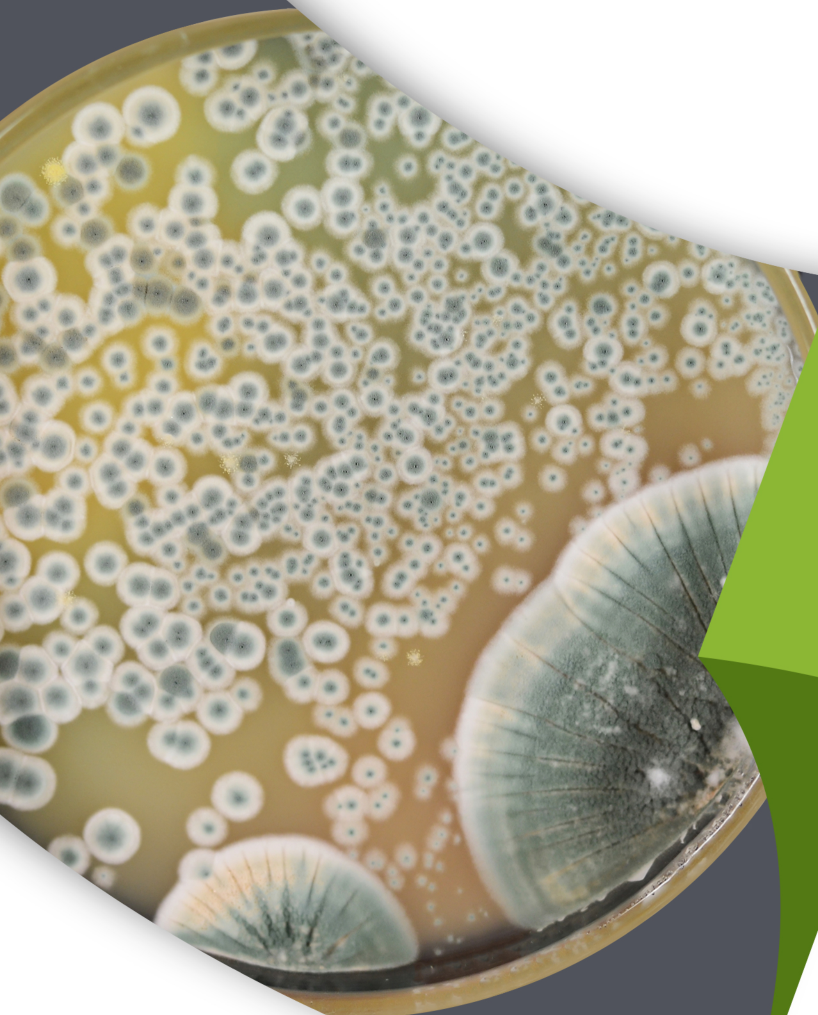

BIOREMEDIATION: CHALLENGES AND ADVANCEMENTS

Editors:
Manikant Tripathi
Durgesh Narain Singh

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Bioremediation: Challenges and Advancements

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FOREWORD

The process of production and consumption to meet the incessant demands of mankind leads to the generation of different undesirable pollutants and waste materials. Such undesirable products are potential threats to the environment and pose different kinds of risks to mankind. We need a proper management system and decontamination technologies for the abatement of pollutants and waste materials in a sustainable manner. Most of the decontamination methods are not only costly and energy-consuming, but the generated byproducts are toxic to the environment. Nevertheless, bioremediation is an ecofriendly and economical method that employs different types of microorganisms for the removal of pollutants from the environment. Microorganisms utilize several strategies to remove contaminants, including enzymatic detoxification, adsorption to cell surfaces, intracellular accumulation, sequestration into exopolysaccharides, volatilizations, and biotransformation into their non-toxic form. The wide metabolic and physiological capabilities of microorganisms allow them to survive in extreme environments. These properties render microorganisms the incredible potential of bioremediation, but microorganisms also meet several challenges when applied to the environment for bioremediation. Researchers are working consistently to combat challenges for the successful development of new bioremediation technologies.

This book titled “Bioremediation: Challenges and Advancements” discusses the concepts of bioremediation, challenges, and advancement in bioremediation of different pollutants such as hydrocarbons, xenobiotics, heavy metals, radioactive compounds, and phytoremediation of industrial wastes. Some of the chapters that make the book unique and distinguish it from its contemporaries are the management of plastic wastes and e-wastes, biomedical wastes, and the management of agricultural wastes. Another very interesting chapter is “Application of ‘omics’ in bioremediation.” I hope this book will be beneficial for undergraduate and postgraduate students, researchers, and environmental scientists involved in the bioremediation of different contaminated sites.

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PREFACE

Waste management is one of the major challenges for environmental and public health worldwide. With the growing population and urbanization, it is increasing every day. These wastes contain various types of toxic pollutants of organic and inorganic nature, which disturb the ecosystem and pose adverse effects to humans and animals. The provision of pollution-free soil, air, and safe water is critical for a balanced ecosystem. Several treatment techniques, including physical, chemical, and biological, are used to remediate hazardous wastes, whereas bioremediation offers cost-effective and green technology for the abatement of toxic pollutants in the environment. However, there are lots of constraints and complexity in dealing with waste management. This book comprises eight chapters that focus on the waste source to its adverse impacts on the ecosystem, and the advanced strategies for their remediation along with associated challenges. The first two chapters explain microbe-assisted remediation technology to detoxify heavy metals and degrade xenobiotic compounds through various biosynthetic mechanisms, along with the significance of recent biotechnological methods in improving the capability of microbial remediation methods. The toxic pollutants are successfully degraded in microbe-assisted remediation along with phytoremediation. The challenges, future outlooks, and limitations are also discussed. Chapter 3 describes strategies including physical, chemical, and biological methods to mitigate radioactive waste from contaminated sites and water bodies. This chapter is focused on eco-friendly and economical solutions for global radioactive waste disposal problems and other associated challenges. Chapter 4 discusses biomedical waste, which is hazardous, and if left untreated, can cause serious health hazards. This chapter detailed the use of microbial-aided remediation techniques for the removal of biomedical waste. Chapter 5 explains the source of electronic waste, its impact on humans and animals, physicochemical and advanced microbiological methods for the management of e-waste, as well as challenges associated with this. Chapter 6 describes bioremediation strategies for the decontamination of solid waste pollutants. Chapter 7 focuses on the application of OMICs approaches such as genomics, transcriptomics, proteomics, and metabolomics in bioremediation. It plays a significant role in generating information about degradative enzymes and pathways involved in the remediation of pollutants by microorganisms. The last chapter describes the bioremediation of agricultural wastes.

The peculiarity of the book is that it does not only cover methods of bioremediation but also describes the challenges as well recent advancements in the bioremediation of different pollutants. This book would be beneficial to students of environmental sciences, including microbiology and biotechnology, environmental engineers, and researchers working for the restoration of contaminated sites.

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CHAPTER 1

Bioremediation of Hydrocarbons and Xenobiotic Compound

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Abstract: In the last few decades, the increase in population, the industrial revolution, and modernization have produced numerous problems in the form of hazardous pollutants in the ecosystem rapidly. These hazardous pollutants such as polycyclic aromatic hydrocarbons (PAHs), heavy metals, manmade pesticides (xenobiotics), radioactive materials, toxic chemicals, and dyes created an imbalance in the ecosystem and increased risks to human, plants, and animal's health. Furthermore, the use of chemical fertilisers, pesticides, and sewage releases toxicants into the soil and potable water, where they enter the food chain and endanger food security. Many strategies and practices have been used to prevent harmful effects of these pollutants up to a certain extent. Various physical and chemical methods have been implemented to remove these contaminants, but due to some limitations, it has not been applied successfully. Despite this, appropriate biological methods are currently applied to decrease pollutants' concentrations from the soil, water, and the environment. The use of biological methods for bioremediation should be cost-effective, eco-friendly, and biodegradable, decreasing the danger to the ecosystem and living beings. Microbe-assisted remediation technology has been developed to degrade xenobiotic compounds through various biosynthetic mechanisms. The objective of this chapter is to discuss different methods of bioremediation, their process, and mechanisms, employing potential plants and microbes in the remediation of pollutants from the environment. In addition, the present chapter highlighted the significance of recent biotechnological methods in improving the capability of microbial remediation methods. These methods successfully degrade pollutants, emphasizing current advances in microbe-assisted remediation along with phytoremediation as well as related challenges, future outlooks, and limitations.

Keywords: Bioremediation, Chemical Fertilizers, Ecosystem, Heavy Metals, Microbial Remediation, Pesticides.

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Manikant Tripathi and Durgesh Narain Singh (Eds.)

1. INTRODUCTION

The global population has exploded and calls attention towards excess production of grains, fibers, and herbal medicines. This leads to tremendous pressure on the environment in order to feed the ever-increasing population. So, the demand for food exceeded the population on earth. To obtain higher productivity and yields, we are compelled to use man-made chemical fertilizers and protectors, which show damaging effects on the environment and human health. Moreover, agricultural, domestic and industrial processes haphazardly introduced several contaminants into the environment, such as polyaromatic hydrocarbons, heavy metals, polychlorinated biphenyls, chlorinated phenols, radioactive, fertilizers, biocides, dyes, and plastics [1, 2]. Since the past decade, a mixture of contaminants, such as hydrocarbons, greenhouse gases, heavy metals, plastics, micropollutants, *etc*., have caused a severe threat to the functioning of the earth's homeostasis globally. These contaminants cause soil, air, and water pollution, ensuing severe infections in life form, or impacting biodiversity completely [3, 4]. In developing countries, agricultural workers/farmers are prone to use a high content of agricultural chemicals, including pesticides, due to a lack of awareness about the application of biofertilizers or biopesticides and related information [5]. These contaminants' exposure is highly susceptible for farmers, followed by production workers, food processors, and loaders. Besides, environmental contamination leads to a polluted ecosystem entirely, which causes deaths and chronic diseases due to contaminants poisoning concentrations to approximately one million per year globally [6, 7]. These contaminants are recalcitrant, therefore, degrade gradually.

To eliminate their lethal and toxic effect on living beings, special measures are required to remove these contaminants from the environment. Since ancient times, various physicochemical methods and their combinations have been employed to solve the problem to a certain extent. But these methods have some limitations and are, therefore, not very successful. Conventional waste disposal processes such as landfilling and incineration are highly expensive to clean up polluted areas in various countries [8]. Since ancient times, waste disposal has been done by throwing it into the river directly or burning it in the field and through incineration methods. At present, human beings have applied remediation practices such as bioremediation for removing these contaminants [9].

Among the biological techniques, bioremediation strategies have evolved as the most promising one because it is cost-effective, fast, efficient, safe, and has a permanent solution to clean up xenobiotic contaminants [10]. Bioremediation is described as the manipulation of biological systems to diminish the toxicity of hazardous wastes from contaminated areas [11]. It is also known as the use of living systems to f*etc*h preferred chemical and physical changes in a limited environment [12]. It is a technology that utilizes biological activity to decrease the concentration of pollutants. It usually applies methods through which microorganisms transform or degrade toxic chemicals in the environment [13]. Bioremediation is a multidisciplinary organic approach to neutralize or remove something detrimental from the atmosphere by the application of biological agents such as microbes and plants [14].

Bioremediation methods are preferred over other methods because of eco-friendly, risk-free, less expensive, and acceptable methods. The limitation of bioremediation techniques is that it is applied only to biodegradable substances [15]. A variety of factors such as type of organisms, nature, and concentration of contaminants, chemical and geological situation at the polluted place, the end product of the procedure, and the environmental policies affect the completion of bioremediation (Fig. **1**) [16].

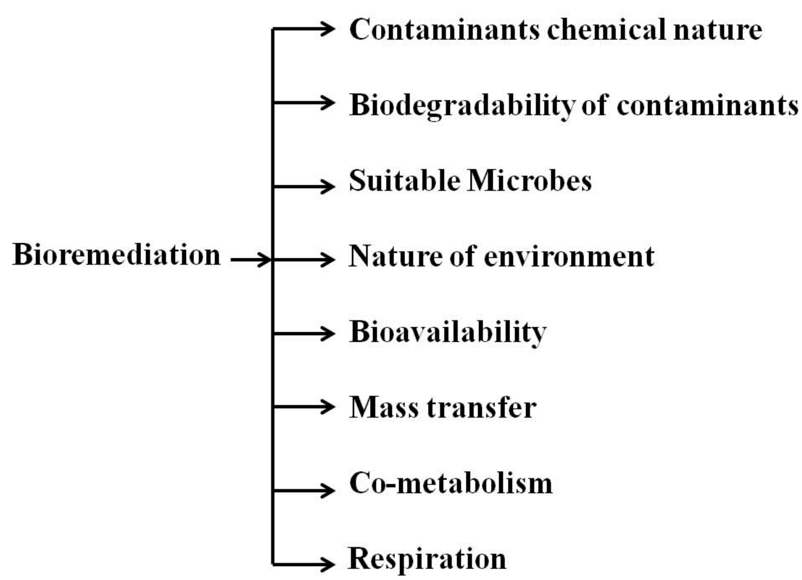

Fig. (1). Factors affecting the bioremediation process.

2. TYPES OF BIOREMEDIATION

Bioremediation has been categorized into *ex-situ* and *in situ* based on the location of waste materials treatment [17, 18]. *In situ* bioremediation helps in the treatment of waste material at the site of its origin. *Ex-situ* bioremediation facilitates the elimination of waste material from the site pursued by its transportation and treatment to some other place. Bioventing, biosparging, phytoremediation, *etc*.,

CHAPTER 2

Bioremediation of Heavy Metal Contaminated Sites

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Abstract: Heavy metal contamination is a global challenge causing potential health hazards to humans and biotic life due to an increase in geologic and anthropogenic activities. Heavy metals generate oxidative stress and are highly toxic even at very low concentrations, and usually bioaccumulate in food chains. Herein, we have discussed and highlighted the role of microbes and plants in bioremediation in terms of tolerance and elimination of heavy metals. The application of microbial biosorbents is ecologically friendly and economical; hence, it proved to be an effective alternative for heavy metal remediation from polluted environments. In parallel, the current chapter also addresses some fundamental concepts of plant-based remediation known as phytoremediation as well as the biochemical mechanisms associated with it. Among the introduced methods, phytoextraction, phytostabilization, and application of the PGPRs are some of the most suitable and eco-friendly techniques, which are currently considered important processes in phytoremediation. Recently, we have shifted our efforts and concepts to a broader panorama, in which particular emphasis is given to the advancements in the field of genetic engineering, metagenomics, and nanotechnology, and many of these strategies discussed are already showing great promise. Using recombinant DNA technology, whole-cell biosensors have been developed for the detection of environmental pollutants, including heavy metals. Similarly, metagenomics has played a major role in the discovery of novel genes, enzymes, pathways, and bioactive molecules involved in heavy metal resistance. Therefore, we anticipate that a discussion of existing resources and limitations will improve tools and technologies for the bioremediation of heavy metals.

Keywords: Bioremediation, Biosorbent, Heavy metals, Metagenomics, Nanotechnology, Phytoremediation.

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Manikant Tripathi and Durgesh Narain Singh (Eds.)

1. INTRODUCTION

Technological and industrialization developments have increased the pollutant load on the environment by discharging large quantities of heavy metals and metalloids that have imposed great damage to our ecosystem. Due to their bioaccumulation, persistence, and resistance to biodegradation, heavy metal contamination has become a severe threat to all the living organisms of our ecosystem [1, 2]. The terminology "heavy metal" refers to any metallic element that has a relatively high density, atomic weight, or number and is potentially toxic at very low concentrations. In general terms, it is applied to a group of metals and metalloids having an anatomic density higher than 4g/cm^3 or five times more than water [3, 4]. Various inorganic metals such as sodium (Na), magnesium (Mg), copper (Cu), nickel (Ni), manganese (Mn), calcium (Ca), zinc (Zn), and chromium (Cr^{3+}) are important elements and are required in a very limited amount for metabolic as well as redox functions. However, some metals like heavy metals [mercury (Hg), lead (Pb), aluminum (Al), cadmium (Cd), silver (Ag), and gold (Au)] do not play any role in biological systems and are very toxic to organisms. The primary reason for their sustained persistence in the environment is their non-biodegradable nature. They can infiltrate the food chain and can accumulate to toxic levels over some time in the human system, causing adverse health effects, which might be irreversible. Heavy metals are found in soils, sediments, water, air, and living organisms and have both natural and anthropogenic origins.

Naturally, heavy metals are released into the environment by weathering igneous and metamorphic rocks, volcanic activities and forest fires, *etc*. [4, 5]. However, in recent years, due to anthropogenic activities such as industrialization (mining, textiles, painting, plating, smelting, *etc*.), landfills, excessive input of hazardous agricultural, municipal and domestic waste discharges have immensely increased the heavy metal ion concentrations in the natural environment [6 - 8]. According to the guidelines issued by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), USA, the maximum permissible concentrations of As, Cd, Cr, Pb, Hg, and Ag in water are 0.01, 0.05, 0.01, 0.015, 0.002, and 0.05 mg/L, respectively, whereas, in the soil, the concentrations of heavy metals should be 3–6, 135–270, 75–150, 250–500, and 300–600 mg/kg for Cd, Cu, Ni, Pb, and Zn, respectively, as established by Indian standards for heavy metals [9].

The existence of heavy metal ions as a general pollutant in water bodies and soil leads to their contamination. At even very low concentrations, they can cause several hazards to both humans and other living organisms. The increase in biomagnification and bioconcentration of heavy metals and their toxicity to all living organisms show the urgent need for the elimination of heavy metals from polluted soil and water [10]. Moreover, treating heavy metal contaminated sites is a major economic challenge as only a few technologies can be used due to the stable and immobile nature of metals. The conventional heavy metal remediation methods like ion exchange, chemical precipitation, reverse osmosis, thermal treatments, electro reclamation, excavation, and landfill are not suitable due to their less efficiency, being expensive, requiring sophisticated infrastructure, and their dependence on certain conditions of the polluted sites. Moreover, they also suffer from a major drawback of generating lots of toxic sludge, which disturbs the environment [11]. In light of this, as compared to conventional physical and chemical remediation methods, the advancement and application of bioremediation technology are considered more feasible, effective, and sustainable technology in terms of its low cost and this technology is economically and environmentally compatible. The bioremediation technique targets an uncontaminated environment while sustaining the regular biological processes related to it.

The process of bioremediation is defined as the use of microbes, green plants, and enzymes to treat and manage the contaminated sites and restore healthy conditions [1, 12]. The bioremediation process is greatly preferred over conventional techniques as it delivers enhanced outcomes through the utilization of cheap economic inputs. In bioremediation, with the help of suitable microbes, toxic chemicals and heavy metals are transformed, absorbed, or accumulated, and during this process, the chemical structure of the toxic substance undergoes changes which are ultimately converted into harmless by-products [13]. Most of the soil microbes are basic components of the ecosystem, and there are continuous complex interactions that exist between microbes and different constituents of the soil ecosystem, such as heavy metals and radionuclides. However, some microbes such as bacteria, yeast, fungi, and protists act as biological agents and use the pollutant as a source of nutrients and energy. These microbes degrade heavy metals and not merely transfer toxic metals from one medium to another but also detoxify it [14, 15]. Heavy metals cannot be degraded completely in this process, although they can only be transformed from one oxidation state or organic complex to another, and during this change in their oxidation state, they are transformed to become less toxic, easily volatilized and less bioavailable. The specialized enzymes are secreted by these microbes, which act on the end product of each metabolized reactant [16]. These microbes decrease the bioavailability and mobility of the heavy metals through the process of biosorption and bio-precipitation, leading to their immobilization in the soil [17].

Plants also possess important physiological, biochemical, and genetic characteristics, which make them suitable candidates for heavy metal remediation.

CHAPTER 3

Bioremediation of Radioactive Contaminants/ Radioactive Metals

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Abstract: Exposure to radioactive radiation-emitting of the nuclear energy power plant, medical industry, food industry causes serious threats to the living system and the environment. Radioactivity is a cause of ionizing emission of high-energy particles like alpha particles, beta particles, gamma radiation with high frequency and intensity. Radioactive wastes are categorized as low-level waste (LLW), intermediate-level waste (ILW), or high-level waste (HLW), depending upon their radioactivity. A plethora of strategies, including physical methods (incineration, filtration), chemical methods (ion exchange, precipitation, absorption), and biological methods (microbial assisted remediation and phytoremediation), have been adopted to mitigate radioactive wastes from the contaminated sites and water bodies. This chapter is focused on bioremediation methods as a powerful technique offering an eco-friendly and economical solution to global radioactive waste disposal problems and other associated challenges.

Keywords: Bioremediation, Ionizing-Radiations, Phytoremediation, Radioactive metals, Radioactive waste.

1. INTRODUCTION

Radioactive contaminants are gigantic hazards posing a serious risk to the environment, human health, and the economy, where nuclear energy generation is a primary source of these contaminants. Serious attention has been paid by both the government and the individuals to shield the world from the impact of nuclear emissions or radioactive pollution [1]. In 1896, French scientist Becquerel discovered the mechanism of converting atoms of one element into atoms of other elements through spontaneous radioactivity, followed by atomic emission and

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electromagnetic radiation [2]. Radioactive contamination is characterized as the direct physical exposure on living organisms and their ecosystem (atmosphere, hydrosphere, and lithosphere) triggered by the introduction of radioactive pollutants into the environment through the manufacturing of radioactive products, nuclear explosions, nuclear research, and decommissioning of nuclear weapons, hazardous ores processing, radioactive waste mismanagement and, its improper disposal or because of severe accidental spillage. Owing to the exponential growth and advancement of industrialization, our environment is exposed to different kinds of waste and degradation products. With the decline of green energy supplies, the need for energy/power production is increasing and emerging as a big research problem worldwide.

Nuclear energy is one of the feasible energy choices to fulfill power demand, but the problem with the use of nuclear energy is the difficulty in the management and storage of toxic wastes/emissions/effluents that are detrimental to all living organisms. Particular attention is needed while handling hazardous waste to achieve a pollution-free ecosystem. To prevent the chances of disease to living organisms, different clean-up approaches are adopted for the mitigation of radioactive wastes [3]. The leakage of radionuclides from nuclear facilities and their resulting environmental instability is a considerable matter of public interest and has sparked much recent work on core radionuclides' environmental fate [4]. The nuclear-powered manufacturing processes and its effluents are the major anthropogenic sources causing environmental radioactivity, while a significant amount of natural and artificial radionuclides are also emitted by accidental release in the 1950s and 1960s, as a consequence of nuclear weapons work (*e.g.*, in 1986 at Chernobyl), and from continued removal of radioactive substances obtained over the last sixty years of nuclear testing [5]. Instead of being processed, nuclear waste is buried deep into the earth or deep into water [6]. Although adequately shielded, the dangerous chemicals frequently penetrate deep into the ground to contaminate the soil to emit radiation that could be due to improper sealing, which could raise exposure to radioactive waste. Few instances of such approaches used to treat radioactive waste are wet oxidation, incineration, and acid digestion. There are many instances where storage has been breached, resulting in contamination of trillions of gallons of water and toxic pollutants and millions of cubic meters of polluted soil, including debris. Despite high costs and the technical limitations of current chemical-based approaches, there has been unprecedented interest in the encounters between micro-organisms and critical radionuclides to develop cost-effective bioremediation methods to decontaminate sediments and waterways [7].

The widespread distribution of microorganisms in the ecosystem is well-known, but it has only recently become possible to get an idea of the scale of microbial colonization in the radioactive environment [5]. Some researchers have studied uranium mine tailings as high-volume, low-specific activity radioactive models and found residues of radioactive material from mining and milling activities [8]. It has been found that bioremediation can dispose and turn nuclear waste into electricity [6]. The above-aforementioned methods have their benefits and drawbacks [9]. Nowadays, the experts are working on the management of radioactive waste as nuclear energy, which would play a significant role in the immediate future, developing current approaches, and implementing innovative ways to handle and dispose of waste through modern technologies; however, there is no appropriate way to handle radioactive waste currently [3]. Therefore, it is important to monitor and handle the disposal of radioactive waste using physical, chemical, and biological methods for the treatment of radioactive waste.

2. SOURCES OF RADIOACTIVE CONTAMINANTS

Radiations are present globally and every living being is subjected to them in one way or another. Environmental pollution by nuclear contaminants is caused by natural and anthropogenic activities. The problem arises if the quantity of pollutants is not handled or managed properly by the community and is released directly into the environment, which causes harm to the ecosystems [10]. There may be a variety of causes for radioactive contamination. Land, air, water, vegetation, buildings, and roads have been contaminated by (i) testing and manufacturing of nuclear weapons [11, 12], (ii) processing of radioactive materials in factories or mines [13], (iii) accidental spills [14], (iv) management of radionuclide wastes [15], and (v) processing and extraction of radioactive material from ores [16].

Cosmic rays from space or nuclear particles from the earth's surface are the major sources of natural radiation. Rocks and soil containing radioactive materials such as thorium, potassium, plutonium, and radium emit radiation from the earth's crust. Radium-226 releases toxic radon gas as it decays, contributing to exposure of terrestrial organisms [17]. Whereas anthropogenic activities involving devising of radioactive isotopes, mining, processing, and preparation of radioactive materials, explosives released from nuclear weapons, radiation-emitting out of nuclear power plants, and equipment used in medical treatments, *etc.*, accounts for 20% of total radiation to which the human population gets exposed [18, 19]. Radioactive contaminants can be further differentiated based on ionization, *i.e.*, ionizing and non-ionizing radiations, with ionizing radiations being are more dangerous than than latter ones [19]. Non-ionizing radiations were transmitted from microwaves, wireless radios, television, phones, laptops, *etc.*, whereas ionizing radiations involve X-rays, gamma-rays, and alpha-rays [20]. The harmful

CHAPTER 4

Microbial Aided Bioremediation and Sources of Biomedical Waste

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Abstract: The increasing population and altered lifestyle have led to the increase of diseases and, correspondingly, the number of hospitals and medical facilities. This rise has led to increased generation of waste of biomedical origin generated from hospitals. Biomedical waste is hazardous, and if left untreated, it can cause serious health hazards. Physical and chemical methods are traditionally employed for the treatment of biomedical waste, which do not eliminate the toxicants and release hazardous gases. Thus, these processes are not environment-friendly. This chapter detailed the use of microbial-aided remediation techniques for the removal of biomedical wastes. The recent development during the last decades in the eco-friendly treatment of biomedical waste suggests that extensive studies are needed to address this issue which is becoming a global concern.

Keywords: Biomedical waste, Bioremediation, Environment, Hospitals.

1. INTRODUCTION

Waste encompasses any object or resource that is discarded, unwanted or wasted, irrespective of whether that resource has any potential application or not. It covers any substance or object that is dumped into the soil or the water or ambient air, drained, injected, sprayed, released, thoroughly cleaned, or discharged [1]. Health care wastes contain a wide variety of products, from discarded needles, syringes, body parts, soiled dressings, semen, diagnostic tests, chemicals, radioactive materials, medicines, and medical equipment [1]. In 2016, the Biomedical Waste: Management, Handling, and Regulations of India classified biomedical waste as "any waste produced during the diagnosis, treatment or immunization of humans

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or animals or in health camps or research activities for the development or testing of biologics" [1]. Medical attention is essential for our lives and wellbeing, but poor disposal of biomedical waste causes adverse effects on human and environmental health, including flora and fauna. Globally, the production of medical waste is growing exponentially; for instance, on average, 3.5 million tons of medical waste is generated by the United States alone annually [2]. In the developed world, the growing use of the medical system is causing a rise in the production of medical waste [2]. The development of healthcare biomedical waste is also increasingly growing due to increased access of people to medical care [3]. In China, the production of medical waste was about 150 million tons per year and has risen by 7-10% annually [4]. Medical waste disposal has drawn the interest of policymakers and scholars worldwide. Because of the infection and high plastic content, medical waste is not adequately treated and disposed off, which can pose a serious threat to humans and the environment [5].

The disposal of biomedical waste is an important aspect of conventional and modern health care programs [1]. In India, the first rule book on biomedical waste management rules was published on 20th July 1998. Subsequently, the occasional revisions and improvements were made to the laws in 2003 and 2011. The general analysis of the biomedical waste is given in the Management and Handling, 1998. Indian regulations are still the responsibility of every "occupier," that is, the individual who only has jurisdiction over the organization and its facilities. It is to adequately follow all needful steps to assure that the hazardous pollutants are managed without causing any harmful effects to the environment as well as human health [6]. By the previous edition, the current Biomedical Waste Management (BMW) regulations, 2016, and amendment guidelines, 2018, were an upgrade for streamlining the BMW management. This was done to keep track of the improvements in the health care setup requirements [7].

Most commonly used physicochemical techniques have been used for the remediation of environmental pollutants over decades, but they are not only too costly, but their byproducts are toxic to the atmosphere as compared to the byproducts generated by bioremediation through fungal species [8]. In particular, there is a great need for more fundamental research and development in the fields of environmental site and waste diagnostics, waste-technology matching, and incorporation of various remediation techniques. Bioremediation is a natural method that provides bacteria or their products to mitigate or remove the harmful effects of pollution on the ecosystem. Researchers have demonstrated that there are several effective remediation methods to eliminate these environmental toxins and, among many of them, the most appropriate and eco-friendly solution is bioremediation [8]. In matrices such as soil, sewage sludge, and other sources of wastewater, bioremediation is mainly applicable and may be applied *in situ* or *ex* *situ* to bioreactors. Its utility, especially if implemented *in situ*, is because of its lower cost and eco-friendliness. Two main methods can be used for *in situ* attenuations, *viz*., bioaugmentation by microbial inoculation, bio-stimulation by the addition of microbial growth-promoting formulations [9, 10].

Generally, when used for bioremediation, microorganisms may convert organic contaminants into inorganic matter, cell biomass, and nutrients [11]. A diverse range of microorganisms has been studied for bioremediation in soil and marine ecosystems, including algae, bacteria, fungi, and genetically modified microorganisms [12]. Increased pollution of the atmosphere leads to a gradual deterioration of the quality of the environment. However, such situations pressure our global community to identify successful remediation steps to reverse the adverse effects that pose a significant threat to human and environmental health. Therefore, new emerging bioremediation methods focused on developments in molecular biology and process engineering need to be established.

2. SOURCES AND TYPES OF BIOMEDICAL WASTES

Biomedical waste (BMW) usually relates to any liquid and solid healthcare waste material, either in containers or bottles or vials that may be covered or uncovered, and any other intermediate waste produced over the long term (long or medium or short) of treatment that may include observation, diagnosis, therapeutic and rehabilitative processes [13]. Biomedical wastes can be divided mainly into two categories, (i) hazardous and (ii) non-hazardous waste [6]. Approximately 75-90% of the wastes, *i.e*., coming out from the healthcare facilities, is non-toxic, and they fall into the general category of waste produced mainly by the administrative and household activities of healthcare facilities [14]. Such waste is managed and taken care of by the local civil authority. However, if not appropriately treated, the remaining 10-25% of patient waste is toxic and poses serious risks to public health [15]. In recent years, there has been a growing public concern about healthcare waste management around the globe, especially in developing countries [16]. Instead of trying to eliminate them, a lack of understanding has caused hospitals to become epicenters of spreading illness [17]. In India, it is estimated that 330 thousand tons of biomedical waste is produced yearly, and the estimated rate of waste generation ranges from 500 to 2000 grams per bed per day across different hospitals [18].

Numerous hospital facilities, like small clinics, pharmacies, nursing homes, and outpatient surgery centers, are the primary roots of these medical wastes [19]. Biomedical waste generation is an eventual result of current patient treatment and procedures [20]. The rapid expansion of hospitals in both the public and private sectors to meet social demand has dramatically increased the number of

CHAPTER 5

Electronic Waste Management: An Emerging Challenge to the Environment

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Abstract: In developing countries, electronic goods are common in use and generate huge bulk of e-waste. Such waste is discharged into the environment due to broken electronic instruments, such as used computer parts, batteries, air conditioners, mobile phones, *etc*. Moreover, we cannot imagine our life without electronic gadgets. The e-waste contains several toxic chemicals such as mercury, lead, cadmium cobalt, nickel, and several other toxicants. Therefore, its disposal into the environment causes pollution of soil, water, and air, posing serious threats to all living beings. These wastes can be managed through product recycling through landfills, but it is still not a safe method because dumping sites can spill over a huge quantity of heavy metals, contaminating the surrounding area of soil and water. Thus, the proper management for the treatment of such wastes is necessary for a green environment. It is necessary to understand the public health risks and the strategies to combat this growing menace. Therefore, the main purpose of this chapter is to provide comprehensive information about the e-waste problems, strategies for their management, including microbiological, physical, and chemical treatments of e-wastes. The bioreactor technology using a specific group of microorganisms concerning to bioleaching of

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metals from the associated E-waste is a safe and ecofriendly remedial measure to combat this problem.

Keywords: Bioleaching, Bioreactor, Contaminants, Ecofriendly, E-waste, Green environment, Heavy metals, Landfill, Microorganisms, Toxicants.

1. INTRODUCTION

Electronic waste (e-waste) is an emerging global environmental and public health issue, as this waste has become the most rapidly growing area of the municipal waste stream [1]. In India, E-waste has now become one of the major problems for the environment. E-waste or Waste Electrical and Electronic Equipment (WEEE) are loosely discarded, surplus, broken, electrical or electronic devices such as computer monitors, motherboards, mobile phones and chargers, compact discs, headphones, television sets, air conditioners, and refrigerators [2]. Puckett *et al*. [3] reported that the United States and some other rich economies use most of the electronic goods and generate most of the e-waste. The United Nations (UN) report indicates that due to poor extraction techniques, the recovery rate of the metal which is required for laptops, smartphones, and electric car batteries manufacturing from e-waste is very less. E-waste recycling is also an important perspective for a green environment. It means the reprocessing and reuse of electronic waste. The valuable materials are recovered from e-waste during its recycling. This process has the potential to diminish the hazardous effects of these pollutants.

Recycling methods must ensure efficient e-waste processing in an environmentally friendly manner. The European Union (EU) has given the direction on Electrical and Electronic Equipment (WEEE Directive) since 2002 to solve the problem of e-waste [4 - 6]. In India, most of the waste electronics are stored in households. Such wastes are complex, containing metals such as gold, silver, and copper, which can be recovered. E-waste management and recycling alliances also employ people [7]. Around 25000 workers, including children, are involved in crude dismantling units in Delhi alone, where tons of e-wastes are handled every year by bare hands. Improper dismantling and processing of e-waste render it harmful to human health and the environment. Therefore, there is a need for proper e-waste management technologies [8].

E-waste is made up of many things that contain 50% iron ore and steel, about 21% plastics, and about 13% of some non-ferrous metals. In non-ferrous metals, some precious metals like silver (Ag), gold (Au), platinum, and palladium were also found [9]. The major challenge behind the recycling of e-waste is the absence of appropriate legislation and awareness of people about this. The cities or countries that are the major source of e-waste have no proper sewage system for their management. Due to inappropriate treatment of such waste, the toxic materials are released into the environment and pose serious health effects to humans. Due to illegal means of recycling, many people get their income and benefits from the secondary market. This is one of the major challenges in the developing countries because it generates income and there is a strong economic force driving the creation of an informal sector, which possesses challenges for enforcement of regulations [10, 11]. E-waste contains several toxicants that can pose serious health and environmental problems if not managed properly. E-waste disposal is one of the major problems faced in many regions of the world. Chai *et al*. [12] studied soil microplastic (size less than 1 mm) pollution in an e-waste dismantling zone of China and found that these are the microplastic hotspots. These plastic particles may enter through food and water and may have serious health effects on the ecosystem.

In developing countries, no clear data are found for e-waste management. In India, some Non-Governmental Organizations (NGOs) are working on these projects. Maharashtra is one of the first states, and Mumbai is the first city in India for the large production of e-waste [13]. India is developing at a very high pace with the use of electronic equipment; thus, the high risk of e-waste is causing harmful effects in the ecosystem. Therefore, such waste should be properly managed. This chapter discusses the associated impacts, challenges, and the possible management of e-waste, including its recycling strategies using physicochemical and microbiological systems.

2. IMPACT OF E-WASTE ON ECOSYSTEM

Electronic equipment contains many hazardous metallic contaminants such as lead, cadmium, and beryllium, and brominated flame-retardants. The fraction including iron, copper, aluminum, gold, and other metals in e-waste is over 60%, while plastics account for about 30%, and the hazardous pollutants comprise only about 2.70% [9]. E-waste is generated from different sources (Fig. **1**).

E-waste is collected from cathode ray tubes, printed board assembly, mercury switches and relays, batteries, cartage drums, liquid crystal displays, *etc*. [14]. Among toxic heavy metals, lead is the most widely used in electronic devices for various purposes, resulting in a variety of health hazards [15]. It enters biological systems through food, water, air, and soil. Children are particularly vulnerable to lead poisoning compared to adults, and their nervous system and blood get affected [16]. If e-waste is managed by landfilling, then lead leaches to the soil

CHAPTER 6

Bioremediation Strategies for the Decontamination of Solid Waste Pollutants

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Abstract: Countries around the globe, including India, face big environmental challenges related to waste generation, improper collection, transport, treatment, and disposal. The huge solid waste generation is also directly correlated with the large urban population and damage the ecosystem. The sludge contains various types of toxic substances such as detergents, pesticides, soluble salts, and a substantial quantity of various heavy metals like zinc, copper, nickel, cadmium, mercury, chromium, and lead that obstruct metabolism and specific enzyme activities. Therefore, a sustainable technique for remediation of such toxic metals and other pollutants from contaminated sites needs to be developed. Several findings have been demonstrated in the present chapter for the use of various efficient plant species to clean up heavy metal and other hazardous materials from sewage and tannery sludge.

Keywords: Bioremediation, Heavy metals, Phytoremediation, Plant species, Sludge, Solid Waste.

1. INTRODUCTION

Every life on earth is directly connected indissolubly to the overall superiority of the environment. Regrettably, with industrialization and the advancement in science and technology, a huge amount extending from raw sewage to nuclear waste is discharged into the ecosystem, thus, creating a big problem for the survival of mankind itself on earth. Generation of huge waste in the form of either liquid or solid and its disposal is a key focusing point for the researchers. Generally, it is considered that waste has a societal impact in the form of spreading contamination, diseases, and pollution. However, industrial and house-

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hold wastes contain various types of contaminants, such as toxic chemicals and heavy metals. In the past, solid wastes are conventionally disposed off by digging a hole and filling it with waste material. This method of landfilling is not suitable and sustainable because every time, there is a need to dig a new hole for filling solid waste. Nowadays, advanced technologies are developed for solid waste management, in which high temperature, incineration, and chemical decomposition (*e.g*., base-catalyzed dechlorination, UV oxidation) are done. Even though these technologies are very effective in terms of reducing a wide range of contaminants but also have many downsides such as not being cost-effective, lack of public acceptance, and complexity. Researchers around the world have made continuous efforts to cut out the deficiencies associated with these methods and found suitable alternate phytoremediation/bioremediation processes.

At present, India is generating annually approximately 960 million tons of solid wastes as by-products during industrial, mining, municipal, agricultural, and other processes. This rise in solid waste generation as a by-product of economic development and daily need of societies, which directed many subordinate laws for amendable methods of disposal and production are made under the umbrella law of the Environment Protection Act (EPA), 1986. The strategic way for efficient industrial and municipal waste disposal is to make sure that the proper separation of waste at the origin point and the waste goes through different streams of recycling and resource recovery. After being deposited at particular sites, the residual part is then scientifically treated and applied in agriculture. Sanitary landfills are the best way to dispose of the municipal inorganic wastes which arise from various processing units that cannot be reused/recycled. However, the only drawback of this method is costly transportation (from source to landfills site) and land availability. This method has also led to the spread of diseases and air pollution. Based on the type of waste, separate rules and legislation for their adequate treatments plan are needed.

2. TOXIC POLLUTANTS CONTAMINATED FROM SOLID WASTE IN THE ENVIRONMENT

Countries around the globe, including India, face big environmental challenges related to waste generation, improper collection, transport, treatment, and disposal. This huge waste generation is also directly correlated with the large urban population and have an impact on the environment and public health [1]. The waste is transported through water, air and gets deposited into the environment, hence, increasing the concentration of metal in the environment [2]. The liquid wastes (effluent) generated from various anthropogenic activities such as metal pickling, mining, rolling industries, smelting, and fly ash contain potentially toxic elements and heavy metals. Other sources of heavy metal and contaminants, such as estuarine salt marshes, are often located near the urban and industrial areas [3]. Metals like iron, zinc, magnesium, and copper are considered to be essential for metabolism, enzymatic activities, photosynthesis, and respiration of the living system [4]. However, some ionic forms of toxic metals include cadmium, mercury, lead, nickel, arsenic, aluminum, platinum, and copper, obstruct metabolism, which leads to dysfunction of the body. In the present day, many countries come across severe environmental contamination with heavy metals, which is posing serious health problems. On the other hand, the people's needs are fulfilled by some industries like tanneries, battery manufacturers, *etc*., which also add pollutants to the environment. Dean *et al*. [5] has also discussed various uses of heavy metals in daily life, which increase environmental contamination.

At the present time, toxic contaminants such as hazardous metal ions, radio nucleotides, and insecticides cause major health problems. Among these, toxic pollutants and heavy metals have contaminated the ecosystems through natural and anthropogenic activities. The source of heavy metals through human activities includes mining, smelting of metalliferous ores, burning of fossil fuels, the use of pigments and batteries, municipal wastes, pesticides, fertilizers, tannery sludge, and sewage sludge [6]. There are two major sources of heavy metal contaminates responsible for soil pollution as well environmental hazards: industrial sludge and municipal sewage sludge.

2.1. *Heavy Metal From Industrial Sludge*

The rapid expansion in world population as a result of rapid industrialization has increased the burden on sludge manifolds, which is expected to increase in the future. At present, two key sources are identified for the heavy metal contamination in the natural environment as well as soil and water pollution. Firstly, the major contributor is tanneries, known for the leather tanning industry, which uses a high level of different kinds of heavy metals, and in the end, contaminate the environment in the form of effluent and solid waste (sludge) (Fig. **1**). Tanneries are also a threat to the environment because it generates not only heavy metal-containing effluents but also solid waste in the form of sludge with metalliferous waste. As compared to other developed/developing countries, India is one of the biggest leather producers and ranked sixth worldwide; about 7 lakh tons of wet salted hides and skin are processed in three thousand tanneries [7]. It has been reported that every day nearly 50 million liters of liquid waste and 305 million kg of solid waste are produced by the tannery industry [8]. In the leather tanning process, various types of chemicals are used, such as ammonium sulfate,

CHAPTER 7

Application of "OMICs" Approaches in Bioremediation

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Abstract: Bioremediation is an eco-friendly and highly efficient technology over other kinds of treatments to remediate contaminated sites. However, it is necessary to take care of every parameter related to microbial diversity and physiology and the metabolism of the microbes during bioremediation, which helps in determining the efficiency and the key factors responsible for accelerating the decontamination process. For this aspect, various OMICs approaches such as genomics, transcriptomics, proteomics, and metabolomics play a significant role in generating the information relevant to the degradation of the contaminants by the microbes. These approaches help in studying the functional and bio-synthetic potential of a microbe in isolation and play a crucial role in studying the functional potential of the community as a whole at a contaminated site. Microbial diversity, an abundance of microbial genera, and their enzymes are involved in the degradation of various types of pollutants in the contaminated environment. The present chapter provides an overview of various studies which are based on the application of OMICs in the field of bioremediation, advancement in tools and technologies in the methodology associated with OMICS, as well as about the key microbial players and enzymes used in the degradation of pollutants.

Keywords: 2D SDS PAGE, Biodegradation, Bioremediation, *De novo* synthesis, Feature extraction, Fluxomics, Functional potential, Genomics, Herbicide, *In silico* omics, LC-MS analysis, Mass spectrometry, Metabolomics, Metagenomics, Metaproteomics, Metatranscriptomics, Microbial community, Microbial diversity, OMICs, Protein, Proteomics, RNA-seq, Sequencing technology, Spectral pre-processing, Transcriptomics.

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1. INTRODUCTION

In the present era, pollution has become a worldwide issue. Biomagnification resulted in an increased level of pollutants at each tropical level along with the food chain, which in turn adversely affects the health of living organisms. Soil, water, and air pollution affect food resources directly. Industries, the key boosters of a nation's economy, are unfortunately the major polluters of the environment [1]. These rely on the use of generally cheap and non-biodegradable chemicals for the production to derive more profits, and usually, the toxicity caused is ignored. Industrial waste consisting of organic and inorganic pollutants cause severe environmental health issues [2, 3]. The most commonly present environmental contaminants include petroleum hydrocarbons, heavy metals, pesticides, solvents, *etc*. [1]. Owing to their long persistence in nature and their toxic effects on microorganisms, plants, animals, and human beings, these have become too problematic. These pollutants are introduced into the environment from untreated industrial waste, anthropogenic activities, oil spills, long-term use of pesticides in fields, dumpsites, *etc.* [4 - 6].

Bioremediation, *i.e*, the use of microorganisms to decontaminate such sites, is considered to be the most promising approach due to its high efficiency and cost-effectiveness for treatment [7]. It chiefly involves degradation and mineralization wherein the pollutants are converted into less toxic forms or mineralized completely into carbon dioxide, methane, and water [8]. *In situ* bioremediation (bioremediation on the site) typically relies on two approaches – the biostimulation strategy and the bioaugmentation. While the former is based on stimulating the growth of naturally existing microorganisms with the potential of decontaminating the environment; the latter involves the addition of microorganisms with known degradation capabilities. Microorganisms harbor a plethora of catabolic genes and pathways thereof, which can effectively degrade the pollutants or utilize them as a source of energy [7, 9], which also depends upon the bioavailability and accessibility of the pollutants to the microbes [10]. But, the knowledge of such genes and pathways is limited as most of the studies in the past were based on culturable microbes.

According to the "great plate count anomaly," it is now a known fact that around 99% of the microbes in the environment are uncultivable and unable to grow in artificial media in the laboratory. Therefore, our current knowledge about the pool of genes and pathways encoded by the uncultivable community of the environment still has a large void. However, with the advancement in sequencing technologies and bioinformatics tools, it has become possible to study the microbial community prevalent in a particular environment. Genome-based studies not only enhance the understanding of the coding potential of a microbe but further, with the help of transcriptomics and proteomics, the change in the gene expression and response to the contaminant of an organism can also be analyzed [11]. This collective study of the pooled DNA and RNA present in a specific environment is referred to as metagenomics and metatranscriptomics, respectively.

A collection of all genomes representing the microbial community is now commonly called the metagenome of that environment. Metaproteomics has emerged as another approach of omics that enable the understanding of the enzymes and proteins encoded by the microbial community, which in turn performs various functions and also helps in predicting the interactions that exist in a community. Additionally, metabolomics and fluxomics also serve as efficient means of studying the metabolites and their rate of conversions by the microbial community. With the help of all these omics approaches, it is now possible to decipher the bacterial genera prevalent in a polluted environment. Further novel microorganisms can also be isolated for the bio-augmentation of the contaminated sites to accelerate the process of bioremediation. Monitoring the community composition, genes, pathways, and the abundance of metabolites throughout the bioremediation process at the contaminated site can be accomplished through omics approaches (Fig. **1**). This chapter not only gives an overview but also describes the application of various omics approaches like genomics, transcriptomics, proteomics, metabolomics in studying contaminated sites and accelerating the bioremediation of pollutants (Fig. **2**).

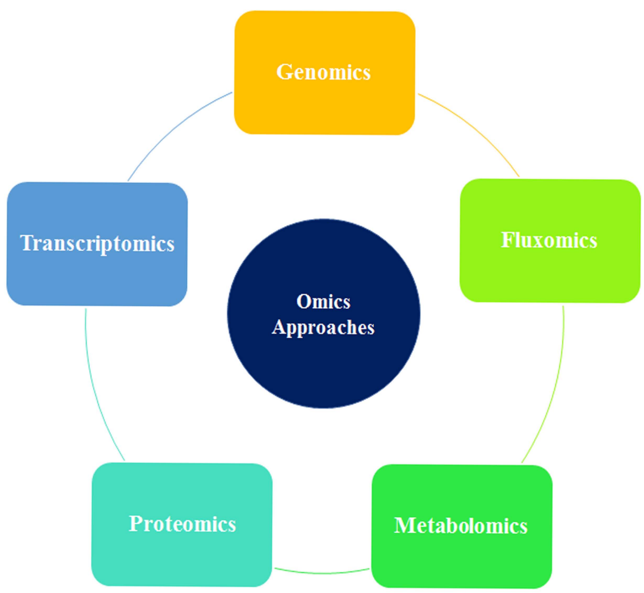

Fig. (1). OMICs approaches applied for bioremediation studies.

CHAPTER 8

Management of Agriculture Waste: Bioconversion of Agro-Waste into Valued Products

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Abstract: Agriculture wastes or agro-wastes are byproducts obtained after the processing of crops and other agriculture products. The worldwide production of a huge quantity of agro-wastes presents different challenges in the environment. Agriculture wastes are potentially toxic to plants, humans, animals, as well as different components of the environment. The burning of agricultural waste causes serious environmental pollution, while dumping causes leaching and soil deterioration. Despite several drawbacks, the valorization of agriculture waste has been a promising approach for their sustainable management. Agriculture wastes are rich in lignocellulosic material that include cellulose, hemicellulose, and lignin and also contain pectin, proteins, lipids, and polyphenols. About 50% agro-wastes are obtained from wheat, rice, and oilseed crops that contain 0.5% N, 0.2% P_2O_5, and 1.5% K_2O. The rich nutrient and mineral content of agro-wastes presents them as a good raw material for the production of different valued products. Production of valued products such as enzyme, ethanol, compost, biogas, mushroom, and animal feed using agriculture wastes as a substrate has been discussed. The present chapter converses the utilization of agro-waste for the production of different value-added products and also describes the challenges and advancements during the fermentation of wastes into products.

Keywords: Advancements, Agriculture wastes, Challenges, Enzymes, Fermentation, Management, Pollution, Valorization.

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1. INTRODUCTION

The rapid growth of agriculture and forestry to feed and meet the demands of the human population resulted in the generation of a huge amount (140 Gt) of biomass waste [1 - 3]. The generation of huge waste represents different environmental challenges. Worldwide, about >2 Gt crop residues are burned, which contribute around 18% of the total global release of CO_2 [4], as well as considerable particulate matter (black carbon) [5, 6]. In the agriculture industry, the by-products obtained after the processing of agricultural products are referred to as "agricultural waste" as they are not the main products [7, 8]. About five million metric tons of agricultural biomass are produced annually [9]. The composition of agricultural waste varies depending on the type of agricultural product/activity. The agriculture waste or argo-waste consists of crop residues (straw, corn stalks, sugarcane bagasse, fruits, and vegetable residues), food processing waste, animal waste (manure, animal carcasses), and toxic agricultural products such as insecticides, pesticides, and herbicides [8]. The majority of agricultural waste (almost 50%) is produced by wheat, rice, and oilseed crops [10, 11]. Agriculture wastes have a profound impact on the environment when disposed off unsafely. For instance, the traditional practice of burning agricultural waste causes serious pollution in the environment [12].

The burning of agricultural wastes releases atmosphere polluting gases such as carbon monoxide, nitrogen dioxide, nitrous oxide, and fine particles known as smoke carbon [13]. Subsequently, gaseous pollutants cause the formation of nitric acid [14], resulting in acid precipitation that causes ecological damages as well different types of risks to humans [15]. Besides, animal wastes, which are excreted as solid, liquid, or gases, are another potential threat to the environment. The solid and liquid waste of animals is a good medium for microbial growth, resulting in the production of microbial biomass as well different gaseous and soluble products that affect the environment adversely, causing air, water, and soil pollution [7]. The volatilization of ammonia from animal waste results in acid deposition, contributing to acid precipitation [16]. Despite several drawbacks, agriculture waste has many benefits while managed properly. Agricultural wastes are rich in lignocellulosic material such as cellulose, hemicellulose, and lignin and also contain pectin, proteins, lipids, and polyphenols. The agro-wastes obtained from wheat, rice, and oilseed crops contain around 0.5% N, 0.2% P_2O_5, and 1.5% K_2O [11]. The rich nutrient, as well as the mineral content of agro-waste, make them good raw materials for the production of different valued products such as enzymes, ethanol, biogas, compost, mushrooms, and animal feeds, *etc*. (Fig. **1**).

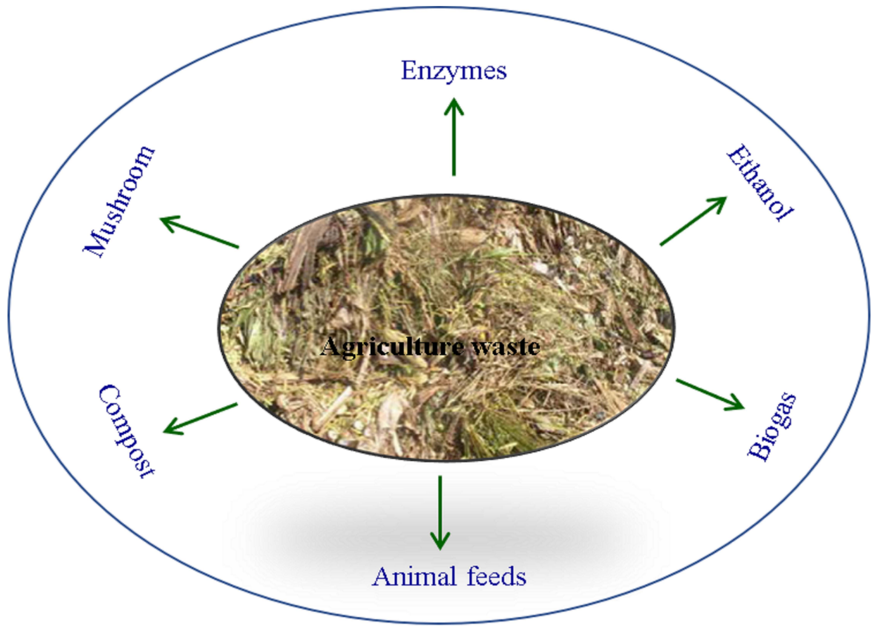

Fig. (1). Schematic representation showing bioconversion of agriculture-waste into value-added products.

2. PRODUCTION OF VALUE-ADDED PRODUCTS

2.1. *Enzymes*

Enzymes present in every living system are very specific biocatalysts that are used in different industries. The paper, pulp, baking, brewing, and detergent industry have wide applicability of enzymes for the processing of products [17]. Production of enzymes involves classical methods as well recombinant DNA technology. Recombinant DNA technology allows the cloning and large-scale production of enzymes in microbes to meet the industrial demand strain improvement; employing mutations is another promising technology used to capitulate enzyme production in industries [18]. Industrial enzymes acquire a large proportion of the global market, which is increasing from \$5.0 billion (the year 2016) to \$6.3 billion (the year 2021) [17, 19]. Despite the enormous demand, enzymes are comparatively expensive, which increases the operational cost of industrial processes, and hence the cost of the products. Around 50% of enzyme production cost is related to capital investment, whereas the cost of raw materials adds to about 1/3rd of the production costs [17]. Therefore, the utilization of agriculture waste, specifically lignocellulosic waste, could be helpful in the reduction of enzyme production costs. Studies demonstrated that pretreatment of lignocellulosic biomass affects the production yield. During pre-treatment, the

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Manikant Tripathi

Dr. Manikant Tripathi is presently working as an assistant professor at the Biotechnology Programme, Dr. Rammanohar Lohia Avadh University, Ayodhya. He has completed his B.Sc. degree (2000-2003) from Deen Dayal Upadhyay Gorakhpur University, Gorakhpur (India). He completed his master's degree (2003-2005) in microbiology from Dr. Rammanohar Lohia Avadh University, Ayodhya (India). Thereafter, he completed his Ph.D. degree (2008-2013) on the topic entitled "Simultaneous bioremediation of chromium (VI) and pentachlorophenol from tannery effluent" from Dr. Rammanohar Lohia Avadh University, Ayodhya (India). He received "Research Fellowship in Sciences for Meritorious Students" by University Grants Commission, New Delhi, and was qualified for ICAR-NET conducted by Agricultural Scientists Recruitment Board, India. Dr. Manikant Tripathi has participated in several international/national conferences/workshops/webinars. He also received Best Poster and Oral Presentation Awards in conferences and Young Scientist Awards by Biological Societies of India. He has published 32 research papers, 11 chapters, edited 03 international eBooks, and 10 review articles in peer-reviewed journals with 660 Google Scholar citations, h-index 14, i-index 16. He has also guided postgraduate students on their dissertation work. His current area of research is microbial biotechnology, green synthesis of nanoparticles, and the bioremediation of industrial pollutants.

Durgesh Narain Singh

In the year 2005, Durgesh Narain Singh completed his postgraduation (M.Sc.-Microbiology) from Dr. R.M.L. Avadh University, Ayodhya, U.P., India. He was awarded the Chancellor gold medal for his outstanding performance in M.Sc. (microbiology) exams. After passing M.Sc. and qualifying for the National Eligibility Test, he joined the Ph.D. program in microbiology at the School of Biotechnology, Banaras Hindu University, Varanasi, U.P., India. His doctoral work in the area of "microbiology and metagenomic of an Indian coalbed" was a pioneering work in India. Based on his Ph.D. work, he delivered an invited talk at an international conference titled "Secondary Biogenic Coal Bed Natural Gas International Conference" organized by the School of Energy Resources, University of Wyoming, Laramie, USA. Moreover, he has attended different national and international conferences. He has worked as a post-doctoral researcher at CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, U.P., India. He joined University College Dublin as a post-doctoral fellow, and after his selection as a CSIR-Senior Research Associate under the Pool Scientist's scheme (Council of Scientific and Industrial Research, India), he joined the Department of Zoology, University of Delhi, Delhi, India. He joined BioNEST-BHU, Banaras Hindu University, Varanasi, as a scientific officer after successfully completing his postdoctoral tenure at the University of Delhi. His research work focused on understanding the structure and function of microbial communities residing in unique/extreme environments. He has been employing "omic" (genomics, metagenomics, and proteomic) approaches for bio-prospection of novel biomolecules from unique niches and bioremediation studies. His research findings have been published in different peer-reviewed journals, and he is the recipient of many awards, including gold medal (2005), FEMS Young scientist meeting grant (2011), DST travel grant (2012), and Young Scientist award (2019). Dr. Singh is currently working as a scientific officer in BioNEST-BHU, Banaras Hindu University, Varanasi, U.P., India. His thrust research area includes microbiology, metagenomics, genomics, gut microbiome, proteomics, bioremediation, biofuel, & bioprospection novel biomolecules.