Chapter 20
Field Application of the Microbial Technology and Its Importance in Sustainable Development

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Abstract Microorganisms are ubiquitous in nature and are a rich source of primary as well as secondary metabolites. The uniqueness of microorganisms and their unpredictable nature attracts them for more and more exploration for the welfare of the humans and society. Products formed by microbes are natural and have the ability to reduce problems like high cost of synthetic chemicals, environmental pollution, hazards to human health, etc., and are helpful in sustaining the environment by applying different microbial technologies and sustainability goals. These indigenous microorganisms are involved in biotechnological field applications such as sustainable agriculture (biofertilizers and PGPR), food technology, chemical technology, recombinant technology, and sustainable environment (wastewater treatment, micro- and nanoparticle synthesis, oil remediation, and radioactive treatment). Apart from this, various strains of microbes are also being modified genetically for defending many environmental sustainability aspects. This review focuses upon the applications of microbial technologies for sustainable development of environment that meets the needs of current generations without compromising the ability of future generation to meet their own needs. Microorganisms like *Micrococcus*, *Pseudomonas*, *Chromobacterium*, *Bacillus*, and many others play a major role in the development of a sustainable environment.

Keywords Microorganisms · Sustainable development · Microbial technologies · Environment

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20.1 Introduction

Microorganisms are small creatures and consist of protozoa, fungi, viruses, microalgae, and bacteria. These microorganisms live in water, animal intestines, food, soil, and different environments (Mosttafiz and Rahman 2012). Microbes can survive extreme environmental challenges. There are many reasons why microorganisms are important, especially because what they produce is valuable to us (Liu 2020). These substances may be very immense substances (such as nucleic acids, proteins, carbohydrate polymers, and cells), or they may be smaller molecules. They are usually divided into metabolites (mainly) essential for vegetative growth and non-essential metabolites (minor). There are many kinds of microorganisms. They play an important contribution to develop sustainable environment and also play a vital role in a series of green processes and cleaner technologies (from biogeochemical cycles to various industrial productions) (Kuhad 2012).

The advanced era provides various means of technology in various fields, and the emergence of the microbes establishes themselves as an advantage for this century. Though the microbes came forefront during the 1660s, their uses in association with technologies marked the beginning of the microbial technology dimension. A microbial technology is defined as a technology that uses microbial system or the organisms or its derivatives for the manufacturing of a product or its modification for any specific purpose. The current situation of the biosphere drives the attention of using any newer technology for its sustainability, and since microbes are a part of the ecosystem, their application for the sustainable development has surrey advantage and acts as a feasible remedy for the global eradication of problems in agriculture and environment. Various microbial technologies including GMOs (genetically modified organisms), plant growth-promoting rhizobacteria (PGPR), biopesticides, and biofertilizer have the potential to resolve many environmental and agricultural issues such as in bioremediation of nutrients in soil, promoting healthy plant growth and maintaining good health of the soil. The deterioration of the biosphere calls for an urgent need to replenish it in a feasible manner.

20.2 Microbial Biotechnology and Its Applications

The application of Microbial Biotechnology in science aims at treatment of materials by microorganisms to produce useful products or processes. The technologies along with their applications are mentioned below.

20.2.1 Agriculture Technology

The widespread use of microorganisms in sustainable agriculture is due to the genetic dependence of plants on the beneficial functions provided by symbiotic inhabitants (Noble and Ruaysoongnern 2010). Plant microbe symbiosis is carried out through the analysis of their ecological effects, which is the best research method for fixing nitrogen (N_2) (Franche et al. 2009). Industrial microbiology has revolutionized agriculture through genetic engineering and related disciplines. The commonly used bacteria, *Bacillus thuringiensis* (insecticidal bacteria) and *Agrobacterium tumefaciens* usually produce corona choloma in dicots. The tumor-forming gene of *Agrobacterium tumefaciens* exists in tumor-inducing plasmid (Ti plasmid). These genes instruct plants to form opines (nutrient factors that bacteria cannot produce by themselves). Ti vector has extremely important value for introducing foreign genes into dicot plants to produce transgenic plants. However, Ti plasmids cannot successfully transfer genes into monocots. For example, they bypassed a problem and developed particle accelerator, which injects metal particles encapsulated with DNA into the host cells or plant cell, thereby avoiding this problem. Along with this, different techniques for microbial applications in agriculture sector are as follows.

20.2.1.1 Biofertilizers

Biofertilizers consist of microorganisms that facilitate the growth of the plant and is also required to meet the growing demands for food by protecting the crops from pathogens with the use of naturally derived fertilizers in soil (Youssef and Eissa 2014). Organic farming is one of the practices that allow microbes to maintain the biodiversity of the soil. Biofertilizers aid in nutrient uptake such as nitrogen and phosphorus and recycle the nutrients back to the soil via various mechanisms including nitrogen uptake, phosphate solubilization, mineralization, production of antibiotics, or degradation of compounds (Gopal et al. 2013). A metagenomic study revealed a core microbiome transfer therapy which provides resistance to crops from the diseases. The technique involves complete transfer of microorganisms by mixing disease-inhibiting soil with the diseased favorable soil. For example, in an experiment by Mendes and colleagues, soils suppressive to *Rhizoctonia solani* were mixed with diseased conducive soil in the ratio of 9:1 which proved to be effective against sugar beet infection. Other successful examples of this treatment include infection of common scab of potato and tobacco black root rot infection (Rosenzweig et al. 2012).

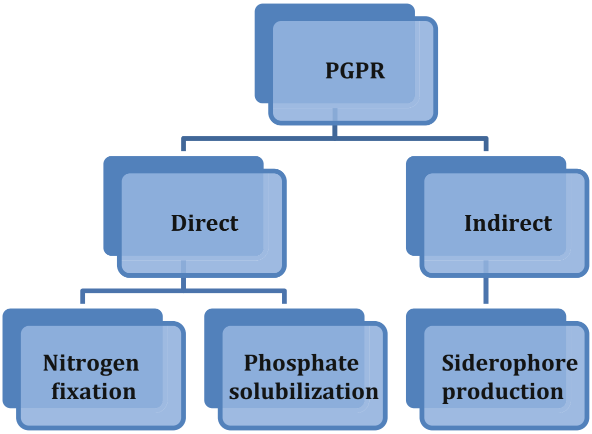
20.2.1.2 Plant Growth-Promoting Rhizobacteria (PGPR)

They are always in a symbiotic relationship with plant- and root-related bacteria. PGPR improve the utilization of nutrients by dissolving unusable forms of nutrients and by producing siderophores, thereby contributing to the transportation of nutrients. There are some examples how PGPR work as a microbial technology:

1. *PGPR as Disease-Suppressive Agents*. To enhance the disease suppression ability of the soil, PGPR secrete metabolites that aid in the protection of plants from various diseases. *Bacillus subtilis* GBO3 produces salicylic acid and jasmonic acid for defense pathway (Ryu et al. 2004). PGPR with *B. amyloliquefaciens* 937b are effective for tomato mottle virus (Murphy et al. 2003). *B. megaterium* IISRBP x17 from black pepper acts against *Phytophthora capsici (*Aravind et al. 2009*)*. *Bacillus subtilis* N11 together with composts controls *Fusarium* infection on banana roots (Zhang et al. 2011). *B. subtilis* (UFLA285) shows resistance against *R. solani* and induces leaf and root growth of cotton plants (Medeiros et al. 2011). *Paenibacillus polymyxa* SQR-21 controls the *Fusarium* wilt in watermelon (Ling et al. 2011). PGPR plays a vital role in restoring plants from blight virus of tomato,cucumber mosaic virus and pepper mottle virus and banana bunchy top virus (Harish et al. 2009). *Glomus mosseae* is found to be used against *Fusarium oxysporum*, the pathogen of basil plant root rot disease (Toussaint et al. 2008). *Psuedomonas fluorescens* and arbuscular mycorrhiza (fungi) reduced root rot disease and also assist in increasing the productivity of *Phaseolus vulgaris* (common bean) (Neeraj 2011).
2. PGPR as Plant Growth inducers

   PGPR showed much effective results when applied alone but was effective much more than usual when used in combination with arbuscular mycorrhiza (fungi) like *Glomus intraradices*; it leads to better nutrient absorption and improves physiological processes in lettuce under stress conditions. *Trifolium alexandrinum* is inoculated with *Rhizobium trifolii*; it increased nodulation under saline stressed condition (Antoun and Prevost 2005). Paul and Nair found that *Pseudomonas fluorescens* (MSP-393) have the ability to overcome the influence of soil with the production of osmolytes and salt-stress-induced proteins. *P. putida* can withstand high alkaline and saline condition by uptake of K^+, Mg^+, and Ca^{2+} and lowering the uptake of Na^+ which gained effectiveness in cotton production (Yao et al. 2010). Arbuscular mycorrhiza (fungi) along with nitrogen-fixing bacteria was effective for legumes in drought conditions, and also inoculation of rice crops with AM increased antioxidant and photosynthetic efficiency (Ruiz-Sanchez et al. 2010). *Pseudomonads* sp. improved the photosynthetic pigments and antioxidants in basil plants under drought condition. They increase the enzymes catalase, glutathione peroxidase, and ascorbate peroxidase activity and chlorophyll content in leaves under drought conditions (Heidari and Golpayegani 2012).

Fig. 20.1 Mechanism of PGPR



20.2.1.2.1 Mechanisms of Plant Growth PGPR

- Direct mechanism (by promoting nutrient acquisition such as nitrogen, phosphorus) or secretion of plant hormone levels.
- Indirect mechanism (by interfering with plant pathogen and promoting plant growth and development). The flowchart of PGPR mechanism is shown in Fig. 20.1.

20.2.1.3 Nitrogen Fixation

Plants cannot utilize atmospheric nitrogen directly, so it needs to be converted by a process called nitrogen fixation, where nitrogenase enzyme is used to produce bacteria such as *Rhizobium* and *Cyanobacteria*. *Rhizobium* forms a symbiotic association with leguminous plant roots by the formation of nodules which act as colonizing sites of rhizobia (Giordano and Hirsch 2004). In non-leguminous plants, rhizobacteria called as diazotrophs form a non-mandatory interaction with the host (Glick 2012).

20.2.1.4 Phosphate Solubilization

Phosphorus occurs in insoluble form in soil which is not assimilated by plants. So insoluble phosphorus needs to be converted into soluble form to be utilized by plants. Soluble phosphorus as monobasic (HPO_4) and dibasic (H_2PO_4) is utilized by plants. Phosphate is provided to soil in fertilizers that is converted into insoluble form in soil, causing phosphorus deficiency in soil; only 0.1% of phosphorus is available for plant usage. Bacteria such as *Flavobacterium*, *Bacillus*, *Azotobacter*, *Erwinia*, *Microbacterium*, *Enterobacter*, *Beijerinckia*, *Pseudomonas*, *Burkholderia*, *Rhizobium*, and *Serratia* are phosphate-solubilizing bacteria (Bhattacharyya and Jha 2012). These bacteria solubilize phosphorus by two mechanisms: solubilization (hydrolyzation of organic and inorganic insoluble phosphorus compounds to soluble phosphorus) and mineralization (conversion of organic phosphorus into inorganic phosphorus). Phosphate-solubilizing bacteria (PSB) secrete phosphatase enzyme that converts insoluble phosphorus into soluble phosphorus by dissolving it. PSB promote plant growth and improve the utilization of other trace elements in the soil which yields a good variety of plants (Zaidi et al. 2009).

20.2.1.5 Siderophore Production

Iron is important for all organisms. Iron (Fe^{3+}) in the environment is present in form of insoluble hydroxides and oxyhydroxides that makes it difficult for plants to uptake them from soil. Bacteria secrete water-soluble siderophores (low-molecular mass iron chelators) which complex with iron and form siderophore-Fe complex. This complex reduces Fe^{3+} to Fe^{2+} and it is introduced into cell through channels in membrane and ultimately siderophore gets destroyed or used up once again (Rajkumar et al. 2010). Bacterial siderophores also reduce heavy metals such as aluminum, cadmium, copper, gallium, indium, lead, zinc, uranium, and neptunium (Neubauer et al. 2000).

20.2.2 Food Technology

Microorganisms have two different roles. First, they play a prime role in fermentation (in this case, genetically modified organisms are not allowed). Second, they become absorbed in the industries to produce food ingredients. Genetic engineering is used to modify the yeast and improve its performance in the fermentation process. Yeasts are optimized to changes in temperature, pH, and high yields on a wide range of products. Amylases are acquired from fungus *Aspergillus niger* (Adejuwon et al. 2015) or bacteria *Bacillus subtilis*; for example, they were used to replace the chemical additives for processing wheat flour, improving dough preparation for baking foods to be possessed (Bueno et al. 2016). The protein extracted from SCP is used as supplements in whole foods, replacing valuable traditional sources and solving the protein deficiency problem. In animal and human food, the single cell protein is used as a source of protein (Sadiku et al. 2019).

Emerging need of the increase in production of food allowed the use of agricultural farming techniques with chemical-based fertilizers, but this did not prove itself to be beneficial for the environment as it offered itself a large number of drawbacks with its extensive and prolonged use. Here the microbial technology stepped forward and in comparison to conventional methods is a much safer practice; it showed a 10–20% increase in economically important crop production. Despite its great advantage, limits itself to the need of the strain of the organism, the selection, and the application of the technology required for a better understanding of the relationship between the inoculants and the microbiome. The understanding of their relationship is important for the use of new technologies involving microfluidics-based technologies like 'microbiome on a chip'; this foregrounds multitrophic plant-microbiome interactions with the expression of environmental parameters and the host response against the treatments (Stanley and van der Heijden 2017). It can induce long shelf-lives and also enhance the effectiveness of the microbial product. One way of accomplishing this goal is by modifying the plant at an early stage (seedling stage) by incorporating the desired bacteria (Mitter et al. 2017). This technique is more reliable and has great advantages including the expression of desired and favorable traits and protection of the plants from another microbiota. The use of the synthetic microbial communities promotes early flowering, enhances nutrient acquisition by plants, and induces resistance to plants (Gopal et al. 2013), but the maintenance of the microbe in plant is achieved by genetic engineering and plant breeding techniques. The plant interacts with the microbes in soil by the release of components which are specific in nature and allows interaction with only the required organism, but the incorporation of the desired organism makes it easy for plants to interact and come up with expected outcomes.

20.2.3 Chemical Technology

Chemicals like organic acids via activity of microbes are very bright. Most organic acids are natural products present in important metabolic pathways or intermediates of microbial metabolism (Sauer et al. 2008). For example, global annual industrial-scale production of citric acid is demanded by the market as a food additive is through glucose fermentation using *Aspergillus niger* to form cane molasses, corn starch, or beet molasses (Wang et al. 2016). In addition to this, the lactic acid fermentation process has recently received more attention due to the increasing demand for new biomaterials, such as biocompatible polylactics and biodegradable products (Gao et al. 2011). The production of butanol and acetone, which was effectively carried out by the genus *Clostridium*, was one of the industrial fermentation processes of global importance, but this production led to chemical synthesis. Likewise, the inability of a chemical compound to compete with a petrochemical has affected the microbial composition of glycerol feedstocks.

20.2.4 Recombinant Technology

The main microbial hosts for the production of recombinant proteins are *Hansenula polymorpha*, *Bacillus subtilis*, *Aspergillus niger*, *S. cerevisiae*, *E. coli*, and *Pichia pastoris.* The recombinant microorganisms have provide the methods for the host to produce glycosylated recombinant proteins with high bacterial content, such as mammalian and insect cell cultures, as well as transgenic animals and plants. Plant breeding along with genetic engineering has become a common practice for the development of in-demand product, and its establishment has contributed to eliminate hunger and poverty on a global scale. The introduction of the GM crops was first developed in the mid-1990s in the USA. Today this technique is adopted globally to meet the increasing demand of the population and a way to move forward toward attaining sustainable production of crops. The GM crops are regulated by three agencies: EPA (Environmental Protection Agency), FDA (Food and Drug Administration), and USDA (US Department of Agriculture). The development of GM crops decreased the use of chemically originate herbicides and pesticides. Besides, the newly modified crop was herbicide resistant naturally. The administration of a soil bacterium called *Bacillus thuringiensis* (Bt) allowed modification in the plants to make them insect resistant; such plants are popularly known as Bt crops. Globally today many forms of Bt plants are available in the market; the advantage of such engineering is that it produced plants of superior quality with the extension of its shelf-life. Some of the crops considered under GMO crops are rice, tomato, cotton, soybean, maize, etc. The crops to be modified are targeted with the bacterium containing the desired gene; primarily the gene is introduced in the crop in vitro, and once the crop attains the growth, it is subjected to the field and allowed to grow in natural conditions. Such crops are usually herbicide tolerant and insect resistant; the commonly used bacteria are *Agrobacterium tumefaciens* and *Bacillus thuringiensis*.

20.2.5 Environmental Health and Microbial Technology

Environmental microbiology is the study of the composition and physiology of the microbial community in the environment. The various microorganisms have been recorded during the solid waste composting process, including autotrophic or heterotrophic aerobic bacteria, fecal coliform bacteria, thermophiles, yeast, actinomycetes, and other fungi (Tiquia et al. 2002). Treatment of waste is based on enzymatic processes and is inexpensive; however, these enzymes are biodegradable, so further research is needed for microbial enzymes that are thermally stable or resistant to significant changes in pH (Hasan et al. 2006).

20.2.6 Wastewater Treatment

Water is essential to sustain the life-forms on earth. Water accounts for 71% of the surface of earth; about 96.5% of water found in the oceans is unfit for the sustainability of life-forms. About 0.3% water is available as suitable for human consumption, which is obtained from rivers and lakes, and only 0.61% of water is available in groundwater. According to a study, 321 billion gallons of water is consumed per day by human beings and 77 billion gallons of water is taken up from groundwater.

Wastewater contains organic and inorganic pollutants which are lethal to the biota system; therefore, prior to discharge the wastewater requires treatment. Modern approach used to treat wastewater is microbial fuel cell (MFC) (Rabaey et al. 2010). MFC has several advantages such as:

1. It restores electrical energy and valuable products.
2. It generates nontoxic effluents.
3. It is easy to monitor and control and provides easy monitoring of the system.

MFC uses microbes at the electrode (either cathode or anode) to catalyze oxido-reduction and generate electric current. The reducing microbes reduce the electrode and donate electrons to the negative electrode (anode). These microbes reduce substrate from the wastewater required for the reaction by microbes to produce energy and provide a healthy biosphere (Clark and Pazdernik 2016).

20.2.7 Oil Remediation

With the increase in the world's population, the demand for the resources also increases; therefore, there is a subsequently increased need for petroleum and petroleum-based products, but accidents related to petroleum and petroleum-based products are also hazardous to all life-forms including marine lives and humans and plants (Strong and Burgess 2008). There have been numerous incidents pertaining to petroleum products as the 1971 incident in Pennsylvania where a gasoline pipeline was damaged and it released 100,000 gallons of the gasoline into the nearby water supply.

The first application of the use of this technique was the Exxon Valdez oil spill which proved to be effective to clean up the petroleum-contaminated ground system; this gained the interest in the use of bioremediation to clean up the environment in a safer way. Petroleum is a natural resource obtained beneath the earth layer which is an admixture of nitrogen, sulfur, and oxygen. It constitutes a variety of compounds such as aromatic compounds, some metals (iron, copper, nickel, vanadium), alkanes, and cycloalkanes as shown in Table 20.1.

The permeation of these compounds into the groundwater or surface water can impose serious health hazards to the biosphere, and the uptake of these compounds by the living organisms can affect their health. Gasoline is considered as a cancer-causing agent to humans by the International Agency for Research on Cancer (IARC) (2000) and tends to cause irritation in the eyes and mucous membrane.

Table 20.1 Composition of compounds present in petroleum by weight

Hydrocarbon	Amount present (%)
Alkanes	30
Naphthalenes	49
Aromatics	15
Asphaltics	6

Table 20.2 Illustrates various petroleum compounds and their effects with the concentration

Petroleum compounds	Effect on humans	Concentration (parts per million)
Benzene	Leukemia	<1
Toluene	Memory loss and coordination impairment Palpations	200–500 500–1000
Gasoline	Cancer	>2000
Cyclohexane	Polyneuropathy	<1000
Other hexanes	Narcosis	1000

Table 20.2 shows various compounds of petroleum and their harmful effects on humans.

20.2.7.1 Remediation of the Petroleum Products

The conventional method of the remediation of petroleum products includes dispersion, sorption, volatilization, recovery, dilution, and abiotic modification of hydrocarbon removal. These require high capital investment and large machineries and also dispose the residues into the environment (Matsumiya and Kubo 2007). On the other hand, bioremediation generates ecofriendly residues and does not require much capital; bioremediation techniques of petroleum products make the affected site free of every contaminant.

20.2.7.2 Petroleum Hydrocarbon Degradation Mechanism

The initial step of the degradation in petroleum hydrocarbons is the oxygenation process in which the organic pollutants are attacked intracellularly and the oxygen is transferred within the cell by the enzymes like oxygenase and peroxidases, followed by the conversion of the pollutants into various intermediates through a number of degradation pathways such as TCA (tricarboxylic cycle). This method is mediated by the enzymes and hence is considered as an enzymatic-dependent mechanism. Below are some of the examples that show the enzymes produced by various microorganisms:

1. *Methylococcus* produces soluble methane and particulate methane that act on C1 to C8 of cycloalkanes, alkenes, and alkanes (McDonald et al. 2006).
2. *Burkholderia* species produces alkanes that act on C5–C16 of fatty acids, alkanes, cycloalkanes, and alkyl benzenes. *Rhodococcus* and *Mycobacterium* produce hydroxylases that act on C5–C16 of alkyl benzenes, fatty acids, cycloalkanes, and alkanes (Jan et al. 2003).

Table 20.3 Microorganisms producing biosurfactants

Biosurfactant	Microorganism	References
Lipomannan	*Candida tropicalis*	Ilori et al. (2005)
Glycolipid	*Aeromonas* sp.	Youssef et al. (2007)
Surfactin	*Bacillus subtilis*	Daverey and Pakshirajan (2009)
Sophorolipids	*Candida bombicola*	Kumar et al. (2008)
Rhamnolipids	*Pseudomonas aeruginosa*	Das and Chandran (2011)

3. *Acinetobacter* produces dioxygenases that act on C10–C30 of alkanes (Maeng et al. 1996).
4. Species of *Caulobacter*, *Mycobacterium*, and *Acinetobacter* produce bacterial oxygenase P450 that acts upon C5 to C16 of cycloalkanes and alkanes (Van Beilen et al. 2006).

Other methods include the production of biosurfactants. Biosurfactants are agents produced by some microorganisms that form micelles by reducing the surface area given in Table 20.3. In this method the cell surface is encapsulated with microdroplets that absorb the petroleum products and degrade them. It was observed that 90% of hydrocarbons was degraded within a time period of 6 weeks in vitro (Cameotra and Singh 2008); with further alteration it was shown that most of the hydrocarbons is degraded with the application of crude biosurfactant (Muthuswamy et al. 2008).

The recent advancement offers application of plasmid DNA incorporation for the biodegradation of hydrocarbons. Plasmid DNA is a mobile DNA that can be transferred by the processes of conjugation and transformation and has the ability to express the quality of the incorporated DNA and change the phenotypic expression of the host. This has been successfully exhibited on *Pseudomonas* sp. by incorporating plasmid DNA for the nutrition of various compounds such as octane, naphthalene, toluene, camphor, salicylate, and xylene. Further incorporation of plasmid DNA has been able to degrade the recalcitrant compounds of petroleum. The plasmid DNA enhances the potential of the recipient after getting incorporated inside the recipient (Okoh 2006).

20.2.8 Radioactive Waste

Radioactive compounds are widely used in every field like industry, research and development, and medical sectors as an innovative technique but their disposal is very heedful. Accumulation of radioactive waste poses a threat to all life-forms. To remediate the pollutant in soil and water, bioremediation has become a successful method. Microbial-associated techniques aim to reduce radionuclides significantly; the genetically engineered (GE) microorganisms affect the properties of

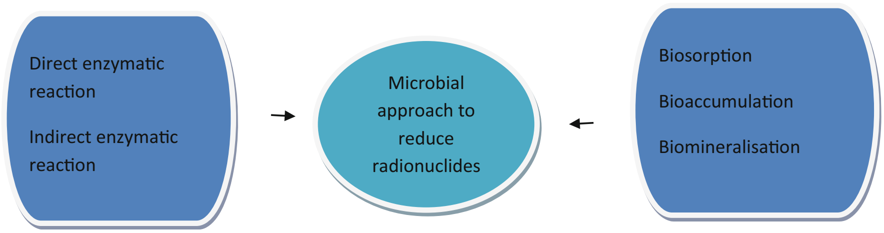


Fig. 20.2 Various microbial techniques for bioremediation of radionuclides

radionuclides and thereby reduce their concentration. The following are the common radionuclides that are released by industrial and biomedical wastes:

Cobalt-60
Uranium-238
Thorium-232
Radium-226
Radon-222
Plutonium-239
Technetium-99

Among this technetium is the most commonly used isotope in medical imaging and has a shelf-life of 6 h, but other isotopes like Uranium-238 have a half-life of 1600 years (Kurnaz et al. 2007). The radioactive wastes not only affect the health of life-forms but also deteriorate the nutrient level in soil if remained for a longer period.

A common way by which soil gets contaminated with radioisotopes is by dumping of radionuclides into the environment along with other wastes. The physiochemical ways are practiced for a long time but failed to be resolved; therefore, bioremediation came forth to act as an alternative way to remediate the soil from radionuclides. In view to this, Fig. 20.2 gives details of different methods for bioremediation of radionuclides. Some microorganisms act directly on the polluted site and convert the radionuclides into soluble product by either oxidation or reduction, allowing their fast removal from soil. Bacteria like *Rhodanobacter* sp. and *Desulfuromusa ferrireducens* act directly on the pollutant (Green et al. 2012).

20.3 Importance of Microbial Technology in Sustainable Development

The microorganisms play important roles in the environment. In recent studies, every possible industrial process, the use of chemicals, the increased use of nonrenewable energy, and the uncontrolled production of waste products pose a huge threat to environmental sustainability. Now, the world has a greater responsibility to adopt cleaner production, green technologies, and sustainable measures in order to protect the earth's ecology for future generations (Kuhad 2012).

Microorganisms play an important role in the urban ecosystem. There are various resident microorganisms in the urban ecosystem, which play an important role like waste management, soil management, industrial productivity, bioremediation, health and disease and marine pollution management, etc. (King 2014).

- By using wastes such as municipal waste, agricultural waste, and sewage sludge, microorganisms can also be used to produce bioenergy (Appels et al. 2011). Microorganisms such as *Penicillium*, *Aspergillus*, *Trichoderma*, and *Clostridium* are highly effective (Elshahed 2010).
- Solid waste management is the biological conversion of its organisms into useful products such as biofuels and biogas. Using microbial *Thermoactinomyces*, *Pseudomonas*, *Actinobifida*, *Microbispora*, and *Bacillus* to compost solid waste as an economically feasible method to convert its organic compounds into useful products. Compost is used as fertilizer for the production of crops, thereby increasing their product activity and developing a sustainable environment.
- Microorganisms such as *Rhizobium* are used as biological synthetic materials and increase the productivity of industrial agriculture.
- The algae *Nostoc* and *Azolla* are used as economical viable sources of bioremediation, which can then be used to produce biofuels.
- GM *E. coli* produces large amounts of insulin.
- Microorganisms show their role in infant health. *Bifidobacterium* and *Lactobacillus* are microbes which are important for the regulation of human immune system (Romano-Keeler and Weitkamp 2015).
- Microorganisms are also used to generate clean electricity. For example, *Geobacter sulfurreducens* and *Shewanella oneidensis* are used to generate usable electricity (Lal 2013).
- Microorganisms such as *Micrococcus*, *Pseudomonas*, *Chromobacterium*, *Bacillus*, *Arthrobacter*, *Candida*, and *Burkholderia* degrade hydrocarbons and crude oil through a method called intrinsic repair without any artificial enhancement (Kumar and Gopal 2015).
- Microorganisms like *Marinobacter*, *Pseudomonas*, *Bacillus*, *E. coli*, and *Streptomyces* help in the remediation of heavy metals (arsenic, mercury, and lead) from waterbodies and control the pollution in marine waters.

20.4 Conclusion

Microbial technology has unique applications in majority of areas including its effectiveness in achieving a sustainable environment. It has not limited its application only in healthcare but has evolved in other sectors too. The present scenario regarding the issues on agricultural and environmental sustainability has increased abruptly with the advancement of urbanization. Meeting the challenges of modernization has greatly deteriorated the conditions of the biosphere. In agriculture, microbial technology has contributed to the production of improved crop varieties. It produces crops with an admixture of different types of crops, resulting in improved version of the crops containing the dominant and admirable traits of the different crops. It has also contributed in increasing nutritional content of the product by manipulating the genes of the product through genetic engineering. In environment, microbial technology has contributed very much in eliminating the pollutants from the contaminated sites which includes the removal of oil spills from massive oceans without generation of any additional toxic residues and also in significantly removing heavy metals from unfertile land.

Resources are also replenished more conveniently by microbial technology than conventional methods since it used microbes that naturally conserve resources or generate such product. Although microbial technology has some drawbacks due to which it has not come forward more distinctively, with the pace in the biotechnology, it may become the only possible, reliable, and ultimate method to resolve all the issues relating to sustainability in agriculture and environment and accomplish the sustainability goals of the UN to meet the demands of the developing urbanization.

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