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TOPIC: **Bioremediation: Future Prospects and Challenges**

Bioremediation in its crudest sense is nothing but the attempt to restore or clean-up contaminated sites including that of water, soil, sub-surface areas with the collective aid of some bacterial consortia. The aim is to either neutralize or reduce the concerned target pollutants/contaminants to atleast a non-toxic level. One going deeper into the history of bioremediation, will eventually find out that this process can be traced back to 600BC or so when the Romans are documented to have used microorganisms to treat their wastewater. The process gained popularity in the 1960s when George M. Robinson experimentally proved the fact that indeed microbial communities are there which can clean up pollutants by enzymatic activities while he was working in his laboratory with some dirty jars. After Dr. Ananda Mohan Chakraborty's finding of "superbug" *Pseudomonas putida* to be an efficient oil-spill cleaner in 1970, the first commercial use of this process was done to clean the Sun Oil pipeline spill in Pennsylvania. Since then, the ever-emerging field of bioremediation have been experiencing newer methods, better yield of microorganisms at every step of its journey and now, with synthetic biology (SynBio) tools working hand-in-hand to make a greener and cleaner environment.

Bioremediation methodology depends on the site and type of pollutant that needs to be neutralized. Based on these parameters, there can be ex-situ bioremediation techniques like biopiling, windrow, land-farming and bioreactor methodologies. On the other hand, in-situ bioremediation includes that of biosparging, bioslurping, bioventing and phytoremediation, the last one being done by plants species. With the advent of SynBio, now it is a very demanding field where new gene combinations are being tried out to generate synthetic microorganisms to deal with multiple different bioremediation processes all at a time. From the beginning of the 20th century, there has been a tremendous increase in newer anthropomorphic chemicals and xenobiotics which naturally occurring microbes have not evolved till now to degrade those. Rapid progress in genetic engineering have led to novel bacterial species with either modified genomes or engineered plasmids encoding genes compatible to detoxification of complex xenobiotics. In developing countries such as those of Asia, biosensor microorganisms such as *Geobacter sulfurreducens* and *Schewanella oneidensis* are being applied to industrial areas to monitor pollutant levels in soil by modifying them such as to be able to generate electricity in minute scales upon degradation of organic pollutants. Artificial organelles built specifically for retrieving excess phosphate from soil has been possible, while on the other hand recombinant protein containing nano-compartments have been employed for neutralizing the heavy-metal toxicity problem prevailing in urban areas. Heavy metals like mercury (Hg) pollute the environment in a variety of ways, minimal concentrations also affecting the survivability of many microbial and algal species. Scientist have successfully devised a way out of it by reconstructing *Mer* operon as a means of biomonitoring the environmentally relevant levels of

Hg^{2+} along with providing bacteria with the gene encoding extracellular nanofibers that can sequester Hg^{2+} with great efficacy, without creating intracellular toxicity for the participant microorganism. On a similar route, bioremediation have been and is continuously being modified for the goal of creating a cleaner and sustainable environment; be it from degradation of microplastics, aliphatic compounds, textile industry dyes, effluent pesticides or in the area of phytoremediation of explosive compounds or bioconversion of cellulosic waste into bioethanol.

Bioremediation, being an emergent field, in some cases do have constraints and may even come with disadvantageous outcomes. In cases of some organic pollutants, radionuclides and heavy metal contaminations, microbial activity might lead to more toxic byproduct, and this is of serious concern mainly in anaerobic contamination sites. A minor subset of in-situ bioremediation process requires the presence of specific microenvironment for the optimum growth of microorganisms to thrive, which may not be possible all the time. A bacterium which is functional at one site might fail to perform the same reaction owing to changes in pH, salinity, nutrient composition status of the soil for which the process of surface bioremediation often becomes too much extensive and costly. In some cases, it happens that pollutant is scattered in an irregular fashion, in which cases detection becomes a difficult task. Bioventing is rather an inexpensive technique to bioremediate contaminated sites; however, this process is extensive and can take a few years to decontaminate a site which is not feasible to compromise in certain instances. Removal of organic pollutants is easier in many cases, but inorganic contaminants pose some extra challenges. Degradative options for these inorganic pollutants are very less and thereby, the scientific community needs to draw attention towards creating of bio-chelating agents, superior adsorbents or accumulator/trapper species which could extract the pollutants from environment without mixing or tampering with the biological system itself. Bioavailability of several pollutants and site-specific nature of water permeability incase of groundwater pollutions is also a limiting factor for bioremediation processes. Therefore, in a cumulative manner it can be said that the major limitations in the field of bioremediation are the challenge in launching the microorganism from lab to the field, careful handling and controlled biostimulation in concerned microenvironments and the third being the difficulty in ensuring proper contact between contaminant and concerned microorganism. Thus, we see that the future world is in desperate need of more advances and breakthrough technologies in the field of bioremediation for the development of a greener, safer, and sustainable Earth for the future generations.

References:

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