Frontiers in Environmental Microbiology
2015; 1(3): 39-43
Published online September 17, 2015 (http://www.sciencepublishinggroup.com/j/fem)
doi: 10.11648/j.fem.20150103.11

Biological Agents of Bioremediation: A Concise Review

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To cite this article:
Karabi Biswas, Dipak Paul, Sankar Narayan Sinha. Biological Agents of Bioremediation: A Concise Review. *Frontiers in Environmental Microbiology*. Vol. 1, No. 3, 2015, pp. 39-43. doi: 10.11648/j.fem.20150103.11

Abstract: Due to intensive agriculture, rapid industrialization and anthropogenic activities have caused environmental pollution, land degradation and increased pressure on the natural resources and contributing to their adulteration. Bioremediation is the use of biological organisms to destroy, or reduce the hazardous wastes on a contaminated site. Bioremediation is the most potent management tool to control the environmental pollution and recover contaminated soil. Use of biological materials, coupled to other advanced processes is one of the most promising and inexpensive approaches for removing environmental pollutants. Bioremediation technology is a beneficial alternative which leads to degrade of pollutants. This article presents the important biological organisms used in bioremediation technologies.

Keywords: Bioremediation, Biological Organisms, Environmental Pollution

1. Introduction

Heavy metals and organic pollutants are considered to be a significant environmental issue for human health. The contamination of soil and water bodies by organic pollutants and toxic metals has been increased for the past few years due to industrialization, intensive agriculture and anthropogenic activity. Indiscriminate and unrestricted disposal of industrial effluents and urban city sewage into the aquatic environment has become an issue of major global concern [1-3]. Excess loading of unsafe and hazardous waste as led to shortage of clean and hygienic water and disruption of soil this limiting crop production [4].

Bioremediation processes are more attractive than physical and chemical techniques such as ion exchange, electrochemical treatment, reverse osmosis, evaporation, precipitation and sorption for heavy metal removal techniques for lower cost and higher efficiency at low metal concentrations. There are a number of biological materials that can be utilized to remove the hazardous metal from waste water such as bacteria, fungi and algae [5, 6].

Most of the advances in bioremediation have been realized through the assistance of the scientific areas of biochemistry, microbiology, analytical chemistry, molecular biology, environmental and chemical engineering, among others. These different fields, each with its own individual approach, have actively contributed to the development of bioremediation progress in recent years [7].

Now-a-days, the experience accumulated over the last decades, has improved our understanding in many aspects of this multidisciplinary technology. The combined evaluation of the technical and non technical issues is an important step towards the successful application of environmental biotechnology in remediation. The states of the art of bioremediation technology as well as examples of more or less successful case studies are published in many books during the last two decades [8-11].

In this review, different techniques used in bioremediation and the ability of some bacteria, fungi and algae to remediate the organic and inorganic pollutants have been critically discussed.

2. Mechanism of Bioremediation

Bioremediation is a biological treatment system to destroy, or reduce the concentration of hazardous waste from a contaminated site. Thus some definitions restrict to the use of microbes only while others seem to incorporate all the biological entities such as plants (phytoremediation). Whatever, it can be define, in fact in nature the process of biological remediation involves both plants and microbes and rather the plant-microbe interaction in root zone has a very important role. pH is the important factor influencing the adsorption. Crist *et al.* [12] reported that with decreasing pH, the number of binding sites reduced and that pH increased during the metal ion uptake.

3. Agents of Bioremediation

Natural organisms, either indigenous or extraneous, are the important agents used for bioremediation [13]. The organisms vary, depending on the chemical properties of the polluting substances, and are to be chosen cautiously as they only sustain within a stipulated limit of chemical contaminants [13, 14]. The first patent for a biological remediation substance was recorded in 1974, was a strain of *Pseudomonas putida* capable of degrading petroleum [13]. Bioremediation can take place naturally or through intervention processes [15].

4. Bioremediation by Bacteria

The microbes have often been reported for the degradation of pesticides and hydrocarbons. A large number of bacteria utilize the contaminant as the sole carbon and energy sources. They are listed in Table 1 and Table 2.

Metals play important role in the life processes of microbes. Some metals such as chromium (Cr), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), sodium (Na), nickel (Ni) and zinc (Zn) are essential as micronutrients for various metabolic functions and for redox functions.

Table 1. *Bioaccumulation and biotransformation of organic molecules by bacteria.*

Bacteria	Toxic chemicals	References
Bacillus sp	Cresol, phenols, aromatics, long chain alkanes, phenol,	[16]
Pseudomonas sp	Benzene, anthracene, hydrocarbons, PCBs	[16, 17]
Flavobacterium sp	Aromatics	[18]
Azotobacter sp	Aromatics	[18]
Xanthomonas sp	Hydrocarbons, polycyclic hydrocarbons	[18, 19]
Nocardia sp	Hydrocarbons	[20]
Streptomyces sp	Phenoxyacetate, halogenated hydrocarbon, diazinon	[18]
Mycobacterium sp	Aromatics, branched hydrocarbons benzene, cycloparaffins	[21]

Table 2. *Heavy metals utilizing bacteria.*

Bacteria	Heavy metals	References
Bacillus sp	Cu, Zn	[22]
Pseudomonas aeruginosa	U, Cu, Ni, Cr	[23-25]
Aerococcus sp	Pb, Cr, Cd	[26]
Aeromonas sp	Cr	[25]
Rhodopseudomonas palustris	Pb	[27]
Citrobacter sp	Cd, U, Pb	[22, 28]

5. Bioremediation by Fungus

Fungi represent the promising group of microbes for biodegradation (Table 3 and Table 4). The ability of fungi, both yeasts and moulds, to convert a broad variety of hazardous chemical substances has developed interest to use them in bioremediation [9]. Fungi can mineralize xenobiotic compounds to CO_2 and H_2O through their non-specific ligninolytic and highly oxidative enzyme system, which is also responsible for the degradation and decolorization of a wide range of dyes [29, 30].

Table 3. *Bioaccumulation and biotransformation of organic molecules by fungi.*

Fungi	Toxic chemicals	References
Coprinellus radians	PAHs, methylnaphthalenes, and dibenzofurans	[31]
Marasmiellus troyanus	Benzo [a] pirene	[32]
Gloeophyllum trabeum	1, 1, 1-trichloro-2, 2-bis (4-chlorophenyl) ethane (DDT)	[33]
Pleurotus ostreatus	Bisphenol A	[34]
Fomitopsis pinicola	1, 1, 1-trichloro-2, 2-bis (4-chlorophenyl) ethane (DDT)	[33]
Penicillium simplicissimum	Polyethelene	[35]
Phanerochaete chrysosporium	Polyvinylamine sulfonate anthrapyridone	[36]

Table 4. *Heavy metals utilizing fungi.*

Fungi	Heavy metals	References
Rhizopus arrhizus	Ag, Hg	[22]
Stereum hirsutum	Cd, Pb	[37, 38]

6. Bioremediation by Algae

Biodegradation of pesticides is determined by two groups of factors, the first relates to microbial consortium and the optimum condition for their survival and activity while the second relates to the chemical structure of the pesticides. Factors related to microorganisms including the presence and number of appropriate microorganisms, the contact between microorganisms and the substrate (pesticide), pH, temperature, salinity, nutrients, light quality and intensity, available water, oxygen tension and redox potential, surface binding, presence of alternative carbon substrates and alternative electron acceptors. Kobayashi and Rittman [39] showed that not only microalgae have the ability to bioaccumulate pesticides, but also capable to biotransform some of these environmental contaminants.

Table 5. *Bioaccumulation and biotransformation of organic molecules by algae.*

Algae	Elements	References
Chlamydomonas sp	Naphthalene	[39]
Dunaliella sp	Naphthalene, DDT	[39]
Euglena gracilis	DDT, Phenol	[39]
Selenastrum capricornutum	Benzene, toluene, chlorobenzene, 1, 2- dichlorobenzene, nitrobenzene naphthalene, 2, 6-dinitrotoluene, phenanthrene, di-n-butylphthalate, pyrene	[39]
Chlorella sp	Toxaphene	[39]
Cylindrotheca sp	DDT	[39]

The capability of algae to absorb hazardous metals has been known for many years. Algae have the ability to remove toxic heavy metals from the environment, which results in higher concentrations than those of the surrounding water [40]. Algae, related eukaryotic photosynthetic organisms, have exclusively developed the production of different peptides capable to attach heavy metals. These organometallic complexes are further seperated inside vacuoles facilitating proper regulation of the heavy metal ions concentration of cytoplasm, thus neutralizing or preventing their toxic effect [41].

Table 6. *Heavy metals utilizing algae.*

Algae	Heavy metals	References
Zooglea sp	Co, Ni, Cd	[22]
Phormidium valderium	Cd, Co, Cu, Ni	[37, 38]
Chlorella vulgaris	Au, Cu, Ni, U, Pb, Hg, Zn	[22, 42]
Volvariella volvacea	Cu, Hg, Pb	[43, 44]
Oscillatoria sp	Ni, Cu, Co, Pb, Zn	[45]
Tetraselmis chuii	Cu	[46]
Spirogyra hyalina	Cd, Hg, Pb, As	[47]
Chlorella pyrenoidosa	Zn, Cu, As, Pb, Cd, Cr, Ni, Hg	[48]
Lyngbya spiralis	Cd, Pb, Hg	[49]

Table 7. *Bioremediation by higher plant.*

Plants	Contaminants	References
Helianthus annuus	Cu, Pb, EDTA	[50]
Brassica juncea	Pb, Cr, Ni, Zn	[51, 52]
Perennial ryegrass	Cd, Ag	[53]
Alfa alfa	Chlorinated aliphatics	[50]
Nicotiana tabacum	Se, Hg, Ti	[50]
Tagetes patula	Benzo [a] pyrene	[54]
Arundo donax	As	[55]
Typha domingensis	Al, Fe, Zn, Pb	[56]
Solanum nigrum	Cd	[57]
Lemna minor	Cd, Hg, Zn, Mn, Pb, Ag	[58]

7. Bioremediation by Higher Plants

Phytoremediation is well suited for applications in low-permeability soils, where most currently utilized technologies have a low level of success, as well as in combination with more conventional removal technologies (foam migration, electromigration, etc.). In appropriate situations, phytoremediation can be a substitute to the much harsher physical and chemical remediation technologies of thermal vaporization, solvent washing, incineration or other soil washing techniques, which essentially degrade the biological constituents of the soil and can intensely change its physical and chemical properties as well, generating a comparatively nonviable solid waste. Phytoremediation actually improves the soil, leaving a better, effective, soil ecosystem at costs estimated at around one-tenth of those presently acquired methods.

8. Conclusion

Soil and water are being polluted by various organic and inorganic pollutants due to rapid industrialization and use of agrochemicals in imbalanced proportions. Restrictive and clean up measures to avert hazards from contaminated soil belong to the curative soil protection. Bioremediation is a unique and cost-effective technique for cleaning up pollution by intensifying the natural biodegradation processes. So developing an understanding of microbial and plant communities with their response to the natural environment and contaminants, elaborating the knowledge of the genetics of the microorganisms helps to increase capabilities to degrade pollutants and recovery of land and ground water.

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