Novel Approach on Bioremediation by Actinobacteria: A Review

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ABSTRACT: A significant environmental problem that has created serious difficulties for the agricultural ecology is toxic pollution. Among the most harmful environmental pollutants are heavy metals and insecticides. Bioremediation techniques include Bio-augmentation, Bio-injection and Phytoremediation. It eliminates and catabolizes environmental contaminants using natural or artificial plants and soil bacteria. Actinobacteria perform numerous essential ecological tasks in nature, including the breakdown and recycling of complex polymers and the production of bioactive compounds. As a result, biotechnologists are interested by the idea of using actinobacteria to remove pollution. This can be done using the green method of Bioremediation, in which certain microorganisms are introduced into contaminated areas to increase their degradative ability. Thus, Actinobacteria make excellent bioremediation candidates, which is important as more contaminants are released into the environment. This article discusses ways to mitigate the effects of heavy metals and pesticides on agricultural ecosystems by using actinobacteria as a Bioremediation agent.

Keywords - Actinobacteria, Bioremediation, Pesticides, Heavy metals, Environmental pollution

INTRODUCTION

In the past two decades, environmentally friendly methods for decontaminating polluted environments have developed that make use of a wide variety of microbial species. The term for this kind of process is bioremediation, and it is typically thought to be less intrusive and more beneficial to soil functioning than traditional physicochemical treatments [1, 2]. Importance of bioremediation as a sustainable technology examining the significant discharge of human-made toxins into the environment [3].Pesticides are chemicals used for pest control and are perhaps the most extensively dispersed environmental contaminants [4]. The dumping of outmoded pesticide stocks has also resulted in the long-term contamination of several locations with extremely high concentrations of chemicals of this sort. According to past official reports, organochlorine (OC) insecticides have been discovered in Brazil, Argentina, Chile, Poland, Spain, the Netherlands, China, Canada, the United States, and India [5, 6]. Because unlawful polluted storage facilities are still present, these are the reports understate the true problem More than 30 tons of OC pesticides, including lindane, chlordane, methoxychlor, aldrin, and DDT, and heavy metals, including Cr(VI), Cu(II), and Cd(II), were illegally dumped southeast of Santiago del Estero, Argentina [7, 8]. Pollution from farming is thought to be diffuse because the composites are spread out over large areas and are in very low concentrations. Pesticides have been found in many places around the world, with the air, water, soil, food, milk, fish, and even human blood and fat tissue [9, 10].

Heavy metals are naturally arising constituents of soil; however, certain heavy metals are vital for the health of animals and plants because of their role as cofactors in a wide variety of enzymes[11]. However, industrial development has exacerbated biosphere contamination by heavy metals, which become very toxic at large doses. The release of heavy metals from a range of various sectors around the world is a major factor in heavy metal poisoning[12]. Heavy metals with copper, chromium, lead, zinc, and cadmium often found in effluents and waste water discharged by industry can have serious effects on the environment and human health [13, 14]. As a result of their widespread distribution across the biosphere and their presence in the air, soil, and water as well as their accumulation in living tissues and the food chain, heavy metals pose a serious threat to human health [15]. It was well known that long-term exposure to heavy metals led to slow growth in babies, the start of different types of cancer, and damage to the liver and kidneys [16] and exposition to a high quantity of heavy metals that results in mortality. Heavy metal poisoning in the environment has been on the rise in recent years, particularly in the agricultural sector. This is attributable to soil buildup and plant absorption, both of which have occurred in recent years[17]. Both plants and people need heavy metals for a variety of organs, but when their concentration rises above a certain point, they are become fatal. Numerous scientific studies have led scientists to the conclusion that the main sources of heavy metals are industry, mining, pesticide manufacture, and agricultural practices [18, 19].

Heavy metal accretion is defined as a buildup of components in the environment. Plant roots must come into contact with ions of heavy metals that have been carried from the soil. They might connect and fix pollutants in the soil, limiting their bioavailability [20, 21]. The mechanisms by which heavy metals are transferred to plants include (I) Phytoextraction, which is a sub process of phytoremediation in which plants eliminate hazardous components from contaminated soil, (ii) Phytostabilization, This is the reduction of the mobility of heavy metals in soil and their immobilisation, and (iii) Rhizofiltration, which is a form of phytoremediation that makes use of plant roots to absorb the various toxic substances. In addition to causing damage to plants, the transfer of these metals down the food chain is detrimental to human health [22, 23]. Due to their prominent branching position in the tree representing the 16S rRNA gene, Actinobacteria is well-known as one of the most notable and diverse phyla within the domain Bacteria. Actinobacteria can be categorized as Gram-positive or Gram-variable aerobes. They have a muramic acid-based cell wall that is rigid. The most are chemo-organotrophs, and free-living species of the phylum are well recognized for having a high G+C content [24]. Actinobacteria have garnered attention as potential bioremediation alternatives for a number of environmentally contaminated areas that contain resistant inorganic and organic contaminants. *Acidimicrobium ferrooxidans*, an extremeophile, can grow at 45°C and a pH of 1.8. *A. ferrooxidans* N39, which was isolated from a spent copper sulphide heap, was tolerant to higher concentrations of several metals, including Zn(II), illustrating its robust adaptation to the hostile environment. In contrast, the collection strain *Acidimicrobium ferrooxidans* DSM 10331T was only tolerant to Zn(II) 33103 mg L-1.[25]. Microorganisms belonging to the genus Streptomyces and belonging to the genera *Arthobacter* and *Rhodococcus*, have established a significant amount of attention as a potential biotechnological method for cleaning up polluted environments[26]. Streptomyces strains may be effective for soil inoculation owing to their metabolic variety, mycelial growth habit, relatively fast growth rates, tendency to colonize semi-selective substrates, and genetic alterability [27]. *Streptomyces* strains may thrive on and breakdown a variety of pesticides, including pyrethroids, atrazine, and diuron, among others [28]. A most prominent actinobacteria that decompose pesticides, according to bibliographies published within the last 20 years, are those belonging to the genera *Arthrobacter*, *Rhodococcus, Streptomyces, Frankia, Janibacter, Kokuria, Mycobacterium, Nocardia*, and *Pseudonocardia*. These bacteria have the capability to proliferate and decompose a wide range of pesticide chemical families, comprising, among others , pyrethroids, ureas, and chloroacetanilides [26].

Table 1: *Streptomyces* strains beneficial in heavy metal bioremediation

Metal and *Streptomyces* strain	**Isolation sample**	**Mechanism**	**Reference**
As(V) VITDDK3	Marine soil samples collected at the Ennore saltpan	ND	[29]
B(III) *Streptomyces* sp.	B-contaminated soils, Salta, Argentina	ND	[30]
Cd(II) *S. rimosus*	Biomass produced during oxytetracyclin	Biosorption	[31]
Cd(II) *S. zinciresistens*	Zincecopper mine, Shaanxi province, Northwestern China	Biosorption/Bioaccumulation	[32]
Cr(III) VITSVK9	Marine sediment, Bay of Bengal, India	Biosorption	[33]
Cr(VI) *S. griseus* NCIM 2020	National Collection of IndustrialMicroorganisms, Pune, India	Reduction	[34]
Cr(VI)*S.thermocarboxydus* NH50	Soil contaminated by leaking drums of metal finishing effluents, Lyon, France	Reduction by agents present in the supertant	[35]
Cu(II) *Streptomyces* sp.	Copper filter plant, Tucuman, Argentina	ND	[36]
Cu(II) *S. flavovirens* ON3	Soil exposed to heavy traffic emissions, Brno, Czech	Biosorption	[37]
Hg(II) *S. coelicolor* M130	Culture collection	Enzymatic reduction	[38]
Ni(II) *S. aureofaciens* NR-3	Riparian sediments contaminated with high levels of Ni and U, Steed Pond, USA	Ni-influx and Ni-efflux transporters would be present to maintain homeostasis	[39]
Zn(II) *S. rimosus*	Biomass produced by an antibiotic production and collected after fermentation	Biosorption	[40]
Pb(II) *S. viridochromogenes*	ND	Biosorption	[41]

Table 2: Characteristics of the major pesticide-degrading actinobacteria genera

Microorganism	Pesticide	Isolation sample	Reference
*Arthrobactersp.*strainAK-YN10	S-triazine (atrazine)	Agricultural field repeatedly treated with atrazine in sugarcane cultivation, India	[42]
Arthrobacter sp. BS1, BS2 and SED1	Urea (diuron)	Soil from the interface between a vineyard and the Morcille River, Franc	[43]
Rhodococcus sp. BCH2	S-triazine (atrazine)	Long-term atrazine-treated grape farm soil, India	[44]
Streptomyces sp. M7	Organochlorine (lindane)	Wastewater sediment from a copper filter plant, Argentina	[45]
Streptomyces sp. AC1-6 and ISP4	Organophosphorus (diazinon)	Soil exposed to continuous applications of chlorpyrifos, Chile	[46]
Janibacter sp. AS2	Pentachlorophenol	Sediments from arid and saline ecosystems, Tunisia	[47]
Gordonia sp JAAS1	Organophosphorus (chlorpyrifos)	Soil from a paddy field exposed to continuous applications of chlorpyrifos, India	[48]

2. PESTICIDE AND HEAVY METAL SOURCES AND DISTRIBUTION

2. 1. PESTICIDES

Pesticide residues have been identified in a range of industrial and agricultural contexts; these residues destroy lives by polluting their food and water while also affecting river ecosystems, marine life, and sediments [49]. Different agrochemicals are often deposited into adjacent rivers by subsurface runoff from agricultural fields [50]. Agrochemicals have been found to exist in both drinking water and groundwater in the past, according to scientists. Pesticides permeate through soil at different rates based on their solubility in water, adsorption by sand grains, and persistence [51]. The amount of organic matter that is present in an area has a significant impact on how long pesticides remain in the soil and sediments. Organic matter offers a variety of binding sites for organic pollutants, mainly hydrophobic ones [52]. It is largely due to organic matter that the retention of HCH isomers differs between soil types. In general, when soil components hold on to contaminants, bioavailability goes down and degradation is slowed [53]. A number of pesticides can vaporize from the soil or foliage and travel long distances. This explains the occurrence of pesticide traces in pristine areas, which suggests that the atmospheric redistribution rather than direct application is answerable for their occurrence. Spain commenced investigating persistent organic pollutants (POPs) in the air in 2008 after the Stockholm Convention's Global Monitoring Plan determined that air is the major channel of long-distance pesticide dispersion worldwide [54]. In order to evaluate the levels of DDT and hexachlorobenzene (HCB), passive air samplers were deployed in four urban and seven isolated Spanish locations. When rural and urban areas were evaluated collectively, the finding showed that HCB was the major pollutant, followed by DDTs in decreasing order [55]. Statistically, urban areas had meaningfully higher concentrations of all studied families with the exception of HCB, signifying that human activities may be source of DDTs [56].

2.2. HEAVY METALS

Heavy metals are originate naturally and anthropogenically in soil, water, air, and living organisms [57]. Anthropogenic sources produce pollution that continues to increase over time, whereas ordinary sources are habitually seasonal, weather-dependent, and do not produce pollution [58, 59]. Heavy metals are accumulated by individuals and are present in wastewater, industry, and farms. These sources aggravate the ecosystem's heavy metal and ecological problems. In the case of these metals, smelting them emits Cu, Zn, and Pb [60] the combustion of fossil fuels produces Hg, and car exhaust contributes to the release of Pb [61]. Some heavy metals are obligatory for the continued existence of all known forms of life. This is due to the fact that they are able to perform multiple functions within biotic systems. Many others, on the other hand, have no known living role. Cells have homeostatic mechanisms that regulate heavy metal concentrations and diminish the harmful consequences of high levels. The absorbed dose, the mode of exposure, and the length of time that an individual is exposed all play a role in determining the toxicity of heavy metals. It is possible, for instance, to become poisoned by certain heavy metals by ingesting them through drinking water. This is the situation with lead poisoning, which can induce loss of appetite, hypertension, renal failure, weariness, arthritis, hallucinations, and vertigo in people who are exposed to it [62-64]. One of the most hazardous heavy metals is mercury that interacts with other substances to form both organic and inorganic mercury. Numerous industries have emitted it into the environment, and it is usually found in higher concentrations in most marine organisms as the trophic level of the organism grows [65, 66].

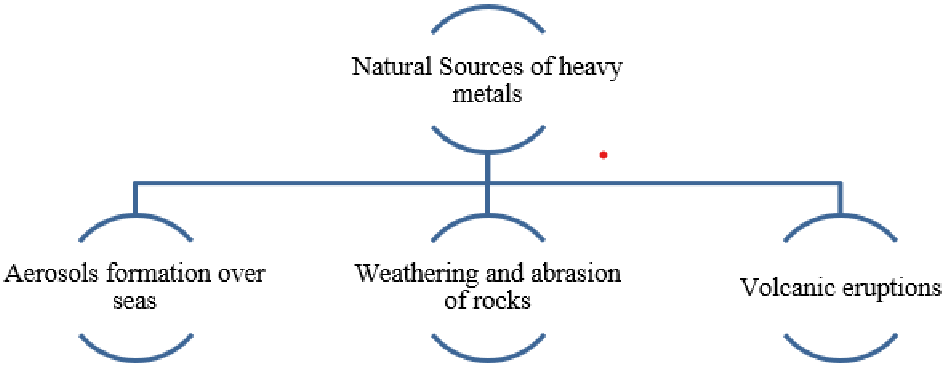

Fig.1: Different Natural sources of heavy metal pollution

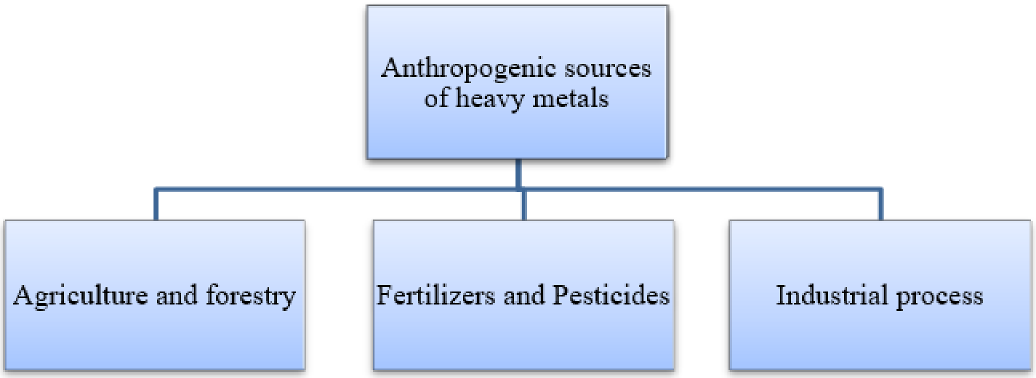

Fig.2: Diverse human-made sources of heavy metal pollution

The two primary causes of heavy metal contamination are sources from the natural world and sources from agriculture 1. Natural sources, that includes soil, weathering of rock surfaces, and the formation of sedimentary rocks and volcanic eruptions. The two types of rocks that are most commonly occurring are igneous and sedimentary rocks [67, 68] It is possible to determine the concentration of heavy metals based on the type of rock and the conditions of the ecosystem in the surrounding area. In adding to river sediments, soil formation is regarded as one of the primary causes of heavy metal accumulation and 2.Agricultural sources : agriculture-related sources: Agricultural pollutants, that are understood to be biotic and abiotic outcomes of farming methods, typically encroach on agro-ecosystems [69].Agro-ecosystems can be contaminated or degraded as a result of these pollutants. Heavy metals can be found in agricultural settings most frequently through the use of fertilizers, pesticides, and sewage sludge. Heavy metals accumulate in the soil and plants used in agricultural production as a result of fertilizer use. Fertilizers provide the soil with a wide range of nutrients, which in turn enhances healthy plant growth and increase the amounts of organic matter in the soil [70]. As a result, fertilizers increase the fertility of the soil. An organic fertilizer is one that is derived from organic matter, while an inorganic fertilizer is one that is synthesized. After the anaerobic digestion (AD) process, ammonium fertilizers (sulphate and nitrate) are formed as organic or bio fertilizers. Chemically manufactured/synthetic fertilizers, also known as inorganic fertilizers, are a mixture of inorganic and chemical ingredients. For example, organic and inorganic fertilizers, which are responsible for releasing heavy metals into our soil [71]. Phosphorus is put to wide-ranging use in the production of fertilizer; however, it is also a major contributor to the buildup of heavy metals in soil. It has been demonstrated that fertilizers that contain phosphorus that is insoluble in water can produce phosphate rocks. Phosphate rocks are crucial to the ability of the soil to precipitate metal phosphates and maintain their immobilization. The accumulation of heavy metals in agricultural soils as a consequence of prolonged and extreme use of fertilizers leads to a reduction in soil fertility, which in turn leads to a reduction in plant growth and productivity [72, 73]. After heavy metals have contaminated the soil, it is enormously difficult to restore its natural environment.

3. EFFECT OF PESTICIDES AND HEAVY METALS TOXICITY ON AGRICULTURE SOIL AND PLANTS

3.1. HEAVY METALS TOXICITY

Heavy metals first affect plants in the rhizosphere, where they react with polymetallic minerals and compounds and root exudates. Carbonate aggregates on plant roots point to mineral oxidation and hydrolysis in the rhizosphere. Metal concentrations have been found to be higher in rhizosphere solutions as a result of these processes. Due to the wide range of physiological and biochemical deficiencies that can result from a high concentration of Pb, the interactions between Cu and Zn, which influence each other, can affect the bioavailability of nutrients[74, 75]. The process through which heavy metals impose their actions, begin with soil deposit and proceeding on to different plants organs. Heavy metals emit free radicals that induce oxidative stress and harm to biological molecules, by enhancing intracellular levels of reactive oxygen species (ROS) [76-78]. The problem with all of these biological molecules causes a lot of problems in the plant's body, such as damage to DNA and cells and the stopping of enzyme activities, which could lead to the death of the whole plant.

3.2. PESTICIDES TOXICITY

When pesticides are used in large amounts and without control on different types of crops, they hurt beneficial organisms. Also, these effects throw off the balance of biodiversity in the whole ecological system. Many pesticides, their byproducts, and metabolites are studied to see if they are somewhat safe for beneficial organisms, especially beneficial insects, to come into direct contact with when they eat plant tissue [79, 80]. The transmission of systemic pesticides through the plant's vascular system contaminates floral and extra floral nectar, resulting in high mortality rates for honeybees and nectar-feeding parasitoids [81, 82]. Endrin, hexachloro benzene dioxy pyrimidine, and other pesticides with chemical structure similar to chlordane can persist in the environment for decades without degrading [83]. In addition, persistent pesticide residues can bio accumulates and reach a bio concentration greater than 70,000 times the initial concentration. Pesticide mechanistic pathway beginning with application and ending with photo degradation, absorption by plant parts, or sorption at the soil level. Once in the soil, pesticides go through several biodegradation processes, including chemical decomposition and biological degradation. Pesticide metabolites and contaminants are carried by roots through xylem to plant parts, which may have adverse effects on the soil and plant. Some of these impacts comprise high ROS production, oxidative stress, DNA damage, photosynthetic blockage, necrosis, chlorosis, leaf twisting, and death of the plant [84, 85].

4. BIOREMEDIATION: A SOLUTION TO THE HEAVY METALS AND PESTICIDE POLLUTION PROBLEM

The usual term for environmental biotechnology is "the use of biological systems to remove contaminants from soil, water, and wastewater"[86]. The exploitation of naturally occurring organisms to alter harmful pollutants into less toxic substances is referred as bioremediation. According to historical sources, the Romans were the first civilization to remediate waste water using bioremediation. Nonetheless, since 1972, bioremediation has been usually employed to clean it up contaminated systems [87]. The bioremediation of hazardous organic compounds is, in general, regarded as a less contentious practice than the bioremediation of heavy metals [88]. This is due to the fact that an organic compound can be completely degraded to carbon dioxide and water via the mineralization process. However, in other cases, bacteria may not even complete the mineralization cycle and instead form mediators that are more hazardous than the raw material. Additional biological treatments may be employed to treat this [11, 89]. In order to meet the fundamental requirements of the world's population, there must be a rise in both the rate of food production and the amount of activity in the industrial sector. One of the consequences of these human-caused activities is that areas all over the world have been found to be contaminated with toxic organic and inorganic compounds. This type of concurrent contamination is known as co-contamination [90] as represents the true difficulty that grey biotechnology faces at the moment. The removal of organic compounds and heavy metals through bioremediation has been demonstrated to be effective, despite the fact that, for the time being, each process is typically carried out separately. Unquestionably, a multifunctional biological process is necessary in order to carry out bioremediation on sites that are co-contaminated. In this context, bacteria that belong to the phylum actinobacteria have a significant amount of potential because it has been demonstrated that they are efficient tools for the bioremediation of pollutants such as pesticides and heavy metals [91]. Because of their potential to bio remediate soils that have been contaminated with multiple pollutants, members of the phylum actinobacteria are currently the subject of research.

5. ACTINOBACTERIA UTILIZING DIVERSE BIOREMEDIATION STRATEGIES

Actinobacteria use different ways to clean up waste such as Cell immobilization, Use of plant-microbe partnerships and Use of microbial produced surface-active compounds.

5.1. CELL IMMOBILIZATION

Cell immobilization is defined as the physical confinement of viable microbial cells to a certain defined space in order to limit their free migration, while maintaining the catalytic activities and enhancing both the biological and physical stabilities of the cells. This is done in order to immobilize the cells without affecting their ability to function normally. Cell encapsulation is another name for the process known as cell immobilization [92]. This technique provides a number of advantages beyond typical suspension systems, such as the retention of higher microbe concentrations in the reactor, easier solid-liquid separation, higher metabolic activity, and higher cell survival [93]. Additionally, the immobilization matrix has the capability of overcoming physicochemical obstacles, such as temperature, pH, and toxic substances; the latter of these is particularly intriguing for its application in bioremediation processes [94]. Based on the results of several studies, immobilizing microbial cells for environmental remediation improved performance, increased efficiency of derivative enzymes, enhanced tolerance to very high concentrations of toxic compounds, completely removed the need to wash the cells, and prolonged the time needed for biological or biotransformation reactions. For the purpose of bioremediation, microbial cells were immobilized[95]. When microbial cells are used, the efficiency of the degradation process as well as the operational stability is improved. The choice of support plays a significant role in the immobilization of cells. For the intent of cleanup contaminated areas, a wide range of attributes are needed, like as minimal price, non-biodegradability, nontoxicity, and non-pollutivity, along with chemical and mechanical stability, high permeability, limited attachment to other organisms, and a high level of chemical and mechanical reliability[96]. Actinobacterial encapsulation has been reported to be effective in the immobilization of a wide range of contaminants, including pesticides. It is possible to utilize *Rhodococcus erythropolis* NI86/21, which was encased in alginate beads, to diminish atrazine concentrations in both soil and liquid medium [97]. Adding bentonite and skimmed milk to the beads' formulation resulted in faster cell release and longer cell survival, respectively. Pesticide removal and actinobacteria immobilization also provided good results for metal bioremediation, providing higher metal resistance and enhanced metal accumulating ability [98]. *Microbacterium liquefaciens* MP30, a chromate-reducing bacterium, was effectively imprisoned in polyvinyl alcohol (PVA)-alginate beads in this particular scenario, which revealed out to be the correct option for cell immobilization and chromate reduction. The immobilisation techniques had a minimal impact on the bioactivity, but the removal of chromate from a solution containing 2.6 mg L-1 was maintained at 90-95 percent for a period of 20 days without any symptoms of bead disintegration [99, 100]. In contrast, the best immobilization matrices for *Microbacterium* sp. NCIMB 13776 for the reduction of Cr (VI) were found to be agar and agarose [101]. Therefore, it is conceivable to conclude that the microorganism employed may have had a more substantial impact on the removal of the metal than the immobilization approach did. The use of immobilized actinobacteria as an approach for the environmental remediation of contaminated areas is mentioned across several papers as a promising alternative since it is capable of eliminating both pesticides and metals from polluted sites. These studies all highlight the efficacy of using immobilized actinobacteria as a bioremediation approach. The efficiency of the process can be affected by a variety of factors, including the pollutants that are present, the longevity and reusability of the immobilized cells, and a number of other factors. Nevertheless, a significant amount of research is required to determine the most appropriate support.

5.2. USE OF PLANT-MICROBE PARTNERSHIPS

In recent years, there has been a growing interest in the impact that microorganisms have on the growth of plants, the bioavailability of contaminants, and their degradation. The influence of plant-associated microorganisms on the effectiveness of phytoremediation is the subject of an ever-increasing number of research studies. It has been suggested that phytoremediation techniques, which are based on the interactions between plants and microorganisms, are methods for decontaminating polluted soils that are both cost-effective and friendly to the environment [102, 103]. The release of plant root exudates (REs), which contain enzymes, amino acids, carbohydrate, low-molecular-mass carboxylic acids, and phenolic compounds, causes an increase in microbial activity, which is attributed to the rhizosphere effect [104]. According to the findings of a number of authors, endophytic bacteria play a role in the biodegradation of toxic compounds, and the plant endophyte association has the potential to be utilized in the cleanup of polluted systems [105]. In addition, the degradation of atrazine was shown to occur when contaminated soil microorganisms were inoculated with *arthrobacter* sp. DNS10 in the presence of the plant Pennisetum. The authors demonstrated the efficacy of the plant-arthrobacter interactions, which resulted in a 98% reduction in atrazine levels when compared with the effects of a single strain and a single plant. This reduction was compared to the effects of a single strain and a single plant [106, 107]. The majority of research on trace element plant-microbe interactions has been conducted within the framework of phytoremediation. It has been postulated that the microorganisms that are present in the soil and in particular the bacteria that are active in the rhizosphere, could assist plants in more effectively mobilizing and absorbing metals. Quite a few actinobacteria behave in this manner due to the fact that members of this phylum are dispersed in the biosphere in a variety of different ways. The biosphere is home to an abundance of secondary metabolite producers. This is typically the result of the production of substances that promote plant growth, such as indole acetic acid, or the production of substances that bind or chelate metals, such as siderophores. Both of these processes are referred to as chelation [108]. In this study, the bacteria that were obtained were, for the most part, resistant to both Cr and Co; however, other tolerance combinations were also found, which indicates that heavy metal resistance evolved independently on multiple occasions [109]. The inherent weaknesses associated with the application of isolated elements can be addressed by developing phytoremediation systems where microorganisms-primarily actinobacteria-interact with plants.

5.3. USE OF MICROBIAL PRODUCED SURFACE-ACTIVE COMPOUNDS

The term "bioremediation" refers to the process of removing or neutralizing contaminants through the utilization of biological agents such as plants and microorganisms, in addition to products that are derived from them [110]. Because the producer microorganisms do not need to be able to grow and survive in contaminated environments, the use of microbial products rather than whole cells for environmental remediation could have undeniable advantages. There is a wide variety of surface-active compounds (SACs) that can be found among the microbial products that have the potential to be used in bioremediation technologies. Various habitats contain these microbial products. Surface tension at the air-water interface is lowered by low-molecular-weight SACs (lipo-peptide, glycolipids, and phospholipids), also known as the bio-surfactants. High-molecular-weight SACs also termed to as bio emulsifiers, lower surface tension at the air-water interface [111, 112]. Although it is not uncommon for bio-surfactants to possess emulsifying properties, it is not always the case that bio-emulsifiers will result in a reduction in surface tension. The demand for surface-active compounds of biological origin as natural alternatives to their counterparts produced synthetically is currently at an all-time high. This is as a result of the fact that surface-active compounds that originate from biological sources have lower levels of toxicity and higher biodegradability than their counterparts that are produced synthetically [113]. These proteins distinguish for a number of reasons, one of which is their high stability under severe pH, temperature, and salinity conditions. These properties enhance the potential uses of these proteins in a number of biotechnological areas. To enhance the availability of organic and inorganic contaminants throughout bioremediation, it is possible to encourage in-situ microbial synthesis of SACs. By increasing the temperature gradient, this can be accomplished [114]. A more realistic approach would be to generate these biomolecules through microbial culture, isolate them, and employ them in soil cleaning systems in the absence of producer microbes in the wash cycle. Pollutants attached to the soil matrix can form complexes with surface-active molecules, permitting the pollutants to desorb into the aqueous phase. Once they access the aqueous phase, hydrophobic pollutants like pesticides are consolidated within the micelles of bio-surfactants, which enhances their mobility and elimination during the washing step [115, 116]. Inorganic pollutants like heavy metals, for example, can be removed from soil by forming micelles with surface-active compounds (SACs). In the last case, however, SAC polar groups can bind, mobilize, and stabilize micelle metals. Numerous actinobacteria capable of producing SACs have been isolated, and subsequent analysis has revealed that they belong to a wide variety of genera. The marine actinobacterium *Nocardiopsis* sp. B4, which was isolated from the western coast of India, was cultivated on a variety of carbons and nitrogen sources. The researchers found that olive oil and ammonium chloride, combined at a C/N ratio of 2:1, resulted in the highest level of production [117]. The marine clay *Brachybacterium paraconglomeratum* MSA21 strain is unusual for its ability to produce bio-surfactants from both industrial and agro-industrial wastes when cultured in solid state culture[118], this discovery could be crucial for promoting the large-scale, cost-effective production of microbial SACs. Therefore, among the most appealing approaches for encouraging ecological sustainability is the selection of microorganisms that can proliferate and produce surfactant/emulsifier molecules from cheap raw materials[119].

6. CONCLUSION

Environmental pollution is a growing global threat to human health and wellbeing. Biological remediation, which employs living microorganisms, is gaining popularity and is a viable alternative to other hazardous techniques. Actinobacteria can bio-remediate oil, rubber, plastics, pesticides, and heavy metals due to their physiological and metabolic versatility. In the past 15 years, significant progress has been made in the utilization of actinobacteria for waste elimination. Bio-augmentation, bio-stimulation, cell immobilization, phytoremediation, bio-surfactant production, and the use of defined mixed cultures were developed to enhance Actinobacteria's bioremediation capabilities.

7. FUTURE PROSPECTS

Due to the constant development of industrial operations, pollutants spread worldwide due to insufficient monitoring of their detrimental environmental consequences. This led to studies on improving contaminated areas. Actinobacteria Bioaugmentation is a green way to rehabilitate the environment. Actinobacteria can metabolise toxins in polluted soils for growth. Actinobacteria may degrade pesticides and remove heavy metals, highlighting their potential as bioaugmentation techniques [120, 121].

DECLARATIONS

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The authors declare no potential conflict of interest.

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