ROLE OF BACTERIA AND PLANTS ON DEGRADATION OF XENOBIOTICCOMPOUNDS – A REVIEW

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ABSTRACT:

Xenobioticcompoundsareman-madecompoundsandwidelyusedindyes,drugs,pesticides,herbicides,insecticides,explosives,andotherindustrialchemicals.Thesecompoundshavebeenreleased into our soil and water due to anthropogenic activities and improper waste disposal practicesand cause serious damage to aquatic and terrestrial ecosystems due to their toxic nature. Remediation is the only way to tackle these so called xenobiotic compounds and to reduce the hazards caused by them. Even though, several practices have been implemented for degrading these recalcitrants, bioremediation step is proved to show the significant impact on them. Giving a brief note on types of xenobionts and their impact on the environment, this study attempts to highlight on different xenobiotic degradationmethodslikebacterialbioremediation,,phytoremediation,etc.

Keywords:xenobiotics ,bioaccumulation ,biodegradation ,anthropogenic :Remediation; Industrial effluents; Xenobiotics; Phytoremediation;

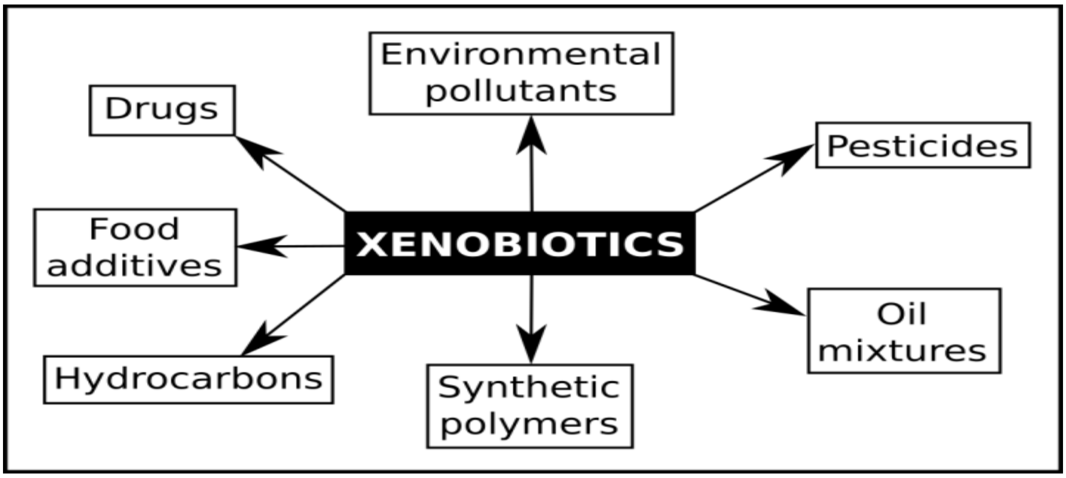
INTRODUCTION:

Xenobiotic is a chemical compound identified within an organism that was not created naturally or that was not expected to be present. Compounds present in higher concentrations than usual can also be considered as Xenobiotic Substance. Plant constituents, drugs, pesticides, cosmetics, flavorings, fragrances, food additives, industrial chemicals, and environmental pollutants are some examples of xenobiotics1. Natural compounds can also become xenobiotics if they aretaken up by another organism, such as the uptake of natural human hormones by fish founddownstreamofsewagetreatmentplantoutfalls,orthechemicaldefensesproducedbysomeorganisms as protection against predators.[2].The term xenobiotics, however, is very oftenused in the context of pollutants such as dioxins and polychlorinated biphenyls and theireffect on the biota, because xenobiotics are understood as substances foreign to an entirebiologicalsystem,i.e.artificialsubstances,whichdidnotexistinnaturebeforetheirsynthesis .3The potential health hazard of a xenobiotic compound is a function of its persistence in the environment as wellas thetoxicityofthechemicalclass[4].The UnitedStatesEnvironmentalProtectionAgency(USEPA)haslistedseveraltoxicsubstancesaspriority pollutants. Bacterial remediation is identified as an emerging technique to remove these substancesfromtheenvironment.4Manybacterialgeneraareactivelyinvolvedinthedegradationo ftoxicsubstances. Among the bacterial genera, the members of the genus Bacillus have a great potential todegrade or transform various toxic substances. Many Bacilli have been isolated and characterized bytheir ability to degrade or transform a wide range of compounds including both naturally occurringsubstances and xenobiotic compounds. Environmental pollution caused by the release of a these wide range of compounds (i.e. persistent organic pollutants, POPs) from industries are creating disturbance to the ecosystem [3],causingclimaticchanges,reductionofwaterlevelsinthegroundaswell as oceans, melting of icecaps, global warming, ozone layer depletion due to photochemical oxidation etc. [4,5] and this made ecologists tofocus more on impacts of pollution and itsreduction.

Features of xenobiotic compounds

Xenobiotics are highly stable in nature. They are not recognized as substrates by degenerative organisms Their solubility in water is very low or insoluble. Highly toxic i.e toxicity of the. Since xenobiotic compounds' molecular weight is very high they reduce the chances of entry into microbial cells .Xenobiotics such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and trichloroethylene (TCE) accumulate in the environment due to their recalcitrant properties and have become an environmental concern due to their toxicity and accumulation. T mostly recalcitrant i.e they don't cooperate with other chemicals . his occurs particularly in the subsurface environment and water sources, as well as in biological systems, having the potential to impact human health.[5] Some of the main sources ofpollutionandtheintroductionofxenobioticsintotheenvironmentcomefromlargeindustriessuch as pharmaceuticals, fossil fuels, pulp and paper bleaching and agriculture.[6]] Forexample, they may be synthetic organochlorides such as plastics and pesticides, or naturallyoccurringorganicchemicalssuchaspolyaromatichydrocarbons(PAHs)andsomefraction sofcrude oil and coal. There are numerous Xenobiotic substances in sewage so this is an issuein Sewage Treatment systems, as [7]Different xenobiotic substancewill present its ownproblemsastohowtoremovethem(andwhether itis worthtrying to) is still a bigger problem.

Xenobiotic Compounds - Types



Sources of xenobiotics

Direct sources: The prime direct source of xenobiotics is wastewater and solid residual releases from the industries like chemical and pharma, plastics, paper and pulp mills, textile mills, agricultural (enhancement products like pesticides, herbicides etc.) (Figure 1). Some of the common residual compounds in the wastewater and other effluents are Phenol, hydrocarbons, different dyes, paint effluents, Pesticides and Insecticides etc.(8)

Indirect sources: Indirect sources of xenobiotics include NSAIDs, pharmaceutical compounds, pesticide residues etc.. These mainly include hormones, anesthetics and antibiotics which bioaccumulate in an organism and passed on the other through the common food chain [9]. Biomaterials developed from the synthetic polymers have the biocompatibility but their degradation into toxic substances in the body is a cause for concern [10]. Even though they are the indirect sources, they cause adverse effect on the ecological cycle. Pollution of aquatic and soil is a worldwide problem that can result in uptake and accumulation of toxic chemicals in food chains and also harm to the flora and fauna of affected habitats [11]. Studies of bioaccumulation characteristics of various ecosystem is essential for long term planning of industrial waste disposal in ecosystem [12]. Bioaccumulation of pesticides and biomagnification processes lead to toxic behavioral effect on animals and mankind. DDT, having a half life of 10 years and BHC are chemicals used in pesticides accumulate in the plant or in plant parts like fruits and vegetables [13]. Non Steroidal Anti-inflammatory Drugs (NSAIDs) are a large diverse chemical group of drugs used in humans and animals for the treatment of inflammation, pain and fever (analgesic) [14]. Diclofenac use in animals has been reported to have led to a sharp decline in the vulture population, 95% decline in 2003, 99.9% decline as of 2008 [15]. Environmental Protection Agency (EPA) is in action to reduce the bioaccumulation and biomagnifications of various such xenobiotics by some genetic modifications and biodegradation strategie

ESTIMATION OF XENOBIOTICS

To estimate the level of xenobiotics in biological systems, the bioaccumulation tests are performed and the results of these tests are expressed in term of bioconcentration factor (BCF). The BCF may be defined as the ratio of average concentration of chemical in the tissues of test organisms in relation to its concentration in the surrounding medium. For instance, BCF for aquatic ecosystem may be expressed as:

BCF = Concentration of chemical in tissues of organisms

Concentration of chemical in water

where CD is the chemical concentration in the organism (g chemical/ kg organism), Cs is the chemical concentration in the sediment (g chemical/kg dry weight sediment), L is the concentration of lipid in the organism (g lipid/ g organism), and TOC is the total organic carbon content in the sediments (g organic carboni g dry weight sediment). The amount of lipid factor comes in the calculation because mostly hydrophobic organic chemicals bioaccumulate in the lipid tissues of organisms11

Xenobiotic degradation

Several methods like physico-chemical and biological methods have been employed in the treatment or removal of xenobiotics. The physico-chemical methods are costly and often produce undesirable products which are toxic, requiring further treatment steps[11]. Such type of techniques often add fragmented elements which cannot be degraded easily and will make the environment still worse. To overcome these problems, many other eco-friendly techniques have been reported such as Bioremediation, phytoremediation etc.(Figure 2).

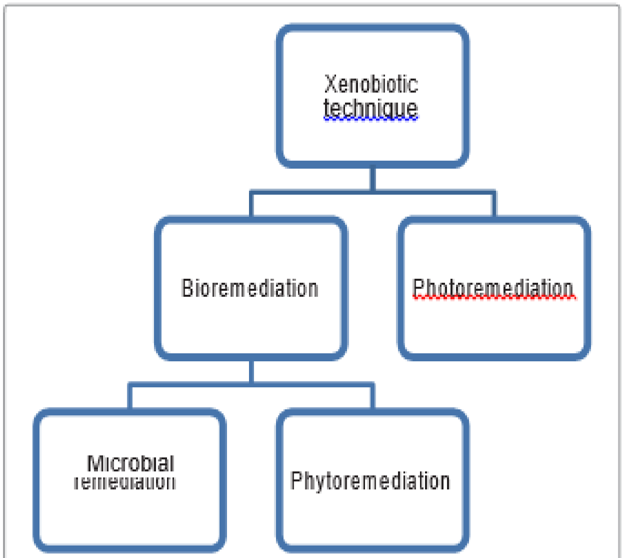
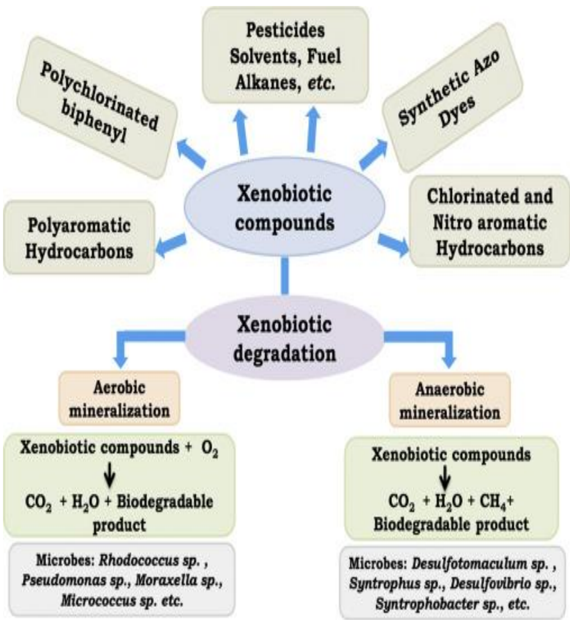


Figure 2: Classification showing different Xenobiotic techniques.



Microbial biodegradation is carried out by different organismslike Bacteria, Fungus, and Algae (Figure3).1. Microbial degradation of xenobiotics is one of the important way to remove the environmentally harmful compounds. The potential of microorganisms to metabolize xenobiotic compounds has been recognizedasaneffectivemeansoftoxicandhazardouswasteremoval [11,36].

Bioremediation can be defined as any process that uses microorganisms or their enzymes to return the environment altered by contaminants to its original condition [17]. It can also be described as "a treatability technology that uses biological activity to reduce the concentration or toxicity of a pollutant [18]. Bioremediation process involvesdetoxificationandmineralization,wherethewasteisconverted into inorganic compounds such as carbon dioxide, water and methane [19]. When compounds are persistent in the environment, their biodegradationoftenproceedsthroughmultiplestepsutilizingdifferent enzyme systems or different microbial populations. Contaminated wastewater, ground or surface waters, soils, sediments and air where there has been either accidental or intentional release of pollutants or chemicalsarethesiteswherebioremediationareemployed[20,21].

Microbialbioremediation:Takingthewasteproductofoneprocess and using it as fuel or food for another process is one way to get done biodegradation; it makes intelligent use of resources decreasing the pollution and microbes does the same. They use these residual compounds as one of their substrate and grow on them, degrading or fragmenting them, which is highly valuable in case of bioremediation [22,23].

Effective Microorganism (EM) is the consortia of valuable and naturally occurring microorganisms which secretes organic acids and enzymes for utilization and degradation of anthropogenic compounds [24].Thesedays,microbesarecollectedfromthewastewater,residual sites and distillery sludges which are believed to have the resistance against the hazardous compounds. This is particularly due to their tolerance capacity even at the higher concentrations of xenobionts [25]. Heavy metals and toxic organic pollutants which are believed to have resistance towards some of the microbes can be degraded using these tolerant microbes [26]. Microbial consortium used in activated sludges and aerated lagoons are used recently for solid waste effluent removal [27]. Biofilter technology is used to remove the hazardous chemicals and heavy metals from the effluents which contain these microbes capable of utilizing the substrates rapidly due to its high surfacetovolumeratioandfixedcellnature[28,29]. Different microorganisms including bacteria (Pseudomonas, Alcaligenes,Cellulosimicrobium, Microbacterium, Micrococcus, Methanospirillum, Aeromonas, Bacillus,Sphingobium,Flavobacterium,andRhodococcus),fungi(Aspergillus,Penicillium,Trichoderma, and Fusarium), and yeasts (Pichia, Rhodotorula, Candida, Aureobasidium, andExophiala) have been reported to be involved in the efficient biodegradation of xenobioticcompoundsfromcontaminatedsoil/waterenvironments,duetotheirexceptionalbioremediationpotential.[19]ThegenusBacillusbelongstothefamilyBacillaceaethatcomprisesof293 species/subspecies

Microorganisms alplytwomodeof actionfordegradationofxenobioticcompound

1. aerobicdegradation

Xenobioticcompound+O_2 -------- CO_2+H_2O+biomass

2. Anaerobicdegradation

Xenobioticcompound --------- CO2+CH4+H2O+biomass
Microbialdegradationofxenobioticcompound.XenobioticcompoundareHalocarbon,Polychlorinate Biphenyls,alkylbenzylsulphonate,oilmixtureandotherXenobioticcompounds.

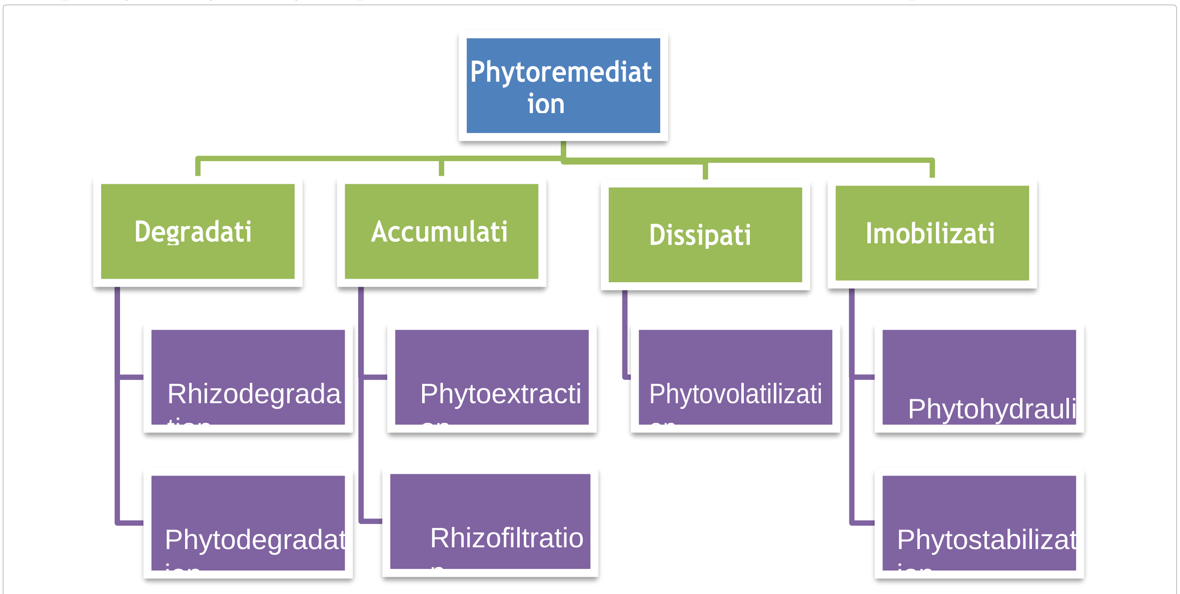


Figure 5: Phytoremediation techniques for xenobiotic

The current study deals with importance of xenobiotic degradation giving preference to different types of remediation process like

- Bacteria Remediation
- Phytoremediation
- Photoremediation
- Othertechniques

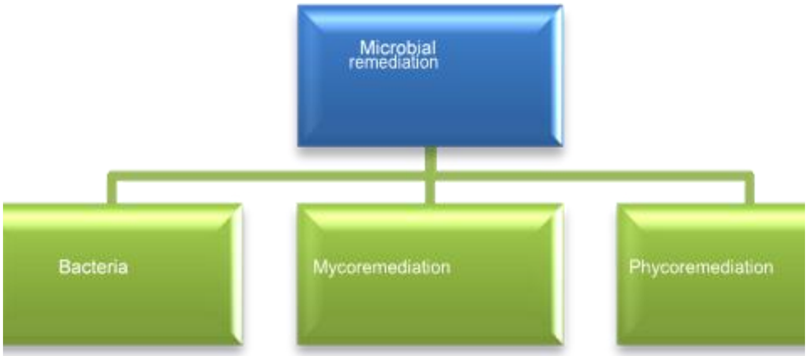


Fig 6 Different types of microbial degradation

Bacteria-Biotic actors in Xenobiotic degradation: The basic sequence followed by bacteria for biodegradation of xenobiotics compounds are (Figure 4). Bacteria which endure

Xenobiotic compound	Bacteria Involved in Degradation

bio-fix, a wide range of xenobiotic chemicals include aerobic, anaerobic, Methanotrophic, methanogenic bacteria, cyanobacteria and Sphingomonads [10] (Figure 5).a)

Aerobic bacteria: Pseudomonas, Escherichia, Sphingobium, Pan- doraea, Rhodococcus, Gordonia, Bacillus, Moraxella, Micrococcus.

b) Anaerobic bacteria: Pelatomaculum, Desulfotomaculum, Syntro- phobacter, Syntrophus, Desulphovibrio, Methanospirillum, Meth- anosaeta [1].

c)Methanogenic bacteria and Methanotrophic bacteria: The process of degrading hydrocarbons resulting methane gas and carbon dioxide as end product is called Methanogenesis [2]. Methanotrophs use oxygen to oxidize methane into carbon dioxide. Methane monooxygenase, enzyme generated by methanotrophs to react with methane can degrade a wide variety of chlorinated hydrocarbons.

d)Cyanobacteria: Cyanobacterial consortia are generally used for degradation of oil derivatives. The use of cyanobacterial mats for bioremediation will avoid the costly use of organic and inorganic fertilizers and their maintenance at large scale can take an advantage [3].

e)Sphingomonads: Sphingomonads have a high capacity to degrade wide range of xenobiotics, including synthetic polymers, aromatic compounds etc and due to its plasmid-borne mechanism. Many Sphingomonads contain large plasmids responsible for xenobiotics degradation which also help them to adapt to new environment quickly. Sphingomonads show adverse effect on polyethylene glycol (PEG) and polyvinyl-alcohol (PVA) degradation

Phenol	*Cryptococcus elinovic Bacillus sterothermophilusBurkholderiacepacia*G4 *Pseudomonas putida Pseudomonas aeruginosa Acinetobacter* sp. *Strain* W-17 [11]
Dyes (textile effluent)	*Serratiamarinorubra* *Bacillus* sp. YW and YDLK consortia *Acinetobactersp* *ThermophilicAnoxybacilluspushchi- noensis* *Anoxibacilluskamchatkensis* *Anoxibacillusflavithermus*
Pesticides and Fungicides	*Pseudomonas* A3 *Pseudomonas putida* *P. aeruginosaSerratiamarinorubra*
Plastics	*BrevibaccillusborstelensisRhodococcusruber* *Pseudomonas aeroginosa*

Phytoremediation: Phytoremediation (also called as green remediation, botano-remediation, agro remediation, and vegetative remediation) is method that use green or higher terrestrial plants for treating chemically polluted soils [30], reducing the amount of hazardous compounds [30]. USEPA (2000) defines phytoremediation as "the use of plants for containment, degradation or extraction of xenobiotics from water or soil substrates" [30]. Using green plants asweapons,phytoremediationisoneofmosteco-friendlytechniquetotarget the organic and inorganic pollutants in the water, soil and air simultaneously.

Plants have exposed the capacity to withstand relatively high concentrations of organic xenobiotic chemicals without toxic effects [26] and also have capacity to take up and convert chemicals quickly tolesstoxicmetabolites[32].Deeproots,luxuriantleaveshavespecial sorptive properties and the associated bacteria in root zones allow plants to absorb, take-up, accumulate, metabolize and/or degrade the pollutants from water, soil andair.

Phytoremediation can be classified in to subcategories depending up on the type of remediation (Figure 6).

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1. **Rhizodegradation:** Rhizodegradation is the enhancement of naturally-occurring biodegradation in soil through the influence of plant roots, and ideally will lead to destruction or detoxification of an organic contaminant. A wide range of organic contaminants are candidates for rhizodegradation, such as petroleum hydrocarbons, PAHs, pesticides, polychlorinated biphenyls (PCBs), surfactants and chlorinatedsolvents.

2. **Phytodegradation:**Phytodegradation,alsocalledasphytotransfor- mation, is the uptake, metabolizing, and degradation of contami- nants within the plant, or the degradation of contaminants in the soil,sediments,sludges,groundwater,orsurfacewaterbyenzymes produced and released by the plant. The term "Green Liver Model" is used to describe phytotransformation, as plants behave analo- gously to the human liver when dealing with these xenobiotic com- pounds (foreign compound/pollutant). Chlorinated solvents like TCE, some organic herbicides and trinitrotoluene can be degraded using this method[33].

3. **Phytoextraction:** Phytoextraction (also known as phytoaccumu- lation, phytoabsorption, and phytosequestration) is contaminant uptake by roots with subsequent accumulation in the aboveground portion of a plant, generally to be followed by harvest and ulti- mate disposal of the plant biomass. Phytoextraction has also been referred to as phytomining or biomining. Phytomining is the use of plants to obtain a gain from hyperaccumulated metals extracted by a plant, whether from contaminated soils or from soils having naturally high concentrations of metals. This is particularly useful for removing metals from soil and, in some cases; incorporation of plant incinerations will help metal reuse [33]. These processes extract both metallic and organic constituents from soil by direct uptake into plants and translocation to aboveground biomass using metal- (hyper) accumulating plants. *Brassica juncea*, *Berkeyacod-dii*,*Allysumbertolonii*,*Thlaspicaerulescens*and*Thlaspigoesingense*are some of the plants involved in phytoextraction [34]. The main advantage of phytoextraction is the process is eco- friendly but will take more time than anthropogenic soil clean-upmethods.

4. **Rhizofiltration:** Rhizofiltration (also known as phytofiltration) is the removal by plant roots of contaminants in surface water, waste water, or extracted ground water, through

adsorption or precipitation onto the roots, or absorption into the roots. Here accumulation can occur in root or can be retained in any portion of the plant. Plants used for rhizofiltration are not planted directly in situ but are acclimated to the pollutant first, which makes the process little tedious and time consuming. Sunflowers grown in radioactively contaminated pools exemplify thisprocess.

Phytovolatilization: Phytovolatilization is the uptake of a water soluble contaminant by a plant, and the subsequent release of avol-atile contaminant, a volatile degradation product of a contaminant, or a volatile form of an initially non-volatile contaminant. Plants as phytovolatilizers have to be studied still for better utilization.

5. **Phytohydraulics(hydraulicplumecontrol):**Phytohydraulicsisthe use of deep-rooted plants to degrade ground water contaminantsthat come into contact with their roots. Ground water plume of methyl-tert-butyl-ether (MTBE) has been recovered using this technique[35].

6. **Phytostabilization:** Phytostabilization (also called as phytoimmo- bilization) is the use of plants to immobilize soil and water con- taminants. Some organic contaminants or metabolic byproducts of these contaminants can be attached or incorporated into plant com- ponents such as lignin and such type of phytostabilization is called phytolignification [36]. Indian mustard appeared to have potential forphytostabilization.

7. **Recent trends used in phytoremediation:** A recent strategy to improve phytoremediation and detoxification of contaminants is the use of endophytic bacteria which are often found genera in soil like*Pseudomonas*,*Burkholderia*,*Bacillus*,and*Azospirillum*[32).

moGdiefinceattiiconoffersanewhopefor phytoremediationas they can be used to over express the enzymes involved in the existing plant metabolic pathways or to introduce new pathways into plants [37]. With increased understanding of the enzymatic processes involved in plant tolerance and metabolism of xenobiotic chemicals, there is new potential for engineering plants with increased phytoremediation capabilities [37]. Transgenic plants thatoverexpressmercury-resistancegeneshavebeenreportedtobe highlyresistanttoorganicmercuryandareeffectivefordegradation, thus bringing a new advancement in the phytodegradation processmoGdiefinceattiiconoffersanewhopefor phytoremediationTransgenicplants thatoverexpressmercury-resistancegeneshavebeenreportedtobe highlyresistanttoorganicmercuryandareeffectivefordegradation, thus bringing a new advancement in the phytodegradation process [38]MeRagichhearrdintroducedanewpathwayinto*Arabidopsis*to detoxify methyl mercury, a bioaccumulativeorganometaliccation, totheelementalmercurywhichcanbevolatilizedbytheplant [39].

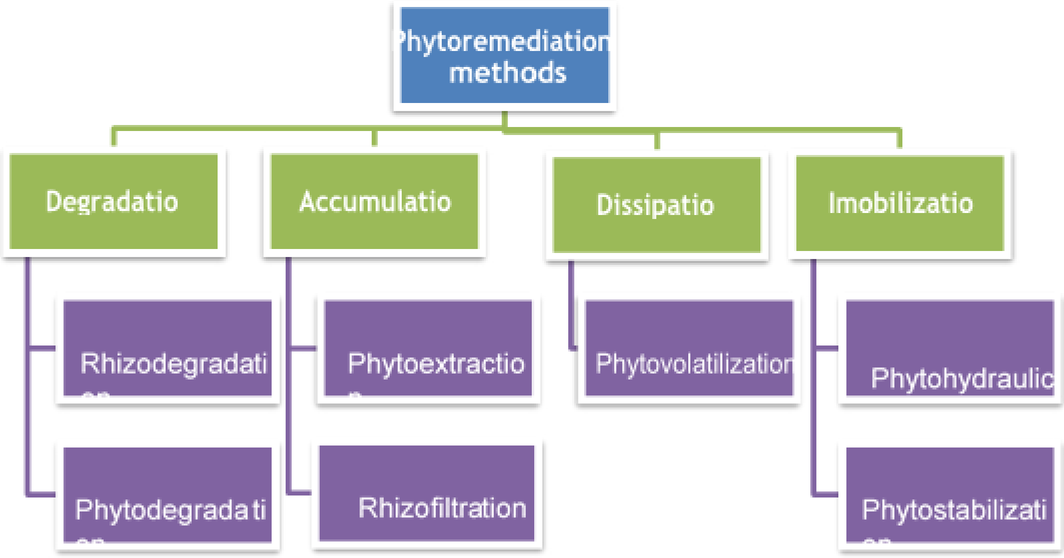

Figure 6: Phytoremediation techniques for xenobiotic

8. **Pros and cons of phytoremediation:** Phytoremediation is considered a clean, cost-effective and non-environmentally disruptive technology, as opposed to mechanical cleanup methods such as soil excavation or pumping polluted groundwater [40]. Over the past 20 years, this technology progressed and has been employed at sites with soils contaminated with arsenic, lead and uranium. On the other hand, one major disadvantage of phytoremediation is that it requires a long-term commitment, as the process is dependent on plant growth, bioaccumulation capacity and tolerance totoxicity.(41)Although phytoremediation is a promising technique to remove pollutants, it is still an immature and developing technology to deal with pollution problems. However, it is clear thatphytoremediation already plays animportant role in removing pollutants from the environment we just need to find the right plant for the right pollutant[42].

CONCLUSION

Due to the resistivity of xenobiotics they are highly resistive and complex. There is a need to control the spread of these compounds in the food chain and prevent their further magnification. For the removal and detoxification of toxins from the environment, the microbial bioremediation technique has recently emerged as the best alternative. Synthetic biology is addressing xenobiotic and related compound decontamination and remediation solutions in the environment. It has been discovered that understanding existing metabolic pathways is a prerequisite for removing xenobiotic compounds. Environmental problems caused by the industrial effluents is mainly due to accumulation of pollutants and other fragmented compounds, which in turn form into other substitutes (natural or manmade), finally forming a xenobiont. There is a quick need to degrade these xenobiotic compounds in an eco-friendly way. Various techniques like microbial remediation, phytoremediation and photoremediation and their subtypes have been discussed

FUTUREASPECTS

Environmentandlivingorganismsareoftenthreatenedbyxenobioticcontaminantsreleasedint othe environmentfromextensive anthropogenic One aspect is the biological persistence and the present paper reviews work in this fieldfocusingonthedegradationofxenobioticsintheenvironment. The future will be the whole microbial bioremediation foundtocoverwiderangeofrecalcitrantdegradationandabetterchoicebecauseofitsnatureofd egradation with almost negligible impact on the environment.

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