different types of chemical compounds in the environment. All substances originated into the environment either by biogenic or anthropogenic sources. Anthropogenic compounds describe synthetic compounds, and compound classes as well as elements and naturally occurring chemical entities which are as weak xenobiotic, however, few of them may persist longer in the environment and not easily degraded is known as recalcitrant compound. A xenobiotic is a chemical which is found in an organism but which is not normally produced or expected to be present in it. It can also cover substances which are present in much higher concentrations than are usual.

The term xenobiotic is also used to refer to organs transplanted from one species to another. For example, some researchers hope that hearts and other organs could be transplanted from pigs to humans.

Source of xenobiotic compounds

1. Petrochemical industry oil/gas industry - Includes refineries and the production of basic chemicals e.g. vinyl chloride and benzenes.
2. Plastic industry - which closely related to the petrochemical industry uses a number of complex organic compounds such as anti-oxidants, plasticizers, cross-linking agents.
3. Pesticide industry most commonly found central structures are benzene and benzene derivatives, often chlorinated and often heterocyclic.
4. Paint industry major ingredient are solvents, xylene, toluene, methyl ethyl ketone, methyl isobutyl ketone and preservatives.
5. Others electronic industry, textile industry, pulp and paper industry, cosmetics and pharmaceutical industry, wood preservation.

Possible environmental fate of a xenobiotic compounds

The fate of xenobioticsin the environment is determined by both abiotic and biotic factors. Xenobiotics are degraded in the environment principally by the action of indigenous microorganism process termed as biodegradation. Which is defined as the breakdown of a substance into small inert end products

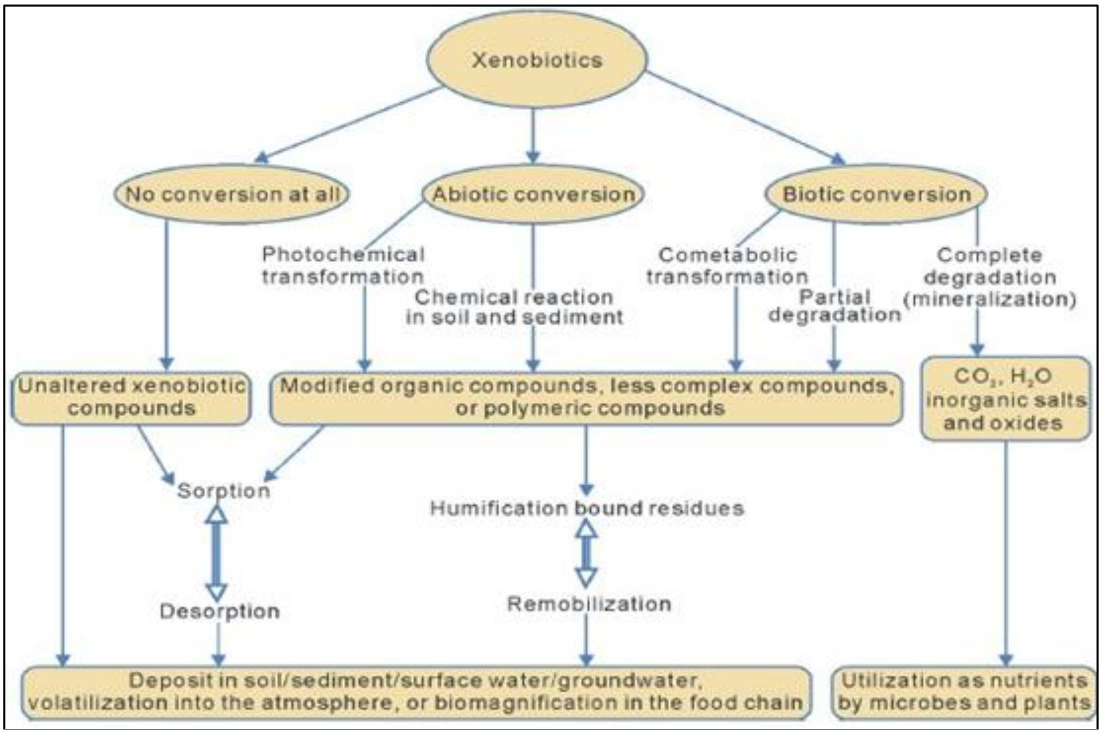

Fig 2: Possible environmental fate of a xenobiotic compounds

Persistence of xenobiotic compounds

These new compounds tend to resist biodegradation, with potential consequences such as persistence in the environment or bioaccumulation in food chains. The presence of artificial groups such as chloro-, nitro- or sulfonate- in many synthetic chemicals makes them resistant to decomposition. The compounds are highly resistant to biodegradation is known as recalcitrant compounds.

Table 1: Persistence of xenobiotic compounds in soil

Xenobiotic compound	Persistence duration
Heptachlor	9 years
Aldrin, Dieldrin	9 years
DDT	10 years
BHC	11 years
Chlorodane	12 years
Diuron	19 months
Simazine	17 months
Atrazine	18 months
Monuron	36 months
2, 4- D	1 to 2 months

Bioremediation

Microorganisms have the ability to act upon xenobiotic and convert them into simpler non-toxic compounds. This process of degradation of xenobiotic and conversion into non-toxic compounds by microorganisms is known as “biodegradation”.

Jame *et al.*, 2010 reported that *Pseudomonas* sp. SA, *Pseudomonas* sp. TK and *Pseudomonas* sp. KA were able to degrade 600 ppm and *Pseudomonas* sp. FA was able to degrade phenol up to 800 ppm of phenol. Complete removal time was also shorter for the isolate *Pseudomonas* FA compares to the other isolates. Patterns of growth were similar for all of the isolates, but maximum growth was found with the isolate FA on 600 ppm phenol. Complete degradation time was decreased with mixed culture and removal rate of phenol was 25 ppmh-1 in mixed culture of all combinations and was higher than that of the single culture of the isolates. In mixed culture study, the growth of bacteria was increased and degradation rate was also

increased similarly Rani and Asha (2012) investigated on biodegradation of phorate in soil and rhizosphere of *Brassica juncea* (L.) by a microbial consortium. Presence of *Brassica juncea* aided the bacterial degradation of phorate in soil as the degradation per cent of phorate increased by 14 per cent in the presence of *Brassica juncea* in comparison with bacterial consortium alone. These results highlight the potential of the plants to be used along with microorganisms for the cleanup of contaminated pesticide waste in the environment.

Method	Description	Advantages	Disadvantages
Thermal	Controlled combustion of either liquid waste or concentrated residue	Destructive Rapid No by-products	High costs Complex Not useful for some chemical
Chemical	Chemical destruction through use of oxidative, reductive, hydrolytic or catalytic reagents	Destructive Rapid	High costs Complex Variable effectiveness
Physical	Removal of chemicals from wastewater by adsorption and/settling	Rapid Possible on-site use	No destruction involved By-products for disposal
Biological	Use of micro-organisms to destroy chemicals	Destructive	High costs Susceptible to shock Relatively slow Variable effectiveness

Fig 3: Xenobiotic remediation methods

Chemical reactions leading to biodegradation of xenobiotics

a. Detoxification: Conversion of the pesticide/ herbicide molecule to a non-toxic compound.
b. Degradation: The breaking down / transformation of a complex substrate into simpler products leading finally to mineralization.
c. Conjugation (complex formation or addition reaction): In which an organism makes the substrate more complex or combines the pesticide with cell metabolites.
d. Activation: It is the conversion of non-toxic substrate into a toxic molecule, for eg. the insecticide phorate is transformed in soil to give metabolites that are also toxic to insects.
e. Changing the spectrum of toxicity: Some fungicides/pesticides are designed to control one particular group of organisms / pests, but they are metabolized to yield products inhibitory to entirely dissimilar groups of organisms, for e.g. the PCNB fungicide is converted in soil to chlorinated benzoic acids that kill plants.
f. Leaching: Since many of the pesticides can be solublized, they are removed by leaching.

General Features of the Microbial Degradation of Xenobiotics

1. Biodegradation: It involves the breakdown of organic compounds, usually by microorganisms, into biomass and less complex compounds, and ultimately to water, carbon dioxide, and the oxides or mineral salts of other elements present.
2. Biotransformation: is the metabolic modification of the molecular structure of a compound, resulting in the loss or alteration of some characteristic properties of the original compound.
3. Co-metabolism: A microbial population growing on one compound may fortunately transform a contaminating chemical that cannot be used as carbon and energy source, a process referred to as co-metabolism.

Factors influence on biodegradation of xenobiotics

Shahgoli and Ahangar, 2014 reviewed on factors controlling the degradation of pesticides in the soil environment. The sorption, desorption, degradation and biodegradation is influenced by physical and chemical characteristics of soil system, such as moisture content, organic matter, clay type, nutrients, temperature, salinity and pH. Various other factors that affect bacterial degradation of pesticides in soil. They are

The soil

1. Presence and number of appropriate microorganisms
2. Contact between the microbe and the substrate
3. pH, temperature and salinity
4. Available water
5. Oxygen tension and Redox potential
6. Nutrient availability
7. Presence of alternative carbon substrates
8. Light quality and intensity
9. Binding to surfaces
10. Alternative electron acceptors

Jadav *et al.*, (2013) studied the Influence of physical parameters, such as pH and temperature on biodegradation of dimethoate by *Actinomycetes sp.* isolated from pesticide contaminated grape garden. However the results showed that optimal pH and temperature growth conditions were 8.5 and 30°C, respectively. The microbial consortia could prove to play a valuable role for the biodegradiation of dimethoate contaminated soil and similarly Agamuthu *et al.*, 2013 reported that after 98 days of exposure to the organic matters, biodegradation of used lubricant in the soil were much higher than that of the control set-ups. Cow dung amended set- ups showed 94 per cent biodegradation while sewage sludge amendment gave 82 per cent, as compared to the control set-up (56%). In addition, cow dung amended-soil was found to be improved soil physiochemical characteristics that enabled speedy adaption by the microbes to the contaminated soil. Cow dung and sewage sludge can be an effective organic amendment for the biodegradation of used lubricant contaminated soil.

The molecule

1. Chemical structure, molecular weight and
2. functional groups, e.g -CI, -CH3, -COOH, -OH
3. Concentration and toxicity
4. Solubility in water.

Ryul *et al.*, 2000 studied the biodegradation of pentachlorophenol (PCP) by white rot fungi under ligninolytic and nonligninolytic conditions. The results showed that the degradation of PCP by *Phanerochaeta chrysosporium* was the highest (76%) among the isolated strains and PCP was degraded under ligninolytic as well as nonligninolytic conditions.

Biodegradation Pathway of Xenobiotic Compounds

- Aerobic biodegradation
- Anaerobic biodegradation

Aerobic biodegradation

Some of the Xenobiotics like petroleum hydrocarbons, chlorinated aliphatics, benzene, toluene, phenol, naphthalene, fluorine, pyrene, chloroanilines, pentachlorophenol and dichlorobenzenes are rapid and potentially degraded by the aerobic degradation process many bacterial consortia capable to grow on these chemicals, they are producing enzymes which degrade toxic compounds into nontoxic compounds. The process of conversion of biodegradable material in to gases like CO2, metane and N2 compounds called mineralization, mineralization process is completed, when all the biodegradable biomass is consumed and all the carbon is converted into CO2.

Xenobiotic compound + O2----------------CO2 + H2O + biomass + residue(s)

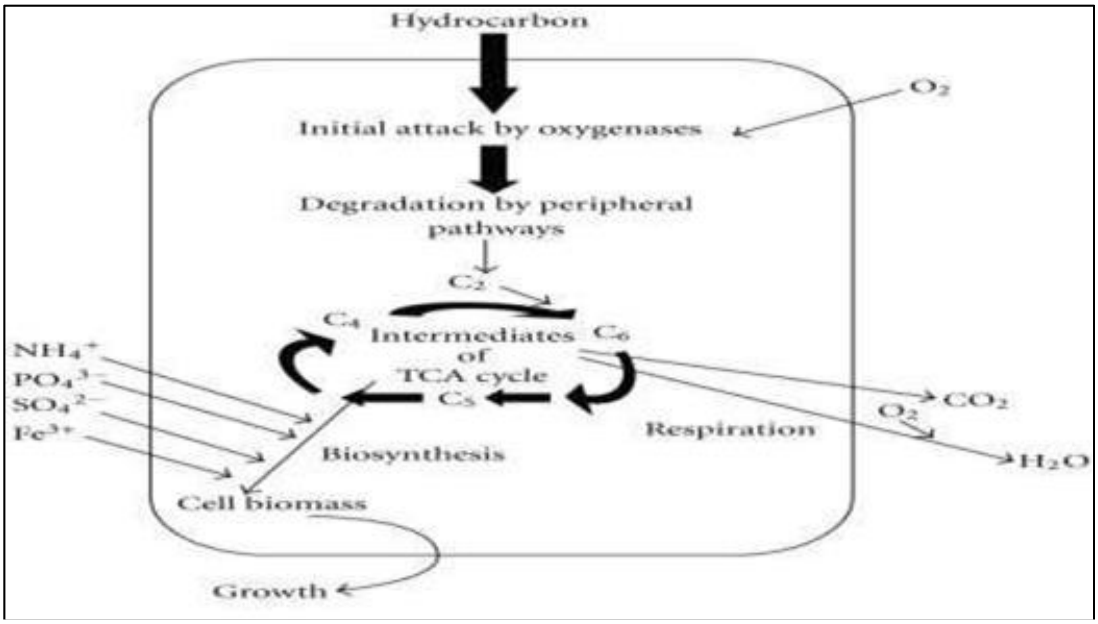

Fig 4: Aerobic biodegradation

Anaerobic biodegradation

Some pollutants are not mineralized by aerobic degradation process. They are Polychlorinated biphenyls (PCBs), chlorinated dioxins and some pesticides like DDT, it is necessary to overcome the high persistence of halogenated xenobiotics from the biosphere for achieving these reductive attack by anaerobic bacteria. A bacteria that capable of degradation of xenobiotics like Pseudomonas, Desulfovibrio spp. Desulfuromonas michiganesis.

Xenobiotic compound------------------------ CO2 + CH4 + H2O + biomass + residue(s)

The hazards posed by xenobiotics

1. These compounds are highly toxic in nature and can affect survival of lower as well as higher eukaryotes.
2. It also poses health hazards to humans like various skin problems, reproductive and even known as a trigger for causing cancer.
3. These compounds are persistent and remain in the environment for many years leading to bioaccumulation or biomagnification.
4. They also find a way into the food chains and the concentrations of such compounds was found to be high even in organisms that do not come in contact with xenobiotics directly.

Effect on plants

1. The insecticides like DDT, methyl parathion, and especially pentachlorophenol have been shown to interfere with legume-rhizobium chemical signalling.

2. Reduction of this symbiotic chemical signalling results in reduced nitrogen fixation and thus reduced crop yields.

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