Chapter

Actinomycetes as An Environmental Scrubber

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Abstract

Biotechnological tools engaged in the bioremediation process are in reality, sophisticated and dynamic in character. For specialized reasons, a broad variety of such devices are employed to produce a safe and balanced environment free of all types of toxins and so make life simpler for humans on planet Earth. Actinomycetes is one of these extremely important and functionally helpful groups. They can be used for a variety of bioremediation objectives, including biotransformation, biodegradation, and many more. Actinomycetes are one of the most varied groups of filamentous bacteria, capable of prospering in a variety of ecological settings because to their bioactive capabilities. They're famous for their metabolic diversity, which includes the synthesis of commercially useful primary and secondary metabolites. They produce a range of enzymes capable of totally destroying all of the constituents. They are well-known for their ability to produce bioactive secondary metabolites. Members of various genera of Actinomycetes show promise for application in the bioconversion of underutilized urban and agricultural waste into high-value chemical compounds. The most potential source is a wide range of important enzymes, some of which are synthesized on an industrial scale, but there are many more that have yet to be discovered. Bioremediation methods, which use naturally existing microbes to clear residues and contaminated regions of dangerous organic chemicals, are improving all the time. In the realm of biotechnological science, the potential of actinomycetes for bioremediation and the synthesis of secondary metabolites has opened up intriguing prospects for a sustainable environment.

Keywords: Actinomycete, Bioremediation, Biotransformation, Biodegradation, Sustainable environment, Bioactive compounds

1. Introduction

The word 'actinomycete' comes from the Greek words 'atkis' (ray) and'mykes' (fungus), both of which contain bacterial and fungal features. Actinomycetes are gram-positive bacteria that generate spores and are found in nature aerobically. They are one of the most important taxonomic units among the 18 major lineages currently recognized within the domain bacteria. The Actinobacteria class is an important part of the microbial population in soils. Their metabolic variety and unique growth features make them ideal bioremediation agents [1–12]. Actinobacteria are a worldwide collection of microorganisms that may be found in

a variety of natural habitats [13]. They are Gram-positive bacteria with a high guanine plus cytosine (G1C) content base in DNA (5575 mol%), however new species have been discovered that do not follow this norm. This group is extremely diverse, as it contains a wide range of microorganisms that differ chemically, morphologically, and physiologically [14]. This morphological variety is demonstrated by a constant shift from basal and bacilliform cells to hyphae that break and branch, generating aerial mycelium with lengthy chains of spores. Actiospores are generated as a result of nutrient deficiency and may withstand protracted desiccation [15]. This capacity to sporulate is critical for their survival in the wild. Temperatures of 2530C and neutral pH are ideal for growth in most cases, however several species have been separated from harsh settings. Most of these bacteria are aerobic, although some may also be microaerophilic or anaerobic. They are heterotrophic, which means they can use both simple and complicated carbon sources [16]. The creation of a significant number of biotechnologically significant metabolites (antibiotics, enzymes, enzyme inhibitors, immunomodulators, and so on) demonstrates physiological variety [14]. Additionally, due to the formation of a metabolite called geosmin, they require a specific odor of damp soil as part of their unique traits.

1.1 Occurrence and habitat

Actinomycetes are the foremost abundant life style saprophytes that form thread-like filaments within the soil. They grow as hyphae like fungi liable for the characteristically "earthy" smell of freshly turned healthy soil. The actinomycetes exist in various habits in nature and represent a ubiquitous group of microbes cosmopolitan in natural ecosystems around the world. Actinomycetes are widely distributed in soil and ocean. There are many reports for isolation of actinomycetes from terrestrial soils [17, 18], marine ecosystem [19, 20], mangrove ecosystem [21, 22], composts, vermicomposts [23]. Environmental factors influence the type and population of actinomycetes in soil. They are found both on mesophilic (25-300C) and thermophilic (400C) environments. The pH is also a major environmental factor determining the distribution and activity of actinomycete. Most of the actinomycetes grow at optimum pH around 7. Vasavada et al. [24] showed that pH, salinity, use of media and carbon and nitrogen sources affect the growth and antibiotic production by actinomycetes. Many mesophilic actinomycetes are active in compost in initial stages of decomposition. However the capacity for self-heating during decomposition provides ideal conditions for thermophilic actinomycetes. Actinomycetes diversity also can be influenced by the range of plant species grown thereon particular soil. Since different plants produce different chemical metabolites, so as to survive the microbes (actinomycetes during this case) got to adapt to the environment [25]. As soil is the best source of Actinomycetes, much research has been focused on the soil ecology. They may be found in a variety of soils, both cultivated and uncultivated, fertile and infertile, in diverse parts of the world. pH is a major environmental element that determines the distribution and activity of soil Actinomycetes. Neutrophiles are found in less numbers in acidic soils with pH < 5.0, but acidophilic streptomycetes are plentiful. Many active mesophilic Actinomycetes may be found in compost. The research have recently been conducted in aquatic settings such as fresh and marine waters. Many researchers saw Actinomycetes as part of the native microflora of marine ecosystems, whereas others saw them as wash-in elements that persist as spores in marine and littoral sediments. Salt tolerance has been demonstrated in creatures from maritime settings. Actinomycetes have been studied for their presence, survival, and activity in a variety of severe settings. Streptomycetes, both acidophilic and aciduric, are common in acidic soils. Actinomycetes have been found in hot springs, marine sediments, and crater lakes, among other harsh habitats

(soda lakes). Lonar Lake, a crater produced by meteorite impact, provides a unique opportunity. Because of the high sodium carbonate concentration, the lake water is salty and alkaline (pH 9.5 to 10.0).

1.2 Structure

The development of usually branched threads or rods distinguishes actinomycetes. In most cases, the hyphae are non-septate. The sporulating mycelium may be branching or non-branching, straight or spiral. Spherical, cylindrical, or oval spores are found. They resemble fungus morphologically, which might be related to the fact that their cell wall composition is similar to that of gramme positive bacteria. They have been separated from ordinary bacteria because of their filamentous form and cultural traits.

1.3 Actinobacteria: growth and reproduction

This diversified group has a lot of morphological differentiation, including septate and nonseptate multicellular strands and a filamentous-type structure. Strains often form compact colonies on solid culture medium, consisting of mycelium, a mass of hyphae pertaining to the microbe, and distinguishing into aerial and substrate mycelium. Actinobacteria have a modest growth rate in general. After 24 hours of incubation, a branching mycelium forms on the surface of a solid medium, which may be examined under a microscope; colonies form after 34 days, but mature aerial mycelium with actinospores occurs after 714 days as shown in **Figure 1**. Some strains that develop slowly may take up to a month to incubate. The development and stability of the substrate and aerial mycelium can be influenced by the culture medium composition. Colonies of Actinobacteria can be elevated or laid flat. Their texture ranges from incredibly soft to exceedingly hard and pasty. White, yellow, orange, pink, red, purple, blue, green, brown, and black are among the colors available. They might have smooth, grooved, wrinkled, granular,

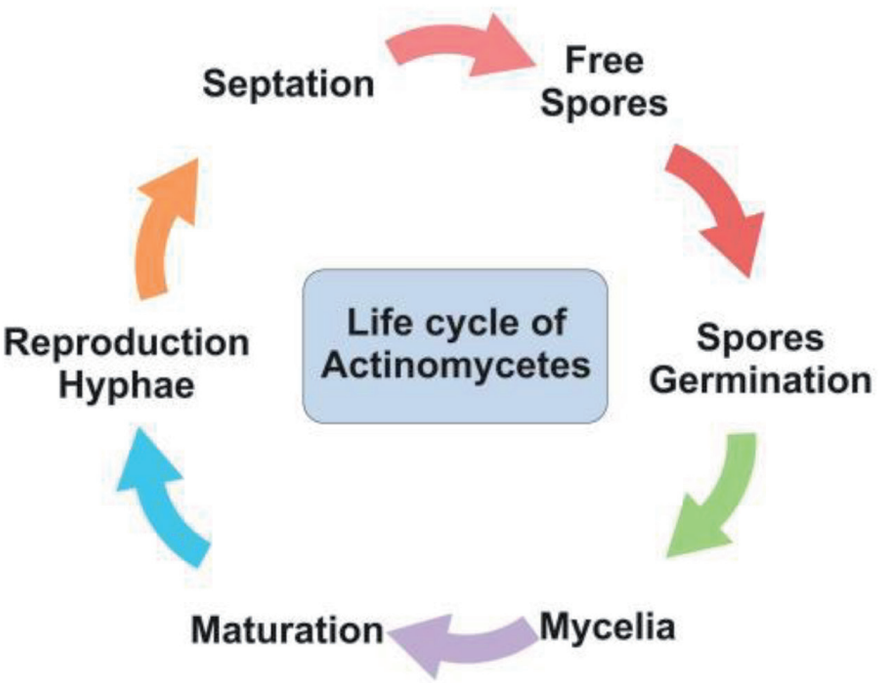

Figure 1.
Life cycle of Actinomycetes.

or flaky surfaces. Their appearance is frequently totally compact, or a mixture of both, with diverse developing zones in concentric rings of radial orientationThe colony size ranges from one millimeter to a few centimeters in diameter, depending on the species, age, and cultivation circumstances. Actinobacteria may grow on liquid medium as well, but only under certain circumstances. To achieve uniform growth, liquid cultures require agitation and aeration, as well as suspension in culture media. Actinobacteria are a common microbial community found in soil, with an average of 5631010 CFU/g of soil. Actinobacteria are found in the soil as latent spores that produce their mycelia only when specific environmental circumstances are ideal, such as nutrition availability, humidity, temperature, or physiological interactions with other microbes. These organisms are investigated for biotechnological applications, particularly in bioremediation of harmful chemicals, because to their metabolic variety and relationship with the environment. The interaction of Actinobacteria with accumulated pollutants in the environment, such as oil, rubber, plastics, pesticides, and heavy metals, has been investigated for more than 20 years [6, 10, 24]. The life cycle of the actinomycetes is shown **Figure 1**. Actinomycetes are mostly mycelioid and Gram-positive. They begin as unicellular creatures, but eventually evolve into branching filaments or hyphae, which multiply rapidly by generating new branches, forming the mycelium. As seen in **Figure 1**, this type of mycelium is known as "substratum or primary mycelium." After a period of development, hyphae of a different sort emerge from the mycelium substratum and begin to grow in the air. Aerial hyphae and aerial or secondary mycelium are the terms used to describe these hyphae. Sheath is an additional cell wall layer seen on aerial hyphae.

2. Classification of actinomycetes

The "Bergey's Manual of Systematic Bacteriology - 2nd edition" for Actinobacteria classification has five volumes, which contain internationally recognized names and descriptions of bacteria. Classification of Actinobacteria has been rearranged. In Volume 5, the phylum Actinobacteria is split into six classes, namely Actinobacteria, Acidimicrobiia, Coriobacteriia, Nitriliruptoria, Rubrobacteria, and Thermoleophilia. The class Actinobacteria is further divided into 16 orders that are Actinomycetales, Actinopolysporales, Bifidobacteriales, Catenulisporales, Corynebacteriales, Frankiales, Glycomycetales, Jiangellales, Kineosporiales, Micrococcales, Micromonosporales, Propionibacteriales, Pseudonocardiales, Streptomycetales, Streptosporangiales, and Incertae sedis. In the order of abundance in soils, the common genera of Actinobacteria are Streptomyces (nearly 70%), Nocardia, and Micromonospora, although Actinoplanes, Micromonospora, and Streptosporangium also are generally found.

Characteristics	Classification
Domain	Bacteria
Class	Actinobacteria
Order	Actinobacteria
Family	Actinomycetales
Genus	Actinomycetes

Table 1.
Classification of actinomycetes.

At present, the molecular identification is predicated on 16S rDNA sequences, which is most vital for Actinobacteria (**Table 1**).

3. Actinomycetes—a biofactory of novel enzymes

Actinomycetes is a genus of bacteria belonging to the Actinobacteria class. They're all gram-positive bacteria. Actinomycetes species are facultatively anaerobes (with the exception of A.meyeri and A. israelii, which are both obligate anaerobes), and they thrive in anaerobic environments. Individual bacteria of Actinomyces species can generate endospores, and colonies of Actinomyces develop fungus-like branching networks of hyphae. The appearance of these colonies led to the false belief that the creature was a fungus, and the name Actinomyces, which means "ray fungus," was given to it (from Greek actis, ray, beam and myles, fungus). Actinomycetes species may be found in soil as well as in animal microbiota, including the human microbiome. They are well-known for their importance in soil ecology; they generate a variety of enzymes that aid in the decomposition of organic plant material, lignin, and chitin. As a result, their presence is critical in the composting process. Humans and cattle have commensal flora on their skin, mouth flora, gut flora, and vaginal flora. They're also renowned for causing infections in humans and cattle, mainly by gaining entrance to the inside of the body through wounds. People with immunodeficiency are more susceptible to opportunistic infections, as they are to other opportunistic illnesses. They are comparable to Nocardia in all of the qualities listed above, as well as in their branching filament production. Actinomycetes species, like many other anaerobes, are finicky and difficult to cultivate and isolate. Although clinical laboratories culture and isolate them, a negative result does not rule out infection since unwillingness to grow in vitro might be the cause.

4. Role of actinomycetes as environmental cleaner

Actinomycetes work as an environmental scrubber for the cleaning of the contaminant place and release potential enzymes for the same. The widely used application of Actinomyectes is shown in **Figure 2**.

4.1 Bioremediation

Actinomycetes are well-known for their bioremediation abilities. Antibiotics and chemical complexes are effectively consumed by actinomycetes. Pesticides and chemical complexes at large dosages can be degraded by them. Petroleum hydrocarbons are widely employed as chemical components and fuel in our daily lives. Petroleum has become one of the most prevalent pollutants of large soil surfaces as a result of increased use, and is now regarded a serious environmental hazard. In the environment, hydrocarbons degrade in a variety of ways. Bioremediation is one of the methods for removing them from the environment.

The utilization of soil organisms to breakdown contaminants into innocuous chemicals is known as bioremediation. Pesticides and other xenobiotics in the environment are successfully disintegrated and bioremediated by the actinomycetes. Actinomycetes play an essential role in the environmental destiny of hazardous metals, altering transitions between soluble and insoluble phases through a variety of physico-chemical and biological processes, and producing considerable quantities of biosurfactants. These mechanisms are key components of natural

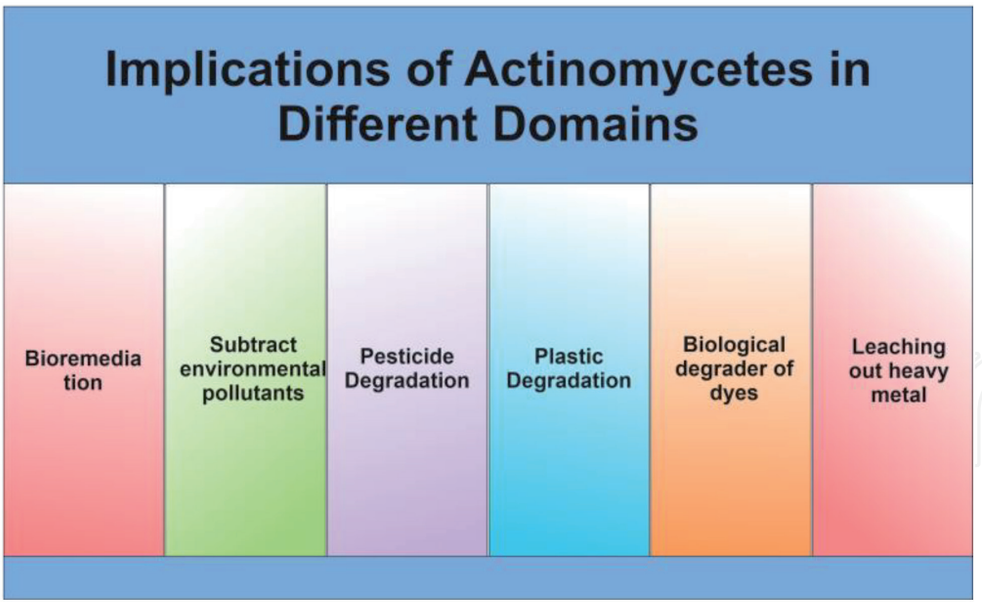

Figure 2.
Implications of actinomycetes in different domains.

biogeochemical cycles for metals and metalloids, and some of them might be used to remediate polluted materials. Actinomycetes' role in bioremediation and stress-related behavior has been well investigated. Numerous Actinomycetes strains from composts are presently being studied to see if they can breakdown certain petroleum hydrocarbons and decolorize several synthetic dyes, which might lead to bioremediation applications. Actinomycetes have a number of characteristics that make them ideal candidates for bioremediation of organically polluted soils. They are capable of degrading complex polymers and play a vital role in the recycling of organic carbon. According to certain research, Streptomyces flora may play a critical role in hydrocarbon breakdown. Many strains produce cellulose- and hemicellulose cellulose degrading enzymes as well as extracellular peroxidase, which may solubilize lignin and destroy lignin-related compounds. Actinomycetes are the leading category of degraders in some polluted locations [26]. Actinomycetes have the capacity to survive in an oily environment. As a result, these bacteria can be used in Bioremediation to remove oil contaminants.

4.2 Actinomycetes to subtract environmental oil pollutants

A dark sticky naturally occurring liquid (petroleum) that is called as Crude oil, a complex mixture of compounds having varying molecular weight and containing 30% polyaromatic hydrocarbons (PAHs). PAH compounds such as naphthalene, acenaphthene, fluorene, phenenthrene, fluoranthene, pyrene, acenaphthylene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k] fluoranthene, benzo[a]pyrene, dibenz[a, h]anthracene, benzo[g, h, i]perylene, anthracene, and indeno[1,2,3cd] pyrene) are pollutants nominated by the United States Environmental Protection Agency as priority PAHs. The most widespread organic pollutants and potentially health hazards are targeted for measurement in environmental samples. On the other hand it is also found in environmental components like cereals, oils, fats, vegetables, cooked that are carcinogenic, mutagenic, and teratogenic. So removal of PAHs is an issue of big interest [27]. Crude oil containing various PAHs, focuses on metabolic pathways for its degradation and microbial degraders. In aerobic or anaerobic conditions, bacterial and fungal strains are able to target the specific PAH through effective and eco-friendly

bioremediation approach currently. Additionally, a new approach will be needed to design for dearomatization of crude oil to shoot a solution in numerous PAH inhabitants.

The nocardioform actinomycetes of the genera *Mycobacterium*, *Rhodococcus* and *Gordona* are the soil microflora able to mineralize PAH. These novel actinomycetes *Sphingomonas paucimobilis* BA2, *Gordona sp*. BP9, *Mycobacterium sp.* VF1 were able to grow on anthracene, pyrene or fluoranthene as the sole carbon source and mineralizing PAH with up to four rings [28]. Actinomycetes were potent to metabolize phenanthrene present at roadside soil polluted with polycyclic aromatic hydrocarbons (PAHs), and two highly PAH polluted soils from industrial sites [26]. *Rhodococcus and Gordonia* were potentially selected actinomycetes to remediation of polycyclic aromatic hydrocarbons in liquid culture and spiked soil. Biosurfactant or degrade phenanthrene when cultured on medium contains glucose, hexadecane and rapeseed oil at 30^0c. Gordonia sp. APB and G. rubripertincta produced emulsion from rapeseed oil whereas Rhodococcus sp. DSM44126 ability to degrade phenanthrene as sole source of carbon and anthracene [29].

A novel anthracene degrading actinomycete was isolated from a hydrocarbon contaminated soil at mechanical engineering workshop. Haloalkalitolerant actinomycetes, Kocuria rosea, Kocuria palustris, Microbacterium testaceum, and Nocardia farcinica were used in investigation of the correct fluorescence method to check the PAHs biodegrading capacity of actinobacteria. In the fluorescence method, excitation and emission fluorescence were used in study of the PAHs biodegrading to determine the residual anthracene concentration [27].

Rhodococcus opacus 412 and *R. rhodnii,* firstly adapted to phenanthrene and antracene containing solid mineral medium that accelerated metabolism of polyaromatic hydrocarbons. It provides microbial growth on phenanthrene as the sole source of carbon and energy in liquid medium, phenanthrene was utilized by these strains. Additionally, first *Rhodococcus opacus 412* was grown to anthracene on solid developed variant strains that transform anthracene in liquid medium to anthraquinone and 6, 7-benzocoumarin [30].

A glass bead system was developed for growth of PAH-degrading actinomycetes in liquid culture. Here, R. *wratislaviensis* was able to degrade phenanthrene and anthracene whereas an actinomycete, *Mycobacterium LP1* with a high capacity to degrade phenanthrene and pyrene. Strains were isolated from an agricultural soil that screen for biosurfactant activity and phenanthrene degradation in the presence of different co-substrates in liquid cultures and in soil. Mycobacterium LP1, favoring biological degradation of low-molecular-weight PAH at the first time of inoculation, and in second step addition of rapeseed oil, which promoted the abiotic transformation, and probably the solubilization, of the high-molecular-weight PAH [29].

Biodesulfurization was a selective and cost-effective method for subordinating the sulfur content of petroleum products. DBT, used as a model polyaromatic sulfur heterocycle for microbial isolation and characterization to check capability of transforming organosulfur compounds found in an assortment of fossil fuels. However, Biotransformations were occurred through metabolic degradative pathways or growing with it as a sole sulfur source and biocatalytic desulfurization for the selective removal of polyaromatic sulfur heterocycle. *Rhodococcus erythropolis* I-19 was used to desulfurize alkylated dibenzothiophenes (Cx-DBTs) from hydrodesulfurized middle-distillate petroleum (MD 1850) with the aid of multiple copies of key dsz genes present in cell [31].

The sulfur oxides released after incineration of fossil fuels, the main environmental problem, cause air pollution and are the key for acid rain. Organosulfur compounds, including dibenzothiophene (DBT) are metabolized by microbes.

Rhodococcus erythropolis IGTS8 have gene clusters of the dsz, three genes, dszA, dszB, and dszC. Genetic analysis of the dsz Promoter and its associated regulatory regions of Rhodococcus erythropolis IGTS8 were done. In genetic investigation, dsz gene clusters are involved in conversion of dibenzothiophene (DBT) to 2-hydroxybiphenyl and sulfite. *Rhodococcus* can use DBT as the sole source sulfur [32].

Rhodococcus sp. strain SY1, dibenzothiophene (DBT)-desulfurizing bacterium utilized dimethyl sulfide (DMS), dimethyl sulfoxide (DMSO), and several alkylsulfonates as sole sulfur sources. Strain SY1 were able to degrade DMS in the oxidative pathway *via* DMSO, $DMSO_2$ (dimethyl sulfone), and methanesulfonate to methane and sulfate, reducing a part of DMSO back to DMS. Sulfate produced can reduce enzymatic expression by the addition of $BaCl_2$ enhanced the degradation rate of DBT about 14%. Spent motorcycle lubricating oils degradation was explored using microbiological standard procedures. Actinomycetes such as Nocardia sp., Gordonia sp., Micromonospora sp. and Rhodococcus sp. were able to degrade 1.035% to 7.53% of the spent lubricating oil [33].

An application of biosurfactants while one needs to clean up oil. Arthrofactin, a novel biosurfactant was produced by Arthrobacter species strain MIS38. Arthrofactin is one of the most effective lipopeptide biosurfactants and it effectively removes oil [34].

4.3 Actinomycetes in pesticide degradation

India, an agricultural country, has lost 30% of agricultural produce to pests. As a result insecticides, fungicides, pesticides and herbicides have rising demand for protection of crops. Monocrotophos (MCP) is organophosphorus pesticide and hazardous and extensively utilized in India to protect economically important crops. Biomineralization of Monocrotophos, by soil bacteria *Arthrobacter atrocyaneus* MCM B-425 and *Bacillus megaterium* MCM B-423 were capable to degrade MCP (concentration of 1000 mg l^{-1}) to the extent of 93% and 83%, respectively. MCP is degraded by metabolic pathway involving the enzymes phosphatase and esterase to carbon dioxide, ammonia and phosphates through formation of one unknown compound – Metabolite I, valeric or acetic acid and methylamine, as intermediate metabolites. Two cultures will be used for bioremediation of waste water treatment and MCP contaminated soil [35].

A pollutant 4-chlorophenol (4-CP), toxic and recalcitrant compound which is formed from chlorination of waste water, in pulp mills, from breakdown of herbicides such as 2,4-dichlorophenoxyacetic acid and from anaerobic degradation of more highly chlorinated phenols, such as pentachlorophenol and 2,4,6-trichlorophenol. In Bioremediation, certain microbial strains are able to degrade 4-CP. A novel strains Arthrobacter chlorophenolicus sp. capable of degrading up to 350 p.p.m. (2.7 mM) high concentration of 4-CP (Westerberg et al., 2000). Arthrohacter ureafaciens CPR706 degrades 4-chlorophenol through the hydroquinone pathway [36].

Triazine rings are found in pesticides, plastic resins, dye s-Triazine herbicides are broadly used in modern agriculture, where they kill susceptible plants by coordinating to the quinone-binding protein in photosystem II, thereby inhibiting photosynthetic electron transfer. Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-s-triazine) is broadly used herbicides in the United States for the control of broadleaf weeds in corn, sorghum, and sugarcane. *Arthrobacter aurescens* TC1, potential organism to metabolize substantial quantities of s-triazine compounds in the environment. A. aurescens TC1 were able to degrade 3,000 mg of atrazine per liter in liquid culture as the sole source of nitrogen, carbon, and energy [37].

A novel *Streptomyces spp.* VITDDK3, halo tolerant Actinomycete was isolated and screened from Saltpan Soil. The Stain was considered potentially for production of biosurfactant, heavy metal resistance activity (to cadmium and lead) and also dyes decolourization activity. 98% of the azo dye and Reactive red 5B were potentially degraded by *Streptomyces spp.* VITDDK3. The new strain will be used further for large scale production of the lead compound [38]. *Rhodococcus chlorophenolicus* were degrade tetrachloro-para-hydroquinone to 1, 2, 4-trihydroxybenzene by metabolic process of microbial enzymes through reductive aromatic dechlorination process [39].

The chloroacetanilides including alachlor [2- chloro-2′,6′-diethyl-N-(methoxymethyl) acetanilide] are selective herbicides extensively used for pre-emergent weed control. The extremely toxic alachlor (144 mg l^{-1} concentration) was biologically degraded enzymatically by the metabolic pathway of the strains *Streptomyces sp*. LS166, LS177, and LS182. The *Streptomyces sp.* were degraded around 60–75% of the alachlor in 14 days [40]. Herbicides are greatly significant for agriculture. Herbicides may act as pollutants, damaging the soil, ground water and surface water. Actinomyces play an important role in the cycle of the elements in nature and in degradation of organic xenobiotic substances. *Streptomyces albus, Streptomyces aureus* and *Streptomyces chrysomallus* were Influence Xenobiotic Substances- Sulfonylurea herbicides, tribenuron-methyl and nicosulfuron, which were commonly used in farming [41].

4.4 Actinomycetes involved in plastic degradation

Plastics, corrosion resistant materials, strong, durable and inexpensive polymers are derived from petrochemicals and chemical processes to produce long chain polymers. At room temperatures the plastic polymers are not considered as toxic, but when heat is released from plastics have undesirable effects on the environment and human health. Plastics are accessible in a variety of forms such as nylon, polycarbonate, polyethyleneterephthalate, polyvinylidene chloride, Urea formaldehyde, polyamides, polyethylene, polypropylene, polystyrene, polytetraflouro ethylene, polyurethane and polyvinyl chloride. Naturally occurring microorganism involved in degradation of organic material- plastic and plastic waste. Styrene is possibly carcinogenic to humans that cause mammary gland tumors in animals [42]. Polystyrene waste accumulates in the environment posing an increasing ecological threat [43].

The plastics of poly (β-hydroxybutyrate)(PHB)-and poly (ε-caprolactone) (PCL) were degraded by aerobic microorganisms that persist in the natural environment. The plastic depolymerizing microorganisms are distributed over many kinds of material, including landfill leachate, compost, sewage sludge, forest soil, farm soil, paddy soil, weed field soil, roadside sand, and pond sediment [44]. Actinomycete strains *Streptomyces* genus and *Micromonospora* genus were isolated and screened for the capability to degrade poly (ethylene succinate) (PES), poly(ε-caprolactone) (PCL) and poly(β-hydroxybutyrate) (PHB) from upstream and downstream regions of the Touchien River in Taiwan [45].

Streptoverticillium kashmirense AF1 was able to degrade a natural polymer; poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) was isolated from municipal sewage sludge by soil burial technique. Extracellular enzymes PHBV depolymerases secreted by *Streptoverticillium kashmirense* AF1 was purified and degrade PHBV film [46]. *Actinomadura*, *Microbispora, Streptomyces, Thermoactinomyces* and *Saccharomonospora* were thermophilic actinomycetes strains able to degrade poly (ethylene succinate) (PES), poly (ε-caprolactone) (PCL) and poly (β-hydroxybutyrate) (PHB). Thermophilic actinomycetes

Microbispora rosea, Excellospora japonica and *E. viridilutea* were able to degrade aliphatic polyester, poly (tetramethylene succinate) (100 mg PTMS film) [47].

Biofilms are the favored bacterial mode of living and survival, most microorganisms—which tend to attach to surfaces—to gain physical support, increase nutrient utilization. Polyethylene (PE), synthetic polymer, is highly inert and virtually non-biodegradable. *Rhodococcus ruber* (C208) has formed a dense biofilm on polyethylene (PE) surfaces when degradation of their analogous substrates within the biofilm [48]. A biofilm-producing strain of *Rhodococcus ruber* was degraded polyethylene by organization yields "mushroom-like" 3D structures on the full-grown biofilm [43]. Rhodococcus sp. strain RHA1, strong polychlorinated biphenyl (PCB) degrader has diverse biphenyl/PCB degradative genes and harbors huge linear plasmids, including pRHL1 (1,100 kb), pRHL2 (450 kb), and pRHL3 (330 kb). Linear plasmids of Rhodococcus sp. strain RHA1 having degradative genes such as bphB2, etbD2, etbC, bphDEF, bphC2, and bphC4 [49].

Polylactic acid (PLA), biodegradable plastic has broadly applicable in food packaging with respect to environmental concern in solid-waste management. Novel polylactic acid-packaging degrading actinomycete, Streptomyces sp. KKU215 biomass productions were carried out in PLA-packaging as sole carbon source. The potent strain was used in biodegradation of PLA-packaging [50]. Amycolatopsis strains, poly(L- lactide) degrader stain has ability to assimilate degradation product like poly lactic acids [51]. *Amycolatopsis sp*. strain HT-6, a poly(tetramethylene succinate) (PTMS)-degrading actinomycete, was observed to degrade poly(tetramethylene carbonate) (PTMC). Actinomycetes strain degrades polycarbonate PTMC in a liquid culture with 150 mg of PTMC film, completely and fast degraded with a high yield of cell growth [51]. Polylactide (PLA)-degrading microorganisms are sparsely distributed in soil environments. An *Amycolatopsis* was potent in degradation of PLA film (100-mg film) added was degraded by the strain in liquid culture after 14 days of incubations [52].

4.5 Actinomycetes as biological degrader of dyes

Synthetic dyes, coloring agents are mostly used in textile industries and spawn a huge amount of wastewater during the process of dyeing. The release of colored effluents in rivers and lakes are the key reason for reduction of dissolved oxygen concentration creating anoxic condition and foremost to the acute toxic effects on the flora and fauna of the ecosystem. In addition to colored effluents in water bodies reduces the photosynthesis as it hampers dispersion of light in water. The color of textile wastewater deduction is a major environmental concern [53]. These synthetic dyes are not easily removed in waste water treatment plants [54].

Azo dyes, water-soluble reactive dyes constitute the most versatile class of synthetic dyes used in the textile, pharmaceutical, paper, food and cosmetic industry due to their ease in production and variety in color compared to natural dyes. Azo dyes are widely used in textile industries. When Azo dyes are left in water bodies without any treatment, they result in environmental pollution and in turn are toxic, carcinogenic and mutagenic. Azo dye Reactive Yellow Biodegradation was carried out by microorganisms isolated from the activated sludge. The isolated actinomycetes were acclimatized to different concentrations of dye from 0.005–0.200% (mg/100 ml). The consortium was developed by mixing five actinomycetes and the found degradation of dye depends on the concentration of dye in addition to the growth of the actinomycetes. Lignin peroxidase, laccase and tyrosinase enzymes were responsible for steady degradation activities. Biosorption of Reactive Yellow dye as occurred by using dead biomass of actinomycetes [55]. The *Streptomyces* spp., indigenous in environment was able to degrade azo blue and azo orange

dyes in optimization of conditions through metabolic pathways with responsible enzymes [53].

Thermobifida fusca BCRC 19214, the thermophilic actinomycetes was produced in laccase. The laccase are diphenol oxidases, could oxidize dye intermediates, especially 2,6-dimethylphenylalanine and p-aminophenol [56]. *Streptomyces spp*. was used in the decolorization of monosulfonated mono azo dye derivatives of azobenzene. Additionally strain was enhancing the biodegradabilities of azo dyes without affecting their properties as dyes by changing their chemical structures. The Change in dye structure was observed with five azo dyes having the common structural pattern of a hydroxy group in the para position relative to the azo linkage and at least one methoxy and/or one alkyl group in an ortho position relative to the hydroxy group. Streptomyces spp. was also decolorized Orange I [57]. Sulfonated Azo Dyes ("4C-radiolabeled azo dyes) and sulfanilic acid were used to study dye substitution patterns and biodegradability-mineralization by a white-rot fungus and an actinomycete. Phanerochaete chrysosporium and Streptomyces chromofuscust mineralization of modified dyes anionic azo dyes, containing lignin-like substitution patterns considered among the xenobiotic compounds. These very specific structural changes in the azo dye molecules enhanced their biodegradability [58].

Reactive dye is the foremostly used one type of azo dye containing different reactive groups. Reactive dyes that derive from dyeing industries increase Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), change the pH of water bodies and it causes serious problems in plant, animal and human beings. The presence of dyes in water is highly visible and affects their transparency and esthetic even though the concentration of the dyes is low [59]. Actinomycete strains were decolorized effluents containing different types of reactive dyes anthraquinone, phthalocyanine and azo dyes. The absorption of reactive dyes was done by the strains cells outcome in the decolorization of the effluents [54]. Actinomycete *Streptomyces krainskii* SUK – 5 was potent to degrade and decolorize textile azo dye- Reactive blue–59 in nutrient medium in shaking condition. Actinomycete were induced enzyme lignin peroxidase, and NADH-DCIP Reductase and MR reductase play key roles in degradation [60].

4.6 Actinomycetes and heavy metal

Heavy metals were successfully removed from wastewaters, and industrial wastes are still a key study area today. Streptomyces coelicolor's application in heavy metal removal via interactions is consistent with traditional heavy metal responses, resistance mechanisms, and secondary metabolite formation. Some physiological features of the salt sensitive cultivar Giza 122 of *Zea mays*, L. plants maintained for 10 weeks in the greenhouse were affected by Streptomyces sp. HM1 and heavy metal Cd (10, 20, 40, and 60 ppm). The presence of Streptomyces spp. HM1 in the soil increased the tested plant's heavy metal tolerance marginally. As a consequence, the maize test cultivar seems prospective for use in heavy metal polluted soils, even when actinomycetes are present [61]. Phytoremediation is a promising method that cleans toxins from the soil, water, and air using plants and their associated Plant Growth-Promoting microorganisms. Plant beneficial actinomycetes have been widely exploited as a heavy metal phytoremediation tool for cleaning up metal-polluted soils, and they play an important role in plant growth, metal/nutrient acquisition, metal detoxification, and reduction of biotic/abiotic stress. It is conceivable to boost microbial inoculants as an ecologically acceptable bio-tool for use in heavy metal phytoremediation in metal-polluted soils based on these positive plant-actinomycetes interactions [62]. Copper bioaccumulation was caused by the actinobacterium Amycolatopsis sp. AB0. Amycolatopsis sp. AB0, a copper-resistant

actinobacterium, was isolated from contaminated sediments and shown excellent copper specific biosorption capacity (25 mg g–1). The existence of copper P-type ATPase genes in Amycolotopsis was discovered for the first time [63].

4.7 Actinomycetes in removal of groundwater pollutant

Pseudonocardia dioxanivorans sp. nov., a novel actinomycete was isolated from industrial sludge contaminated with 1,4-dioxane that grows on 1,4-dioxane which is a probable human carcinogen. Novel strain was also growing on tetrahydrofuran, gasoline aromatics and several other toxic environmental contaminants [64].

5. Conclusion

Pollution of the environment is becoming more of a global issue. This circumstance necessitates rapid technological adaptation. Biological remediation, which involves the use of live organisms or their products, is a viable option. Actinobacteria have proven to be an effective instrument for carrying out this procedure on various matrices, under various growth conditions, as pure cultures or consortia, or as enzyme and emulsifier providers. The next stage is to use this information to a larger scale in the field. Actinomycetes strains can be identified and used for solid waste biodegradation with success. The consortium of selected actinomycetes strains might be used to assess their economic viability in the biodegradation process. This broadens their applications in biotechnology and environmental research.

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References

[1] Albarracín, V.H., Amoroso, M.J. and Abate, C.M., 2005. Isolation and characterization of indigenous copper-resistant actinomycete strains. Geochemistry, *65*, pp.145-156.

[2] Albarracín, V.H., Alonso-Vega, P., Trujillo, M.E., Amoroso, M.J. and Abate, C.M., 2010a. Amycolatopsis tucumanensis sp. nov., a copper-resistant actinobacterium isolated from polluted sediments. International Journal of Systematic and Evolutionary Microbiology, *60*(2), pp.397-401.

[3] Albarracín, V.H., Amoroso, M.J. and Abate, C.M., 2010b. Bioaugmentation of copper polluted soil microcosms with Amycolatopsis tucumanensis to diminish phytoavailable copper for Zea mays plants. Chemosphere, *79*(2), pp.131-137.

[4] Alvarez, A., Benimeli, C.S., Saez, J.M., Fuentes, M.S., Cuozzo, S.A., Polti, M.A. and Amoroso, M.J., 2012a. Bacterial bio-resources for remediation of hexachlorocyclohexane. International Journal of Molecular Sciences, *13*(11), pp.15086-15106.

[5] Álvarez, A., Yanez, M.L., Benimeli, C.S. and Amoroso, M.J., 2012b. Maize plants (Zea mays) root exudates enhance lindane removal by native Streptomyces strains. International Biodeterioration & Biodegradation, *66*(1), pp.14-18.

[6] Benimeli, C.S., 2004. Biodegradación de plaguicidas organoclorados por actinomycetes acuáticos. *Universidad Nacional de Tucuman., San Miguel de Tucumán*.

[7] Benimeli, C.S., Castro, G.R., Chaile, A.P. and Amoroso, M.J., 2007a. Lindane uptake and degradation by aquatic Streptomyces sp. strain M7. International biodeterioration & biodegradation, *59*(2), pp.148-155.

[8] Cuozzo, S.A., Fuentes, M.S., Bourguignon, N., Benimeli, C.S. and Amoroso, M.J., 2012. Chlordane biodegradation under aerobic conditions by indigenous Streptomyces strains. International Biodeterioration & Biodegradation, *66*(1), pp.19-24.

[9] Fuentes, M.S., Sáez, J.M., Benimeli, C.S. and Amoroso, M.J., 2011. Lindane biodegradation by defined consortia of indigenous Streptomyces strains. Water, Air, & Soil Pollution, *222*(1-4), pp.217-231.

[10] Polti, M.A., Amoroso, M.J. and Abate, C.M., 2007. Chromium (VI) resistance and removal by actinomycete strains isolated from sediments. Chemosphere, *67*(4), pp.660-667.

[11] Polti, M.A., García, R.O., Amoroso, M.J. and Abate, C.M., 2009. Bioremediation of chromium (VI) contaminated soil by Streptomyces sp. MC1. Journal of Basic Microbiology, *49*(3), pp.285-292.

[12] Saez, J.M., Benimeli, C.S. and Amoroso, M.J., 2012. Lindane removal by pure and mixed cultures of immobilized actinobacteria. Chemosphere, *89*(8), pp.982-987.

[13] Ghanem, N.B., Sabry, S.A., El-Sherif, Z.M. and El-Ela, G.A.A., 2000. Isolation and enumeration of marine actinomycetes from seawater and sediments in Alexandria. The Journal of General and Applied Microbiology, *46*(3), pp.105-111.

[14] Goodfellow, M., 1989. Supregeneric classification of actinomycets. Bergey's manual of systematic bacteriology, *4*, pp.2333-2339.

[15] McCarthy, A.J. and Williams, S.T., 1992. Actinomycetes as agents of biodegradation in the environment—A review. Gene, *115*(1-2), pp.189-192.

[16] Leveau, J.Y. and Bouix, M., 2000. Microbiología industrial: los microorganismos de interés industrial. *Editorial ACRIBIA, SA p*, pp.3-88.

[17] Jeffrey, L.S.H., 2008. Isolation, characterization and identification of actinomycetes from agriculture soils at Semongok, Sarawak. African Journal of Biotechnology, *7*(20).

[18] Salim, F.M., Sharmili, S.A., Anbumalarmathi, J. and Umamaheswari, K., 2017. Isolation, molecular characterization and identification of antibiotic producing actinomycetes from soil samples. J Appl Pharm Sci, *7*(9), pp.69-75.

[19] Attimarad, S.L., Ediga, G.N., Karigar, A.A., Karadi, R., Chandrashekhar, N. and Shivanna, C., 2012. Screening, isolation and purification of antibacterial agents from marine actinomycetes. International Current Pharmaceutical Journal, *1*(12), pp.394-402.

[20] Mohseni, M., Norouzi, H., Hamedi, J. and Roohi, A., 2013. Screening of antibacterial producing actinomycetes from sediments of the Caspian Sea. *International journal of molecular and cellular medicine*, *2*(2), p.64.

[21] Mangamuri, U.K., Muvva, V., Poda, S. and Kamma, S., 2012. Isolation, identification and molecular characterization of rare actinomycetes from mangrove ecosystem of Nizampatnam. Malaysian Journal of Microbiology, *8*(2), pp.83-91.

[22] Zainal Abidin, Z.A., Abdul Malek, N., Zainuddin, Z. and Chowdhury, A.J.K., 2016. Selective isolation and antagonistic activity of actinomycetes from mangrove forest of Pahang, Malaysia. Frontiers in Life Science, *9*(1), pp.24-31.

[23] Gopalakrishnan, S., Pande, S., Sharma, M., Humayun, P., Kiran, B.K., Sandeep, D., Vidya, M.S., Deepthi, K. and Rupela, O., 2011. Evaluation of actinomycete isolates obtained from herbal vermicompost for the biological control of fusarium wilt of chickpea. Crop Protection, *30*(8), pp.1070-1078.

[24] Vasavada, S.H., Thumar, J.T. and Singh, S.P., 2006. Secretion of a potent antibiotic by salt-tolerant and alkaliphilic actinomycete Streptomyces sannanensis strain RJT-1. *Current science*, pp.1393-1397.

[25] Oskay, A.M., Üsame, T. and Cem, A., 2004. Antibacterial activity of some actinomycetes isolated from farming soils of Turkey. African journal of Biotechnology, *3*(9), pp.441-446.

[26] Johnsen, A.R., Winding, A., Karlson, U. and Roslev, P., 2002. Linking of microorganisms to phenanthrene metabolism in soil by analysis of 13C-labeled cell lipids. Applied and Environmental Microbiology, *68*(12), pp.6106-6113.

[27] Lara-Severino, R.D.C., Camacho-López, M.Á., García-Macedo, J.M., Gómez-Oliván, L.M., Sandoval-Trujillo, Á.H., Isaac-Olive, K. and Ramírez-Durán, N., 2016. Determination of the residual anthracene concentration in cultures of haloalkalitolerant actinomycetes by excitation fluorescence, emission fluorescence, and synchronous fluorescence: Comparative study. Journal of analytical methods in chemistry, *2016*.

[28] Kästner, M., Breuer-Jammali, M. and Mahro, B., 1994. Enumeration and characterization of the soil microflora from hydrocarbon-contaminated soil sites able to mineralize polycyclic aromatic hydrocarbons (PAH). Applied Microbiology and Biotechnology, *41*(2), pp.267-273.

[29] Pizzul, L., del Pilar Castillo, M. and Stenström, J., 2006. Characterization of selected actinomycetes degrading

polyaromatic hydrocarbons in liquid culture and spiked soil. World Journal of Microbiology and Biotechnology, *22*(7), pp.745-752.

[30] Leneva, N.A., Kolomytseva, M.P., Baskunov, B.P. and Golovleva, L.A., 2009. Phenanthrene and anthracene degradation by microorganisms of the genus Rhodococcus. Applied Biochemistry and Microbiology, *45*(2), pp.169-175.

[31] Folsom, B.R., Schieche, D.R., DiGrazia, P.M., Werner, J. and Palmer, S., 1999. Microbial desulfurization of alkylated dibenzothiophenes from a hydrodesulfurized middle distillate by Rhodococcus erythropolis I-19. Applied and environmental microbiology, *65*(11), pp.4967-4972.

[32] Li, M.Z., Squires, C.H., Monticello, D.J. and Childs, J.D., 1996. Genetic analysis of the dsz promoter and associated regulatory regions of Rhodococcus erythropolis IGTS8. Journal of Bacteriology, *178*(22), pp.6409-6418.

[33] Idemudia, M.I., Nosagie, O.A. and Omorede, O., 2014. Comparative assessment of degradation potentials of bacteria and actinomycetes in soil contaminated with motorcycle spent oil. Asian Journal of Science and Technology, *5*(8), pp.482-487.

[34] Morikawa, M., Daido, H., Takao, T., Murata, S., Shimonishi, Y. and Imanaka, T., 1993. A new lipopeptide biosurfactant produced by Arthrobacter sp. strain MIS38. Journal of bacteriology, *175*(20), pp.6459-6466.

[35] Bhadbhade, B.J., Sarnaik, S.S. and Kanekar, P.P., 2002. Biomineralization of an organophosphorus pesticide, Monocrotophos, by soil bacteria. Journal of applied microbiology, *93*(2), pp.224-234.

[36] Bae, H.S., Lee, J.M. and Lee, S.T., 1996. Biodegradation of 4-chlorophenol via a hydroquinone pathway by Arthrobacter ureafaciens CPR706. FEMS Microbiology Letters, *145*(1), pp.125-129.

[37] Strong, L.C., Rosendahl, C., Johnson, G., Sadowsky, M.J. and Wackett, L.P., 2002. Arthrobacter aurescens TC1 metabolizes diverse s-triazine ring compounds. Applied and Environmental Microbiology, *68*(12), pp.5973-5980.

[38] Lakshmipathy, T.D., Prasad, A.A. and Kannabiran, K., 2010. Production of biosurfactant and heavy metal resistance activity of Streptomyces sp. VITDDK3-a novel halo tolerant actinomycetes isolated from saltpan soil. Biol. Res, *4*(2), pp.108-115.

[39] Apajalahti, J.H. and Salkinoja-Salonen, M.S., 1987. Complete dechlorination of tetrachlorohydro quinone by cell extracts of pentachlorophenol-induced Rhodococcus chlorophenolicus. Journal of bacteriology, *169*(11), pp.5125-5130.

[40] Sette, L.D., Da Costa, L.M.A., Marsaioli, A.J. and Manfio, G.P., 2004. Biodegradation of alachlor by soil streptomycetes. Applied microbiology and biotechnology, *64*(5), pp.712-717.

[41] Filimon, M.N., Popescu, R., Borozan, A.B., Bordean, D.M., Dumitrescu, G. and Voia, S.O., 2012. Influence of xenobiotic substances on Actinomycete Comunities in soil. Scientific Papers Animal Science and Biotechnologies, *45*(2), pp.221-224.

[42] Raziyafathima, M., Praseetha, P.K. and Rimal, I.R.S., 2016. Microbial degradation of plastic waste: A review. Chemical and Biological Sciences, *4*, pp.231-242.

[43] Sivan, A., Szanto, M. and Pavlov, V., 2006. Biofilm development of the polyethylene-degrading bacterium Rhodococcus ruber. Applied

microbiology and biotechnology, *72*(2), pp.346-352.

[44] Nisida, H. and Tokiwa, Y., 1993. Distribution of poly (β-hydroxybutyrate) and poly (ε-caprolacton) aerobic degrading microorganisms in different environments. J. Environ. Polym. Degrad, *1*, pp.227-233.

[45] Hoang, K.C., Lee, C.Y., Tseng, M. and Chu, W.S., 2007. Polyester-degrading actinomycetes isolated from the Touchien River of Taiwan. World Journal of Microbiology and Biotechnology, *23*(2), pp.201-205.

[46] Shah, A.A., Hasan, F., Hameed, A. and Ahmed, S., 2007. Isolation and characterisation of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) degrading actinomycetes and purification of PHBV depolymerase from newly isolatedStreptoverticillium kashmirense AF1. Annals of microbiology, *57*(4), pp.583-588.

[47] Jarerat, A. and Tokiwa, Y., 2001. Degradation of poly (tetramethylene succinate) by thermophilic actinomycetes. Biotechnology letters, *23*(8), pp.647-651.

[48] Gilan, I. and Sivan, A., 2013. Effect of proteases on biofilm formation of the plastic-degrading actinomycete Rhodococcus ruber C208. FEMS microbiology letters, *342*(1), pp.18-23.

[49] Shimizu, S., Kobayashi, H., Masai, E. and Fukuda, M., 2001. Characterization of the 450-kb linear plasmid in a polychlorinated biphenyl degrader, Rhodococcus sp. strain RHA1. Applied and environmental microbiology, *67*(5), pp.2021-2028.

[50] Yottakot, S. and Leelavatcharamas, V., 2019. Isolation and optimisation of Polylactic acid (PLA)-packaging-degrading Actinomycete for PLA-packaging degradation. Pertanika Journal of Tropical Agricultural Science, *42*(3).

[51] Pranamuda, H., Chollakup, R. and Tokiwa, Y., 1999. Degradation of polycarbonate by a polyester-degrading strain, Amycolatopsis sp. strain HT-6. Applied and environmental microbiology, *65*(9), pp.4220-4222.

[52] Pranamuda, H., Tokiwa, Y. and Tanaka, H., 1997. Polylactide degradation by an Amycolatopsis sp. Applied and environmental microbiology, *63*(4), pp.1637-1640.

[53] Pillai, H.P.J.S., Girish, K. and Agsar, D., 2014. Isolation, characterization and screening of actinomycetes from textile industry effluent for dye degradation. Int. J. Curr. Microbiol. App. Sci, *3*(11), pp.105-115.

[54] Zhou, W., W., Zimmermann (1993). *FEMS Microbiol.* Lett, *107*, pp.157-162.

[55] Bagewadi, Z.K., Vernekar, A.G., Patil, A.Y., Limaye, A.A. and Jain, V.M., 2011. Biodegradation of industrially important textile dyes by actinomycetes isolated from activated sludge. Biotechnol Bioinf Bioeng, *1*(3), pp.351-360.

[56] Chen, C.Y., Huang, Y.C., Wei, C.M., Meng, M., Liu, W.H. and Yang, C.H., 2013. Properties of the newly isolated extracellular thermo-alkali-stable laccase from thermophilic actinomycetes, Thermobifida fusca and its application in dye intermediates oxidation. *AMB express*, *3*(1), p.49.

[57] Pasti-Grigsby, M.B., Paszczynski, A., Goszczynski, S., Crawford, D.L. and Crawford, R.L., 1992. Influence of aromatic substitution patterns on azo dye degradability by Streptomyces spp. and Phanerochaete chrysosporium. Applied and Environmental Microbiology, *58*(11), pp.3605-3613.

[58] Paszczynski, A., Pasti-Grigsby, M.B., Goszczynski, S., Crawford, R.L.

and Crawford, D.L., 1992. Mineralization of sulfonated azo dyes and sulfanilic acid by Phanerochaete chrysosporium and Streptomyces chromofuscus. Applied and Environmental Microbiology, *58*(11), pp.3598-3604.

[59] Gowri, R.S., Vijayaraghavan, R. and Meenambigai, P., 2014. Microbial degradation of reactive dyes-a review. International Journal Current Microbiology and Applied Sciences, *3*, pp.421-436.

[60] Mane, U.V., Gurav, P.N., Deshmukh, A.M. and Govindwar, S.P., 2008. Degradation of textile dye reactive navy–blue Rx (reactive blue–59) by an isolated Actinomycete Streptomyces krainskii SUK–5. Malaysian Journal of Microbiology, *4*(2), pp.1-5.

[61] El Sayed, H.E., Othaimen, H.S., Aburas, M.M. and Jastaniah, S.D., 2015. Efficiency of an Cd-tolerant actinomycete isolate obtained from wastewater in removal of heavy metals and enhancing plant growth of Zea mays L. plant. Int J Curr Microbiol Appl Sci, *4*, pp.553-565.

[62] Taj, Z.Z. and Rajkumar, M., 2016. Perspectives of plant growth-promoting actinomycetes in heavy metal phytoremediation. In *plant growth promoting Actinobacteria* (pp. 213-231). Springer, Singapore.

[63] Albarracín, V.H., Ávila, A.L., Amoroso, M.J. and Abate, C.M., 2008. Copper removal ability by Streptomyces strains with dissimilar growth patterns and endowed with cupric reductase activity. FEMS microbiology letters, 288(2), pp.141-148.

[64] Mahendra, S. and Alvarez-Cohen, L., 2005. Pseudonocardia dioxanivorans sp. nov., a novel actinomycete that grows on 1, 4-dioxane. International Journal of Systematic and Evolutionary Microbiology, *55*(2), pp.593-598.