*Scientific Article*

# ACTINOMYCETES GENERAL CHARACTERISTICS AND THEIR ROLE IN SOIL, PLANT, AND HUMAN HEALTH

**Iman A.Khudhair**
**Biology Dept. – College of Science - University of Anbar**

**Huda M. Mahmood**
**Biotechnology Dept. - College of Science - University of Anbar**
**huda.mahmood@uoanbar.edu.iq**

**Gulboy A. Nasir**
**College of Agricultural Engineering Sciences- University of Baghdad**

## ABSTRACT

**Actinomycetes are free, spore-forming, high (G+C) ratio (>55%) saprophytic microorganisms that are widely distributed in most soils, colonize plants, and are prevalent in water. This is frequently accompanied by the production of filament airborne mycelium. Actinomycetes are well-known microcolonies for creating antibiotics and other critical bioactive components that are beneficial to humans. Approximately 70% to 80% of commercially available medications and antiviral active compounds have been synthesized so far. Secondary metabolites produced by microbes have the potential to be used in a variety of sectors, including antimicrobial agents, enzyme technology, pigment manufacture, antitumor agents against cancer cells, and toxin production. antiviral medications, protein innovation, pigment production, generally pro agents, and toxin creation. Around 7000 botanical extracts that come from actinomycetes' bioactive molecules were added to the list of natural products. Pollution may be defined as an introduction of unwanted and unacceptable compounds into the natural system which in turn may prevent natural processes in environment and may have undesirable health effects Biotechnological applications are helpful to obtain microbial strains with high efficiency toward pollution control. The genetic engineering approaches and strain improvement techniques are useful to develop a microbial system with a good ability to degrade environmental pollutants. The sake of bioremediation there requires several genetic systems to be exploited, additionally, the strain utilized in study was improved through a variety of techniques, including immobilization and mutation. Actinomycetes perform a variety of environmental functions. these are epiphytic bacteria that digest inorganic debris, notably complicated polymers like chitosan, keratin, hemi-cellulose, synthetic rubber, cellulose nanocrystals, gelatin, and glucose, as well as some active ingredients found in soil, also crucial in rhizosphere plant link because they can control plant life and shield plant roots from toxic fungus. Actinomycetes also break down pesticides with a large number of different structures, like organochlorine pesticides, triazinones, s-triazines, organophosphorus, esters, acetanilides, organophosphonates, and sulfonylureas, which are all types of pesticides. Modern technology and biotechnological equipment advancements have led to creation of a number of highly integrated software-based strategies for maximizing final product generation in any bioreactor or process. The Analytical Method (RSM), when combined with a relevant analysis design, seems to be a relatively recent development and critical technique for accomplishing this goal.**

تاريخ استلام المقالة 2022/10/9. تاريخ القبول للنشر 2022/11/10.

مقالة علمية

# الصفات العامة للبكتريا الخيطية ودورها في التربة والنبات وصحة الإنسان

ايمان عباس خضير
قسم علوم الحياة – كلية العلوم – جامعة الانبار

هدى مصلح محمود
قسم علوم الحياة – كلية العلوم – جامعة الانبار

كلبوي عبد المجيد ناصر
كلية علوم الهندسة الزراعية – جامعة بغداد

## المستخلص

الأكتينوميسـيتات هي كائنات حية مجهرية، مكونة للأبواغ، ذات نسـبة عالية من GC (>55%) منتشـرة على نطاق واسـع على سـطح التربة، تسـتعمر النباتات وتتواجد في الماء. غالبًا ما تكون مصـحوبة بإنتاج خيوط مايسـيليا هوائية وتتمايز الميكروبات المختلفة تسلسـلات مختلفة. الأكتينوميسـيتات تتميز بمستعمرات دقيقة معروفة بإنتاج المضـادات الحيوية وبعض المركبات المفيدة للإنسـان. ان ما يقارب من 70% إلى 80% من الأدوية المتاحة تجارياً والمركبات النشطة والمضادة للفيروسات الموجودة حاليا هي نتيجة الأكتينوميسيتات.

ان مركبات الايض الثانوية التي تنتجها الميكروبات تستخدم في مجالات متنوعة، بما في ذلك كعوامل مضادة للميكروبات، وتكنولوجيا الإنزيمات، وتصنيع الأصباغ، والعوامل المضادة للأورام السرطانية، وإنتاج السموم والأدوية المضادة للفيروسات. تمت إضافة حوالي 7000 مستخلص من تلك التي تنتجها البكتريا الخيطية إلى قائمة المنتجات الطبيعية. يمكن تعريف التلوث على أنه إدخال مركبات غير مرغوب فيها وغير مقبولة الى النظام الطبيعي، والتي بدورها قد تمنع العمليات الطبيعية في البيئة وقد يكون لها آثار صحية غير مرغوب فيها. تساعد تطبيقات التكنولوجيا الحيوية في الحصول على سلالات جرثومية ذات كفاءة عالية في مكافحة التلوث وتساعد أساليب الهندسة الوراثية في تطوير نظام ميكروبي يتمتع بقدرة ممتازة على تحطيم الملوثات البيئية. تتطلب المعالجة الحيوية عدة أنظمة وراثية ليتم استغلالها؛ بالإضافة إلى ذلك، تم تحسين السلالات المستخدمة في الدراسات من خلال تقنيات مختلفة، بما في ذلك تقنيات التثبيت والتطفير. البكتريا الخيطية مجموعة متنوعة الوظائف البيئية حيث ان لها القابلية على هضم البقايا غير العضوية، ولا سيما البوليمرات المعقدة مثل الكيتوزان، والكيراتين ، والهيميسليلوز، والمطاط الصناعي، وبلورات السليلوز النانوية ، والجيلاتين، والجلوكوز، بالإضافة إلى بعض المكونات النشطة الموجودة في التربة ، وهي أيضًا مهمة في ارتباط جذور النبات في الأرض لأنها تستطيع التحكم في حياة النبات وحماية جذور النبات من الفطريات السامة. تقوم الاكتينومايسيتات أيضًا بتفكيك المبيدات الحشرية، مثل مبيدات الآفات العضوية الكلورية، والتريازينون، والتريازينات ، والفوسفور العضوي ، والإسترات ، والأسيتانيليد ، والفوسفات العضوية، والسلفونيل يوريا. قد أدت التطورات في التكنولوجيا الحديثة ومعدات التكنولوجيا الحيوية إلى إنشاء العديد من الاستراتيجيات المتكاملة للغاية للاستفادة من الاكتينومايسيتات في مجال المعالجة الحيوية .

<u>الكلمات المفتاحية</u> : الأكتينوميسيتات, المعالجة الحيوية للتربة, المركبات النشطة البيولوجية, منتجات الايض الثانوي.

# INTRODUCTION

**Actinomycetes are unique, bodacious, and appealing gram-positive filamentous bacteria that have a high G+C content (more than 55%) and precise aerial hyphae. They are members of the phylum Actinobacteria, which is one of primary taxonomic groupings among 18 major lineages that have been identified within the bacterial domain, with numerous variations within the soil category (Farda *et al*., 2020). Phylogenetic and molecular methods have also had a big impact on how they classify things when they've been used (Devanshi *et al*.,2021). On the other hand, thanks to the emergence of molecular technology, a number of creatures that were previously classified incorrectly have been reclassified (Jagannathan *et al*.,2021). However, in recent years, 16S rRNA and the use of PCR for sequencing and analysis have frequently resulted in classification of species and phylogenies (Rathore *et al*., 2021). At the microscopic level, life cycle of actinomycetes has three distinct appearances: vegetative mycelium (growth), aerial mycelium bearing spore cuffs (Mishra *et al*.,2021). Both culture and microscopic traits work together to**

help researchers organize actinomycetes until they reach a genus (Bhattacharyya *et al*.,2022). Approximately 70% to 80% of commercially available medications and antiviral active compounds have been synthesized so far (Rajivgandhi *et al*.,2021). Due to the declining success rate of discovering novel strains, A lot more work was done to look for new chemical compounds, but it didn't work out very well because actinomycetes have been improving their abilities for a long time(Cimermanova *et al*.,2021). Actinomycetes manufacture over 80% of all rationally developed antibiotics, with Streptomyces and Micromonospora being the most common producers (Xie *et al*.,2022). Furthermore, actinomycetes include a variety of bioactive compounds, including anthracyclins, aminoglycosides,carbapenem, cephalosporins, quinolones, lactams, proteomics, nucleobases, hydrocarbons, polyamides, and oxytetracycline( Raja & Prabakarana., 2011). Antimicrobials pure components or quasi-derived products of natural bacteria ( He *et al*.,2022). The separation of secondary metabolites from novel actinomycetes remains an important endeavor for achieving this exciting isolation and characterization of novel actinomycetes from natural income (AbdElgawad *et al*., 2021). *Streptomyces* is most common actinobacteria strain found in the natural environment( Dai *et al*., 2021). Actinomycetes can be antimicrobial, plant estrogens, immunomodulatory, fungicidal, antibiotic, genotoxic, antitumor, and antiviral in nature( Rani et al.,2021).

# LITERATURE REVIEW

## The Origin of Actinomycetes

Actinomycetes are respiration, fungal growths, and staphylococci bacteria that relate to actinomycetales arrange (Shanthi, 2021). Their DNA showed a high (G+C) ratio (>55%), which is phylogenetically linked to 16S ribosomal cataloguing and DNA-rRNA combination study findings (Rastimesina *et al*., 2022). It is one of the main taxonomic groups of the 18 major bacterial lineages that we know about now(Afianti *et al*., 2022). Actinomycetes are derived from Greek words "attacks" (a ray) and "makes" (fungus), implying that it possesses both fungi and bacteria-like features(Shengping *et al*., 2022). Antibiotics, immunosuppressive agents, anticancer agents, and enzymes are examples of them, furthermore, antibacterial, antioxidant, antifungal, anticancer, neurogenic, antialgal, antimalarial, anti-inflammatory, and antihelmintic properties have been demonstrated for these metabolites (Shengping *et al*., 2022). They play a big role in soil nutrient cycle in environment because they help move vegetable matter around in soil (Kapoor *et al*., 2021). Actinobacteria are intended to make up a third of the human gut microbiota and most important probiotic bacteria genus is good for humans and nutrition (Xue & Wang., 2021). Additionally, to accomplish this objective, concentrated hard effort can be increased to isolate and screen unique strains for the discovery of new substances (Kalmykova et al.,2022).

## The Environment of Actinomycetes

Actinobacteria are the most prevalent micro-organisms in essence, and they are grown as familiar spores. That also makes the dirt smells like a "woodsy scent" when it's just been converted over (Shanthi *et al*.,2022). Actinomycetes are a varied group of microorganisms that are found in a wide range of environmental habitats worldwide (Figure 1). These are

**predominantly terrestrial (soli) dwellers (Roulia *et al*.,2022) and have been found in a very wide range of marine biological units, including samples recovered from the sea (Yang *et al*., 2021) and the Mariana Trench's maximum depth(Bhattacharjee *et al*.,2022). Their presence has also been documented in harsh environmental conditions, most notably in cryophilic locations(Magan *et al*.,2022). For example, soils have been collected from Antarctica (Nayak *et al*.,2022) and even from desert dirt(Turan *et al*.,2022). It has been demonstrated that in a proportionate survey, actinomycetes are the most abundant residents of soils and that they originate from a surface layer that gradually diminishes in depth, actinomycete strains are present in all soil strata(Sehrawat *et al*.,2021). While the information on the actinomycete diversity in limestone settings is still lacking, certain studies on the microbial community of caves, particularly limestone caves, have been allowed(Anode & Onguso *et al*., 2021).**

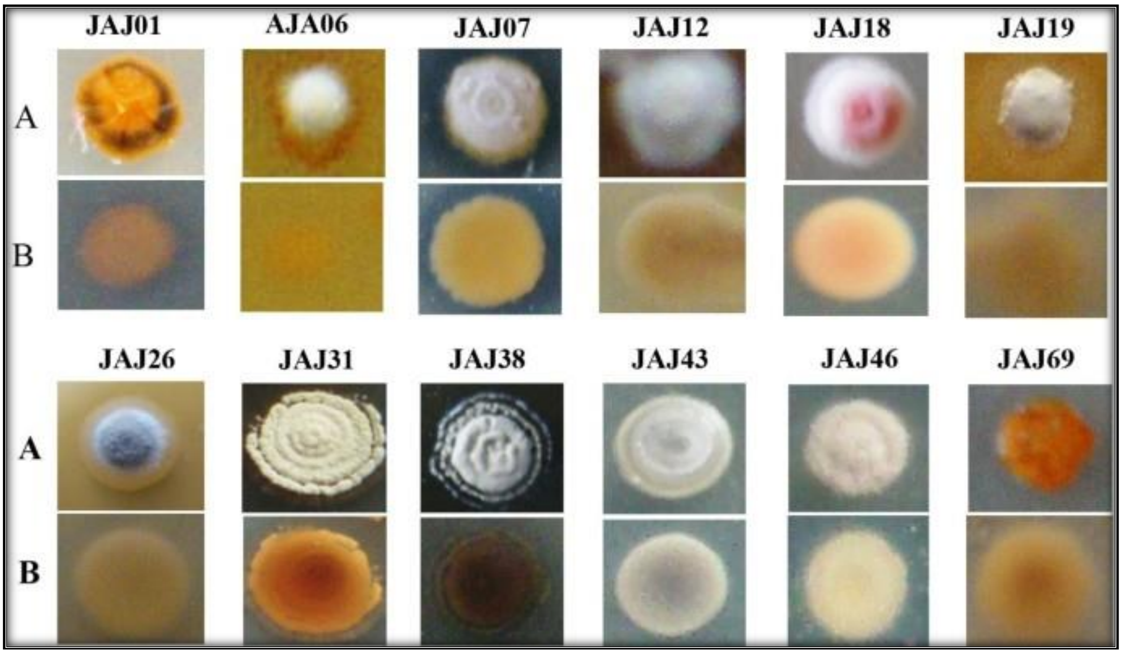


**Figure 1. Diversity of the actinomycetes colonies (Jose & Jebakumar, 2012).**

**In nature, actinobacteria have been the most common class of microbes(Gunjal, A., & Bhagat *et al*., 2022). That unpleasant odour, mostly in the atmosphere following a rainstorm during a drought, is caused by soil actinomycetes producing geosmin(Costa-Gutierrez *et al*., 2021). Currently, the literature review cites around 600 *Streptomyces* species (Kontro & Yaradoddi., 2021). Certain species, like *Frankia*, have very improved growth conditions and hatching requirements, nevertheless, several actinobacteria grow on commonly used laboratory media, including nutritional media, gram stain, tryptose peptone, and dextrose agar, and mind-heart flow agar (Javed *et al*., 2021).**

## Existence of Actinomycetes

**A natural cycle is characterized by various tissues (fungal growths, photosynthetic, and fertile hyphae), as well as physical variation and alterations that are strongly related to physiological segregation (Roulia *et al*., 2021). Apoptosis occurrences are part of the multistage biological growth cycle of this**

bacteria, which serves as an example for complex microbes(Wani *et al*., 2021). Streptomycetes have a complex life cycle and are classed as neither multicellular nor unicellular (Tatar., 2021). The vegetative mycelium next evolves into sporophores that grow vertically to the surface, resulting in formation of aerial mycelium, and the polynucleated aerial mycelium is generated when filamentous and spiraling are fragmented, the final sheaths dissolve into germs, beginning the cycle where microbes' bioactive compounds are nearly chemical molecules found naturally (Tripathi *et al*., 2021).

## Actinomycetes: Structure, Diversity, and Taxonomy

At their most basic level, Actinobacteria are defined by their tendency to generate growing filaments or poles where mycelia are not usually septated but septa can appear in a variety of shapes and sizes under certain conditions also the sporulating mycelium can be branched or not, linear or spiral in shape (Behera *et al*.,2022). Actinomycetes produce spores that are spherical, cylindrical, or oval in shape, furthermore, actinomycetes create early microcolonies that are made up of branching filaments that convert into diptheroids, short chain, and coccobacillary forms within 24 to 48 hours(Chougule & Bangale *et al*., 2021). Actinomycete, epithelial tissue seems to be an unyielding layer that maintains the form of unit and prevents it from exploding owing to excessive hydrostatic potential(Shakya *et al*.,2021). The exterior is made up of a variety of different compounds, such as glycoprotein, teichuronic acid, cysteine residues anhydride, and carbohydrates where peptidoglycans are made of an unstructured sequence of acids (NAM) acid ,diaminopimelic hydrochloric, and (NAG) and (DAP), that are found solely inside the cellular membranes of microbial systems as well Teichoic and teichuronic acids, as well as peptidoglycan, have chemical linkages (Nahas, 2021). Although their cell walls are chemically identical to those of gram positive bacteria (Salam & Nilza,N. 2021).

## Isolation of Actinomycetes

The practice has demonstrated that when novel selection algorithms are utilized, previously undiscovered and significant natural bioactive chemicals are discovered (Tripathi *et al*., 2021). Actinomycetes are difficult to isolate from natural diverse microbiology due to their modest growth rate compared to other bacteria. However, there are still a lot of ways to get rid of actinomycetes that are important for technology (Sharma, P., & Kumar., *et al* 2021).

## Substrate Selection

Actinomycetes have been isolated from soils, freshwater, and marine environments(Dilip *et al*., 2013; Valli; *et al*., 2013). Isolating actinomycetes from marine environments thus opens up a new avenue for developing new organisms and medicines (Lakshmi *et al*., 2021). *Streptomyces* has been the subject of studies on the diverse cell well shapes of actinomycetes spores during germination (Tripathi *et al*., 2021). Additionally, When fungal strains sections are cultivated on a flat substrate, they produce a complexity of mycelium that grows on either the top or bottom of agar (Tripathi., 2021). One that results in formation is referred to as "aerial hyphae," while the one that forms beneath the surface is referred to as "subsurface mycelium." grows under the surface is referred to as "substrate hyphae." Normally, the existing septa split the hyphae into long cells (20 mm), each of which contains several bacterial chromosomes (Tripathi., 2021). Actinomycetes are gram-positive actinobacteria that contain a high proportion of nucleotide bases in their DNA (about 69%–73% mol), considerable substrate branching, and aerial mycelia(Mandragutti *et l.*, 2021).

## Media Selection

In the isolation media, bioactive molecules like phenolic or Potassium Acetate have also been established to restrict bacterial activity and molds, hence encouraging the growth of actinomycetes, also such changes frequently allow the growth of pollutants in permissible quantities and may also hinder the growth of actinomycetes at greater concentrations (Rahayu *et al.*,2021). Chitin agar treated with sodium chloride is more successful at extracting actinobacteria from liquid than chitosan gelatin alone, as well as Chitin agar, exhibited a higher degree of selection, over other media when it came to isolating actinomycetes from water and dirt (Rahayu *et al.*, 2021).

## The Incubation Period

Antibiotic-producing actinomycetes species thrive best at temperatures between 25 and 30ºC (Goodfellow & Williams, 1986). Systems engineering is cultured at a temperature of 40–45ºC, and microbes are incubated at a temperature of 4–10ºC. Plate separation requires an incubation period of between 7 and 14 days (Goodfellow & Williams, 1986). Longer incubation times have frequently gone unreported because actinomycetes are candidates who are unfit for commercial and residential fermentation (El-Gendy & Nassar, 2021). Nonetheless, by giving bioactive molecules, certain species of bacteria can modify the nutritional condition of the separation plates (El-Gendy & Nassar, 2021).

## Establishment of bacterial colonies

The one that takes the longest aspect of the isolation process is selecting the colony for isolation and it depends on the screening plan's objectives, and there may be considerable duplication of colonies in the screening protocol (Shanthi *et al*., 2022). Experts are now using a binocular microscope to pick out promising colonists and transfer them to a wooden pole with a point at the top for them to grow(Tripathi *et al*., 2021). It is helpful to define and choose microcolonies. To facilitate better transmission, the coarse wooden tips contain a suitable number of germs or mycelium pieces (Yang *et a l.*, 2021). The sample frame, the goal of the enrichment technique, knowledge of an isolate's bioactive compound, and the purpose of the culture media all play a role in separating possible isolated types (Chougule & Bangale, 2021).

## Identification of Actinomycetes

Numerous actinomycete species grow on standard bacteriological such as nutritional gel, agar media, tryptose agar, medium supplemented agar and Sporoactinomycetes require specialized media to facilitate segregation and pigment development of their unique spores (Williams & Cross, 1971). However, many of these environments are economically unavailable and must be created in laboratory using liquid chitosan, plant elixirs, and ground extracts (Lakshmi *et al.*,2021). When the bacterium is cultivated on a medium that is more suitable for growing, including oats or chemical starch agar,

**colonies that are pale and hard can be warped into light yellow colonial possessions that are chalky white and have spirals of arthrospores (Lacey & Dutkiewicz, 1976). This is acceptable only if there is no evidence of strain degeneration due to culturing or inappropriate care (Vijayakumar, 2021). Specific varieties of such species, including *S.cerevisiae*, cover the colonial using straight, loose mycelium enveloped by a hydrophilic coating that grows further into land's residual air (aerial mycelium) (Magan *et al*., 2022). Colonies seem velvety or powdery and can easily be distinguished from more conventional bacteria. *S. cerevisiae* organisms possess distinct spore rings on their mycelia that are not present on the foundation mycelium (Magan *et al.*, 2022). The fundamentals of recognition are as follows: separation of anaerobic colonies grown on gram staining or embryo culture, accompanied by confirmation via laboratory tests, application of new species lists or genetic technology (Nayak & Nanda, 2021).**

## Optimizing Actinomycetes' Bioactive Compound Production

**Traditionally, increasing the synthesis of any bioactive substance from actinomycetes species has been accomplished using a number of physicochemical, molecular, dietary, immobilization, and mutation-regulated mechanisms (Janardhan *et al.*,2014). The Analytical Method (RSM), when combined with a relevant analysis design, seems to be a relatively recent development and critical technique for accomplishing this goal (Turan *et al*., 2022). Numerous actinomycete species, particularly Streptomycetes, are capable of growing on nutritional, Lange yeast extract using the soya plate method with trypticase (Sehrawat *et al*., 2021). as well as on any Carbon or Nitrogen source. Additionally, air, heat, pH, electrolytes, as well as a few additional factors, all contribute significantly to the synthesis produced by separated actinobacteria (Anode & Onguso, 2021).**

## The Significance & Variety of Bioactive Compounds in Actinomycetes

**Bioactive compounds are byproducts of actinobacteria germs, and are natural materials believed to contribute to progress, reproduction, and survival of the microbes (Javed *et al*.,2021). Secondary metabolites produced by microbes have the potential to be used in a variety of sectors, including antimicrobial agents, enzyme technology, pigment manufacture, antitumor agents against cancer cells, and toxin production. antiviral medications, protein innovation, pigment production, generally pro agents, and toxin creation (Bhattacharjee *et al*., 2022). Actinomadura species have also yielded napthacene-quinone and macrolactam antimicrobials, while *Saccharopolyspora* and *Micromonospora* strains have yielded a variety of macrolide-type antibiotics (Sehrawat *et al*.,2021). Apart from antimicrobial chemicals, actinomycetes generate a variety of other important compounds, such immunotherapy, vitamin supplements, and enzymes that are used as biocatalysts in a wide range of applications are also on the list (Xue & Wang, 2021).**

## Actinomycetes: Secondary Products of Metabolism

**Actinomycete has the potential to create a vast Numerous pharmacologically important chemicals, including antibacterial agents, immunomodulatory, proteolytic enzymes, enzymes, and functional ingredients for animals and plants (Kalmykova *et al*., 2022).**

## Actinomycetes uses in environmental and ecosystem sciences

**Actinomycetes perform a variety of environmental functions (Dilip *et al*., 2013).These streptomycetes are epiphytic bacteria that digest inorganic debris, notably complicated polymers like chitosan, keratin, hemi-cellulose, synthetic rubber, cellulose nanocrystals, gelatin, and glucose, as well as some active ingredients found in soil (Roulia *et al*., 2021). Additionally, it has been demonstrated that some Streptomyces species protect several plant species from soil-borne pathogenic fungal diseases (Kontro & Yaradoddi, 2021; Vijayakumar, 2021). Similarly, Frankia and other actinomycetes are capable of N2 fixation in the environment(Cheng *et al*., 2022). They have a broad host range and have been proven to produce root nodule symbioses with over 200 types of flowering plants(Wani et al., 2021).**

## Actinomycetes' role in biodegradation agents

**Some of effluents will be cleaned up by color removal or even the dye will be absorbed into the molecules (Cooper, 1993). Actinobacteria found in environment and other oil-based materials have a main biotransformation activity, releasing a wide range of proteolytic enzymes and illustrating the ability to digest refractory compounds (Narancic & O'Connor,2019). Moreover, among several ground actinobacteria, there are many examples of a wide number of approaches, from periods of rapid growth and sporulation to preserving the population. through slow growth and scavenging (Nayak & Nanda, 2021). Actinomycetes native to the soil, particularly durian, have been reported to breakdown the pesticide (Tripathi *et al*., 2021).**

## Potential Enzymes of Actinomycetes

**Enzymes are acknowledged as antimicrobial producers and are currently being investigated extensively (Anode & Onguso, 2021). Additionally, mycolytic and bacteriolytic enzymes extracted and isolated from actinobacteria, they can be used to purify wine and beer, as well as to serve as quasi-preservatives. Additionally, actinomycetes'-produced enzymes appear to be particularly as frozen solutions for normal clinical diagnostic procedures, they appear to be promising (Kalmykova). Food processing, detergent manufacturers, pharmaceutical manufacturing, textile industries, therapeutic treatment, molecular genetics, and bioorganic chemistry all make extensive use of enzyme production, among many other things (Nahas *et al*., 2021)**

# REFERENCES


- **Farda, B., Djebaili, R., Vaccarelli, I., Del Gallo, M., & Pellegrini, M. 2020. Actinomycetes from Caves: An Overview of Their Diversity, Biotechnological Properties, and Insights for Their Use in Soil Environments. *Microorganisms*, (10), 453.**
- **Devanshi, S., Shah, K. R., Arora, S., & Saxena, S. 2021. Actinomycetes as An Environmental Scrubber. In *Crude Oil-New Technologies and Recent Approaches*. IntechOpen.**
- **Jagannathan, S. V., Manemann, E. M., Rowe, S. E., Callender, M. C., & Soto,W.(2021).Marine actinomycetes, new sources of biotechnological products. *Marine Drugs*, *19*(7), 365.**
- **Rathore, D. S., Sheikh, M., & Singh, S. P. 2021. Marine Actinobacteria:**

New Horizons in Bioremediation. In *Recent Developments in Microbial Technologies* (pp. 425-449). Springer, Singapore.

- Mishra, M., Singh, S. K., & Kumar, A.2021. Environmental factors affecting the bioremediation potential of microbes. In *Microbe Mediated Remediation of Environmental Contaminants* (pp. 47-58). Woodhead Publishing.
- Bhattacharyya, P. N., Sonowal, S., Bhattacharyya, L. H., Prasad, R., & Sarma, H. 2022. Bioremediation of cytostatic pharmaceutical and personal care products and emerging technologies. In *Emerging Contaminants in the Environment* (pp. 579-601). Elsevier.
- Rajivgandhi, G., Vimala, R. T. V., Maruthupandy, M., Alharbi, N. S., Kadaikunnan, S., Khaled, J. M., ... & Li, W. J. 2021. Enlightening the characteristics of bioflocculant of endophytic actinomycetes from marine algae and its biosorption of heavy metal removal. *Environmental Research*, *200*, 111708.
- Cimermanova,M., Pristas, P., & Piknova, M. 2021. Biodiversity of Actinomycetes from Heavy Metal Contaminated Technosols. *Microorganisms*, *9*(8),1635.
- Xie, H., Liu, R., Xu, Y., Liu, X., Sun, F., Ma, Y., & Wang, Y. 2022. Effect of In Situ Bioremediation of Soil Contaminated with DDT and DDE by Stenotrophomonas sp. Strain DXZ9 and Ryegrass on Soil Microorganism. *Microbiology Research*, *13*(1), 64-86.
- He, T., Zhang, M., Ding, C., Wu, Q., Chen, M., Mou, S., ... & Wang, Y. 2022. New insight into the nitrogen removal capacity and mechanism of Streptomyces mediolani EM-B2. *Bioresource Technology*, *348*, 126819.
- AbdElgawad, H., Zinta, G., Abuelsoud, W., Hassan, Y.M., Alkhalifah, D. H. M., Hozzein, W. N., & Schoenaers, S. 2021. An actinomycete strain of Nocardiopsis lucentensis reduces arsenic toxicity in barley and maize. *Journal of Hazardous Materials*, *417*, 126055.
- Dai, Z. L., Yang, W. L., Fan, Z. X., Guo, L., Liu, Z. H., & Dai, Y. J. 2021. Actinomycetes Rhodococcus ruber CGMCC 17550 degrades neonicotinoid insecticide nitenpyram via a novel hydroxylation pathway and remediates nitenpyram in surface water. *Chemosphere*, *270*, 128670.
- Rani, K., Parashar, A., & Wati, L. 2021. Estimation of hydrolyzing potential of chickpea actinomycetes for degradation of complex compounds through enzymes and acid production.
- Shanthi, V. 2021. Actinomycetes: Implications and Prospects in SustainableAgriculture. *Biofertilizer: Study and Impact*, 335-370.
- Rastimesina, I., Postolachi, O., Bogdevich, O., Josan, V. V., Nicolau, E., & Culîghin, E. 2022. Microbiological characteristic of soil for the bioremediation of POPs contaminated sites. In *Ecological and environmental chemistry*(pp.178-178).
- Afianti,N.F.,Rachman, A., Hatmanti, A., Yogaswara, D., Anggiani, M., Fitriya, N., & Darmayati, Y. 2022. Microbial Biofilm of Plastic in Tropical Marine Environment and their Potential for Bioremediation of Plastic Waste. *Journal of Ecological Engineering*, *23*(4), 261-275.
- Shengping, X. U. E., & Xiaohuan, W. A.N.G.2021.Inoculation Of Soil With Cadmium-Resistant Actinomycetes Flora Reduces Cadmium Accumulation In Rice (*Oryza Sativa* L.). *International Journal of Environmental Pollution and Remediation*, *9*, 01-11.
- Shengping, X. U. E., & Xiaohuan, W. A.N.G.2021. Inoculation Of Soil With Cadmium-Resistant Actinomycetes

Flora Reduces Cadmium Accumulation In Rice (*Oryza Sativa* L.). *International Journal of Environmental Pollution and Remediation*, *9*, 01-11.
- Kapoor, R. T., Salvadori, M. R., Rafatullah, M., Siddiqui, M. R., Khan,M. A., & Alshareef, S. A. 2021. Exploration of microbial factories for synthesis of nanoparticles–a sustainable approach for bioremediation of environmental contaminants. *Frontiers in Microbiology*, *12*, 1404.
- XUE, S., & WANG, X. (2021). Inoculation of Soil With Cadmium-Resistant Actinomycetes Flora Reduces Cadmium Accumulation in Rice (Oryza Sativa L.).
- Kalmykova, E. V., Belyaev, A. I., Petrov, N. Y., Pugacheva, A. M., & Aksenov, M. P. 2022, February. Bioremediation of contaminated light-chestnut soils in southern Russia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 996, No. 1, p. 012026). IOP Publishing.
- Shanthi,T.R., Vasanthy, M., & Mohamed Hatha, A. A. 2022. Bioremediation of Lindane-Contaminated Soil and Water Ecosystems: A Review. *Organic Pollutants*, 199-227.
- Roulia, M., Kontezaki, E., Kalogeropoulos, N., & Chassapis, K. 2021. One step bioremediation of olive-oil-mill waste by organoinorganic catalyst for humics-rich soil conditioner production. *Agronomy*, *11*(6), 1114.
- Yang, T. T., Zhang, H. W., Wang, J., Li, X. Y., Li, X., & Su, Z. C. 2021. High bioremediation potential of strain Chenggangzhangella methanolivorans CHL1 for soil polluted with metsulfuron-methyl or tribenuron-methyl in a pot experiment. *Environmental Science and Pollution Research*, *28*(4), 4731-4738.
- Bhattacharjee,A., Sengupta, A., Basu, S., Singh, P., & Kumar, A. 2022. Role of halophiles in xenobiotic bioremediation. In *Development in Wastewater Treatment Research and Processes* (pp. 45-60). Elsevier.
- Magan, N., Gouma, S., Fragoeiro, S., Shuaib, M. E., & Bastos, A. C. 2022. Bacterial and fungal bioremediation strategies.In *Microbial Biodegradation and Bioremediation* (pp.193-212). Elsevier.
- Nayak, S. K., & Nanda, P. K. 2021. Bioremediation: An Ecofriendly Technology for Sustainable Aquaculture. *Bioresource Utilization and Management: Applications in Therapeutics, Biofuels, Agriculture, and Environmental Science*, 21.
- Turan, M., Argin, S., Bolouri, P., Arjumend, T., Ersoy, N., Yıldırım, E., & Birinci,D.2022. Bioremediation of contaminated soil with plant growth rhizobium bacteria. In *Assisted Phytoremediation* (pp. 265-284). Elsevier.
- Sehrawat, A., Phour, M., Kumar, R., & Sindhu, S. S. 2021. Bioremediation of pesticides: an eco-friendly approach for environment sustainability.In *Microbial Rejuvenation of Polluted Environment* (pp. 23-84). Springer, Singapore.
- Anode, S., & Onguso, J. 2021. Current Methods of Enhancing Bacterial Bioremediation of Pesticide Residues in Agricultural Farmlands. In *Microbial Rejuvenation of Polluted Environment* (pp. 167-187). Springer, Singapore.
- Gunjal, A., & Bhagat, D. S.2022. Diversity of actinomycetes in Western Ghats. In *Microbial Diversity in Hotspots* (pp. 117-133). Academic Press.
- Costa-Gutierrez, S. B., Aparicio, J. D., Delgado, O. D., Benimeli, C. S., & Polti, M. A.2021. Use of glycerol for

**the production of actinobacteria with well-known bioremediation abilities. *3 Biotech, 11*(2), 1-10.**
- **Kontro, M. H., & Yaradoddi, J. S. 2021.Actinomycetes in Environmental Applications. In *Actinobacteria* (pp. 247-270). Springer, Singapore.**
- **Javed, Z., Tripathi, G.D., Mishra, M., & Dashora, K. 2021. Actinomycetes–The microbial machinery for the organic-cycling, plant growth, and sustainable soil health. *Biocatalysis and Agricultural Biotechnology, 31,* 101893.**
- **Vijayakumar, N. 2021. Review on halophilic microbes and their applications. *Bull. Env. Pharmacol. Life Sci, 10,* 23-36.**
- **Wani, M. S., Tantray, Y. R., Malik, N. A., Dar, M. I., & Ahmad, T. 2021. Microbial Bioremediation of Pesticides/Herbicides in Soil. In *Microbiota and Biofertilizers, Vol 2* (pp. 21-60). Springer, Cham.**
- **Tatar,D.2021. Isolation, phylogenetic analysis and antimicrobial activity of halophilic actinomycetes from different saline environments located near ÇorumProvince. *Biologia, 76*(2), 773-780.**
- **Tripathi, M., Singh, D. N., Prasad, N., & Gaur, R. 2021. Advanced Bioremediation Strategies for Mitigation of Chromium and Organics Pollution in Tannery. In *Rhizobiont in Bioremediation of Hazardous Waste* (pp. 195-215). Springer, Singapore.**
- **Behera, H. T., Mojumdar, A., & Ray, L. 2022. Biology, genetic aspects and oxidative stress response of actinobacteria and strategies for bioremediation of toxic metals. In *Microbial Biodegradation and Bioremediation* (pp. 181-192). Elsevier.**
- **Chougule, V. V., & Bangale, S. 2021. Green synthesis of magnesium nanoparticles from actinomycetes and their therapeutic applications. *Journal of Advanced Scientific Research, 12*.**
- **Shakya, M., Verma, P., Kumar, S., & Sandhu, S. S. 2021. Microbes: A Novel Source of Bioremediation for Degradation of Hydrocarbons. *Microbial Rejuvenation of Polluted Environment,* 247-261.**
- **Nahas, H. H. A., Nouh, F. A. A., Husien, S., Gezaf, S. A., Mansour, S. A., Abdel-Azeem, A. M., & Saied, E. M.2021. Lipopeptides Biosurfactants Production, and Applications in Bioremediation and Health. In *Microbial Surfactants* (pp. 63-84). CRC Press.**
- **Salam, M., & Nilza, N. 2021. Hazardous components of landfill leachates and its bioremediation. In *Soil Contamination-Threats and Sustainable Solutions*. IntechOpen.**
- **Tripathi, M., Kumar, S., Singh, D. N., Pandey, R., Pathak, N., & Fatima, H. 2021. Bioremediation of Dye Contaminated Soil. *Soil Bioremediation: An Approach Towards Sustainable Technology,* 115-142.**
- **Cheng, X., Chen, K. X., Jiang, N. D., Wang, L., Jiang, H. Y.,Zhao, Y.X., & Dai, Y. J. 2022. Nitroreduction of imidacloprid by the actinomycete Gordonia alkanivorans and the stability and acute toxicity of the nitroso metabolite. *Chemosphere, 291,* 132885.**
- **Mandragutti, T., Dokka, M.K., Panchagnula, B., & Godi, S. 2021. Molecular characterization of marine bacterial isolates of Visakhapatnam coast-efficacy in dye decolorization and bioremediation of cadmium. *Journal of Genetic Engineering and Biotechnology, 19*(1), 1-11.**
- **Sharma, P., & Kumar, S. 2021. Bioremediation of heavy metals from industrial effluents by endophytes and their metabolic activity: Recent**

advances. Bioresource Technology, 339, 125589.

- Lakshmi, K., Jenifer, G., Aishwarya, C., Divya, K., Josephine, J. J., Putra, K.G.D., & Malliga,P.2021. New approaches in bioremediation of heavy metals from tannery effluent using microorganisms. In *New Trends in Removal of Heavy Metals from Industrial Wastewater* (pp. 487-524). Elsevier.
- Rahayu,H.M.,Putri,W.A., Khasanah, A.U., SEMBIRING, L., & Purwestri, Y.A. 2021. Indigeneous Streptomyces spp. isolated from Cyperus rotundus rhizosphere indicate high mercuric reductase activity as a pontential bioremediation agent. *Biodiversitas Journal of Biological Diversity*, *22*(3).
- El-Gendy,N. S., & Nassar, H. N. 2021. Soil Bioremediation and Sustainability. In *Rhizomicrobiome Dynamics in Bioremediation* (pp. 315-334). CRC Press.
- Raja, A., & Prabakarana, P. 2011. Actinomycetes and drug-an overview. *American Journal of Drug Discovery and Development*, *1*(2), 75-84.
- Dilip, C.V.,Mulaje,S.S., & Mohalkar, R.Y.2013. A review on actinomycetes and their biotechnological application. *International Journal of pharmaceutical sciences and research*, *4*(5), 1730.
- Valli, S., Suvathi, S. S., Aysha, O. S., Nirmala, P., Vinoth, K. P., & Reena, A. 2012. Antimicrobial potential of Actinomycetes species isolated from marine environment. *Asian Pacific Journal of Tropical Biomedicine*, 2(6), 469-473.
- Wildermuth, H., & Hopwood, D. A. (1970). Septation during sporulation in Streptomyces coelicolor. *Microbiology*, *60*(1),51-59.
- Glauert,A.M.,& Hopwood,D.A. 1961. The fine structure of Streptomyces violaceoruber (S. coelicolor) III. The walls of the mycelium and spores. *The Journal of Cell Biology*,*10*(4),505-516.
- Goodfellow, M., & Williams, E. 1986. New strategies for the selective isolation of industrially important bacteria. *Biotechnology and Genetic Engineering Reviews*, *4*(1), 213-262.
- Williams, S. T., & Cross, T. 1971. Chapter XI actinomycetes. In *Methods in microbiology* (Vol. 4, pp. 295-334). Academic Press.
- Lacey, J., & Dutkiewicz, J. 1976. Methods for examining the microflora of mouldy hay. *Journal of Applied Bacteriology*, *41*(1), 13-27.
- Janardhan, A., Kumar, A. P., Viswanath, B., Saigopal, D. V. R., & Narasimha, G. 2014. Production of bioactive compounds by actinomycetes and their antioxidant properties. *Biotechnology research international*.
- Cooper, P. 1993. Removing colour from dyehouse waste waters—a critical review of technology available. *Journal of the Society of Dyers and Colourists*, *109*(3), 97-100.
- Narancic, T., & O'Connor, K. E. 2019. Plastic waste as a global challenge: are biodegradable plastics the answer to the plastic waste problem?. *Microbiology*, *165*(2), 129-137.
- Jose, P.A., Jebakumar, S.R.D.2012. Phylogenetic diversity of actinomycetes cultured from coastal multipond solar saltern in Tuticorin, India. *Aquat.Biosyst.* 8,23.https://doi. org/10.1186/2046-9063-8-23