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House of industrially important bioactive metabolites: A review on actinobacteria

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The actinomycetes are Gram-positive bacteria present in natural habitats, most profoundly in soil, freshwater, sea water and composts. Actinomycetes have high GC (guanine-cytosine**)** content and characterized by a complex life cycle. The morphology of actinomycetes looks like fungi and the reproduction takes place either by hyphae fragmentation or by spore production in the mycelium. Actinomycetes serves as a large pool for secondary metabolites production with potent biological activities and therapeutic properties like antifungal, antibiotics, enzymatic, plant growth promoting rhizobacteria (PGPR), in xenobiotics and bioremediation. These bioactive metabolites production can be enhanced using high-throughput fermentation and by combinatorial biosynthesis during optimization. Present research should be focused on the potential of less explored actinomycetes from extreme environments that can be utilized as sustainable herald for green biotechnology. In this review, habitat, life cycle and production optimization of actinomycetes in selective media are explained but article is emphasized on biotechnological potential of actinomycetes that are relevant for industries, agriculture and allied sectors.

Keywords: Actinomycetes, secondary metabolites, enzymes, antibiotics, bioremediation, applications.

Introduction

Actinomycetes are also called actinobacteria and it is made up of two words i.e. aktis which means lightning and mykes means fungus that was initially classified as an interposed group between bacteria and fungi[1]. Actinomycetes are Gram-positive bacteria that have been placed within the phylum of actinobacteria while the class is actinobacteria, subclass is actinobacteridae and order is actinomycetales which currently consists of 10 suborders and it has more than 30 families and approximately 160 genera[2]. The important source of isolating endophytic actinomycetes is medicinal plants, which can induce secondary metabolites production which possess immense applications at industrial level. The endophytic microorganisms do not cause any direct and harmful effect while colonizing living internal tissue[3]. Although endophytic and rhizospheric are both plant-associated bacteria that give valuable effects on the host plants but endophytic bacteria are more reliable and specific as they are present within the tissues of the plant. Pyrosequencing method is used to reveal a wide range of bacteria (like actinobacteria, bacteroides, verrucomicrobia and proteobacteria) that live in and around the roots of the plant[4]. Actinomycetes are one of the most important microorganisms in microbial diversity and they are explored from a range of habitats and unusual environment that produces wide variety of useful secondary metabolites like antibiotics and immune suppressive compounds that are commercially important[5]. The bioactive potential of these bacteria facilitates their continued existence even in distress and favorable ecological conditions. The general characteristics of actinobacteria are summarized in Table 1.

Structure of Actinomycetes

Actinomycetes are filamentous and spore forming bacteria that are habitually found in soils. These bacteria contain ~57-75% of GC content in their DNA[14]. Actinomycetes are recognized by their branching and filamentous growth pattern which forms a mycelium, a very large colony of filaments which split individually to form rods or spheroidal shapes, called bacillus. The lysine is present in the peptidoglycan of actinomyces species. The other internal structures are thallus which is a tissue like mass that grows in cultures and mycelium which is tangled mass of hyphae that is found in nature and some actinomycetes can form spores. They are mainly chemo-organotrophic that grows at neutral pH but are

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Table 1 — Characteristics of actinomycetes

Genus	Aerobic/ Anaerobic	GC content (%)	Size (µm)	Morphology	Motility	Other characteristics	References
Actinoplanes	Aerobic	72-73	They have irregular size and shape, forms sporangia which are 5-18 µm in diameter	Branched mycelium and aerial growth is little and no fragments	Their spores are motile and flagella are polar	They are found in soil and decaying plant material, they are highly colored and often contain hyphae in palisade arrangement	6
Arthrobacter	Aerobic	59-70	08-12 × 10-80	Young cells are arranged in irregular rod shapes, and older cells are small cocci	Usually non-motile	Their growth cycle is rod-coccus, catalase positive, found in soil and contains respiratory metabolism	7
Bifidobacterium	Anaerobic	55-67	05-13 × 15-80	Usually curved and varied shaped rods	Non-motile	Their cells are in clubbed or branched shaped, pairs are often in V-arrangement They ferment carbohydrates to accelerate lactate production but no CO_2 generated, catalase negative	8
Corynebacterium	Facultative anaerobic	51-63	03-08 × 15-80	The rods are straight or slightly curved with clubbed ends	Non-motile	Cells are often arranged in V formation or in palisades of parallel cells, they are catalase positive, fermentative and contains polyphosphate granules	9
Frankia	Aerobic to micro aerophillic	66-71	05-20	They have no aerial mycelium and vegetative hyphae, and form multicellular sporangia	Non-motile sporangio-spores	They fix nitrogen, usually contains type-III cell walls, mostly symbiotic strains with angiosperms	6
Micrococcus	Aerobic	64-75	05-20	Cocci are in pairs and clusters are uneven	Non-motile	Usually red or yellow colour colonies catalase positive, respiratory metabolism present, found in soils and primarily on mammalian skin	10
Mycobacterium	Aerobic	62-70	02-06 × 10-10	The rods are straight and slightly curved, some are branched, acid fast and non sporing	Non- motile	Catalase positive, they form readily fragmented filaments, high lipid content walls, some species are parasitic and found in soil and water	11
Nocardia	Aerobic	64-72	05-12	Extensive vegetative hyphae that can fragmented into rod shaped and cocci forms	Non- motile	They are catalase positive and forms aerial hyphae It contains type-IV cell walls and found in soil	12
Streptomyces	Aerobic	69-78	05-20	Mycelium is vegetative and extensively branched and the chains of three to many spores are formed by aerial mycelium	Non-motile	They form discrete lichenoid or leathery colonies, that often are pigmented, respiratory metabolism is present and as a nutrient they use many organic compounds present in soil	13

also capable to grow in alkalophilic and acidophilic conditions and some of them are phototrophic, autotrophic and heterotrophic. When actinomycetes is grown on an agar-surface, then it forms a network of hyphae like branch form, growing both inside and outside of the agar. The on-the-surface hyphae are called aerial hyphae and the under-surface hyphae are called substrate hyphae. Septa normally divide the hyphae into long cells about 20 mm and longer, and having bacterial chromosomes (nucleoids). There are the aerial hyphae that expand over the substratum and reproduce asexually. Mainly actinomycetes are non-motile but restricted to flagellated spores, when motility is present. The composition of cell wall varies significantly among various groups and is of considerable taxonomic significance[15]. Actinomycetes lacks membrane bound organelles and nucleus because they are like bacteria containing double stranded DNA (ds-DNA) and ribosomes in cytosol. Many bacterial cells also contain plasmids, which are circular DNA molecules. A particular ribosomal RNA sequence i.e. 16S rRNA is present in actinomycetes. There is an incomplete mycelia development is present during active growth in actinobacteria, while in, well-matured actinobacteria, there are two types of mycelium i.e., rhizoids in the substrate and aerial mycelium on the outside substrate.

Habitat of Actinomycetes

The actinomycetes are ubiquitous and are commonly present in natural substrates like soils of garden, field, forests and the soils which comprises virgin and cultivated are the ideal source for the isolation and cultivation of actinomycetes species. They are also isolated from the sea water and sea bottom, Fresh water, lake, river water and bottom, Manures and composts, atmosphere and in food and dairy products. They are also found in bodies of plants and animals as a temporary or permanent habitat in which some are reported to cause disease in plants. But above all the sources, soil is the richest source for the isolation for actinomycetes[16].

Life Cycle of Actinomycetes

Mainly the actinomycetes are mycelioid and are Gram-positive. They start their growth as unicellular organisms but develop into branched filaments or hyphae which grow profusely by producing further branches constituting the mycelium. The width of the hyphae is usually 1 µm. The delicate mycelia often grow in all directions from a central point and produce an appearance that has been compared with the rays of sun or of a star. Therefore, the actinomycetes are also called ‘ray fungi’[17]. They often produce complicated designs and resemble some of the drawings in modern art exhibitions. The protoplasm of the young hyphae appears to be undifferentiated, but the older parts of the mycelium show definite granules, vacuoles and nuclei. Many actinomycetes at first produce a very delicate, widely branched, mycelium that may embed itself into the soil, or if grown in culture, into the solid medium. This kind of mycelium is therefore called the ‘substratum or primary mycelium’ as shown in the Figure 1.

After a period of growth, hyphae of a different kind develop which raise themselves up from the substratum mycelium and grow in the air. These are called as aerial hyphae and the corresponding mycelium is the aerial or secondary mycelium. The color of the aerial mycelium may be white, yellow, violet, red, blue, green, or grey and many form pigments that are excreted into the medium, and slightly wider than the substratum mycelium. The aerial hyphae possess an extra cell wall layer called as sheath. The hyphal tip undergoes septa formation within this sheath to form a chain of conidia. Conidial cell contains a plump, deeply staining, oval or rod-shaped nuclear body.

Optimum Conditions for the Growth of Actinomycetes Species

The maximum yield of bioactive metabolites from actinomycetes depends on the optimum parameters

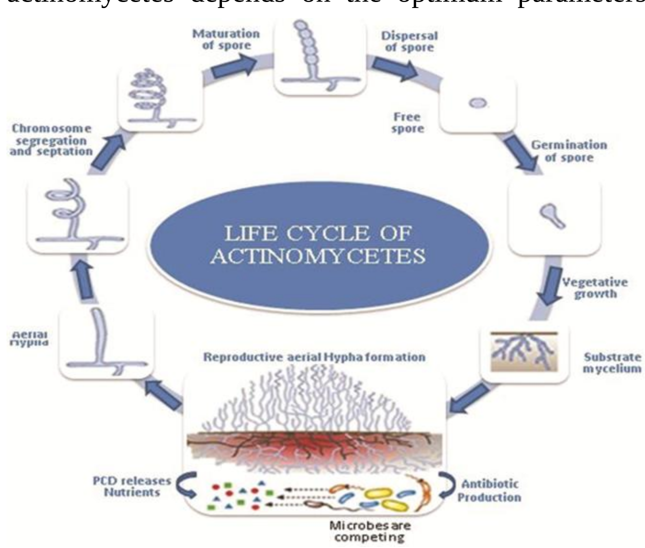

Fig. 1 — Life cycle of actinomycetes

required for the growth. Production of metabolites has been influenced by the components of medium and cultural conditions such as aeration, agitation, pH, temperature and glycerol concentration[18-19]. The streptomyces species of actinomycetes were grown better and produced the pigments on solid media in comparison of broth cultures. Also, it is very difficult to extract pigment when growth is done in liquid phase[20]. These findings indicate that choice of media, its components and the method employed for the production of metabolites from microbes play very crucial role for the production optimization especially when required at industrial scale. Selective media were used to measure the optimal conditions for the isolation of rare actinomycetes from soil using macromolecules such as casein, chitin, hair hydrolysate, and humic acid as carbon and nitrogen sources. Carbon and nitrogen ratio in media also have a reflective effect on the antibiotic production by actinomycetes[21]. Various actinomycetes and there optimum parameters are summarized in Table 2.

Table 2 — Optimization parameters for growth of actinomycetes species

Name of Actinomycetes	Sources	Different parameters		Media	References
		Temp (°C)	pH		
Actinokineospora Bangkokensis	Rhizospheric soil samples, Thailand	25-55	7-9	Water proline agar, ISP-2, ISP-9 medium	22
Actinomadura adrarensis	Saharan soil	25-37	7-10	Bennett's agar, yeast extract-malt extract agar (ISP 2), oatmeal agar (ISP 3)	23
Actinomadura oligospora	Soil collected from India	30	-	Czapek solution agar, tomato paste-oatmeal agar, yeast-dextrose agar	24
Actinomycetes	Soil	10, 45	78	Heart infusion broth	25
Actinoplanes	Red soil samples from mountain of Australia	32	68	Glucose asparagine agar, Potato dextrose agar	26
Endophytic *Actinomycetes*	*Emblica officinalis* plant	37	7	Bennet agar, starch casein broth	27
Georgenia sediminis	Sea sediment, Austria	24-60	6-10	Marine agar	28
Glycomyces harbinensis	Soil	20-40	-	Bennett agar, calcium malate agar, Czapek agar	29
Glycomyces rutgersensis	Soil	20-37	-	ATCC 172 medium	30
Glycomyces sambucus	Endophytic actinomycetes are isolated from the stem of *Sambucus adnata*	28	-	ATCC 172, Bennett agar	31
Microbacterium mangrovi	Mangrove soil of Tanjung Lumpur river, state of Pahang, Malaysia	28	4-10	ISP-2, ISP-7 media, starch casein agar	32
Micromonospora	Soil & bottom of aquatic environments	28	8	Starch-casein agar	33
Mumia flava	Mangrove soil of Tanjung Lumpur river, state of Pahang, Malaysia	28	4-10	ISP-2, ISP-7 media, starch casein agar	34
Nocardia	Soil and other natural materials	28	70	Yeast glucose agar, Bennett's agar, soil dextrose agar	35
Nonomuraea sp	Indian Coastal Solar Saltern	25-45	6-9	Starch casein agar, glycerol nitrate agar, glucose asparagine agar, ISP-3, ISP-4, ISP-5, ISP-6, ISP-7	36
Rhodococcus canchipurensis	isolated from a limestone deposit site Manipur, India	28	70	Starch casein nitrate agar	37
Rhodococcus gordoniae	clinical material and phenol-contaminated soil	28		M3 agar	38
Saccharomonospora viridis	Hot water spring, India	35-60	7-10	ATCC medium	39
Sinomonas humi	Mangrove soil of Tanjung Lumpur river, state of Pahang, Malaysia	28	4-10	ISP-2, ISP-7 media, starch casein agar	40

(*Contd*.)

Table 2 — Optimization parameters for growth of actinomycetes species (*Contd*.)

Name of Actinomycetes	Source	Different parameters		Media	References
		Temp (°C)	pH		
Streptomyces	Marine sediments & rhizosphere soil	10-50	20-80	Starch-casein nitrate agar	41
Streptomyces calidiresistens	Hot spring sediment, South West, China	40-65	7	Starch mineral salt agar	42
Streptomyces flavofuscus	Soil samples of Madhya Pradesh	35	4-10	Starch-casein broth medium	43
Streptomyces sp	Marine sediments & rhizosphere soil	30	76-8	YMG agar & starch-casein agar	21
Streptomycetes	Forest soil	25	72	Starch-casein medium	44
Thermoactinomyces daqus	Isolated from high-temperature Daqu	55	5-10	Streptomyces Project (ISP) medium 2	45
Thermotunica guangxiensis	Mushroom residue compost	37-65	6-9	ISP2, ISP3, ISP4, ISP5, ISP6 and ISP7 media	46

Biotechnological Potential of Actinomycetes

The secondary metabolites which are produced by microbes have been received much attention, especially in the beneficial effects of human health, due to their useful biological activities. Actinomycetes have various chemical structures and biological activities by which they are playing an important role in the drugs and medical industries by their secondary metabolites producing capacity. About 23,000 of active secondary metabolites were produced by microbes, in which 10,000 were isolated from the species of actinobacteria. Among them, *Streptomyces* species were produce ~7,600 bioactive compounds, depending on the isolation and biological function of actinomycetes[47]. Many bioactive metabolites have been isolated and characterized and many of them have been developed into drugs for treatment of many diseases in human, veterinary, and agriculture sectors[48-50]. Therefore, the actinobacteria are considered to be the most potential source of secondary metabolites, antibiotics, enzymes and other bioactive compounds. It is well recognized that each actinobacterial strain has genetic potential ability to produce 10-20 secondary metabolites[51-52]. The vast majority of actinobacteria can produce many biologically active compounds, i.e. antibacterial, antiviral and antifungal agents. It has been estimated that more than 90% of antibiotics that are used today were originated from actinobacteria. It is also estimated that about two-third of the substances are bioactive and of microbial origin produced by this group of bacteria[53]. *Actinomycetes*, particularly from the genus of *Streptomyces*, has been widely known as antibiotic producers, such as streptomycin (*Streptomyces griseus*), erythromycin (*Streptomyces erythrus*), chloramphenicol (*Streptomyces venezuelae*) and tetracycline (*Streptomyces aureofaciens*)[54]. There are many secondary metabolites of bioactive substances that are produced by actinomycetes and these metabolites are known to possess antibacterial, antifungal, antioxidant, anti-cancer, anti-algal, anti-helminthic, anti-malarial and anti-inflammatory[55-56]. Many researchers are involved in the study of the bioactivities and industrial applications of actinobacteria as it is attractive source of novel bioactive compounds[57-60]. The researchers are paying much attention on actinomycetes because they can produce a lot of natural drugs, bioactive metabolites, including antibiotics, enzymes, enzyme inhibitors, antimicrobial substances, immunomodifiers, and growth promoting substances, etc. for plants and animals as summarized in Figure 2.

Antibiotics

Actinomycetes are the greatest source of antibiotics. Two third of today's antibiotics are obtained from actinomycetes. These antibiotics are best recognized and most valuable. The essential antibiotics from actinomycetes include anthracyclines, aminoglycosides, β-lactams, chloramphenicol, macrolides, tetracyclines, nucleosides, peptides and polyethers, amphotericin, nystatin, gentamycin, erythromycin, vancomycin, novobiocin, neomycin (Table 3).

Enzyme Production

Actinomycetes involves in the production of variety of enzymes like amylase, catalase, cellulase, l-asparaginase, lipase, urease, protease, chitinase, etc. Figure 3 describes the role of enzymes in various sectors of biotechnology which are produced by actinomycetes. Table 4 describes the source and optimum conditions of temperature and pH required for the production of actinomycetes.

Bioactive Compounds from Actinomycetes used as Bio-pesticide Agents

As the contamination of environment increases by poisonous chemicals, researchers are doing many efforts for controlling pest populations and it becomes investigation priority. Actinomycetes are playing an important role in insect's biological control against housefly by producing insecticidal active compounds[83].

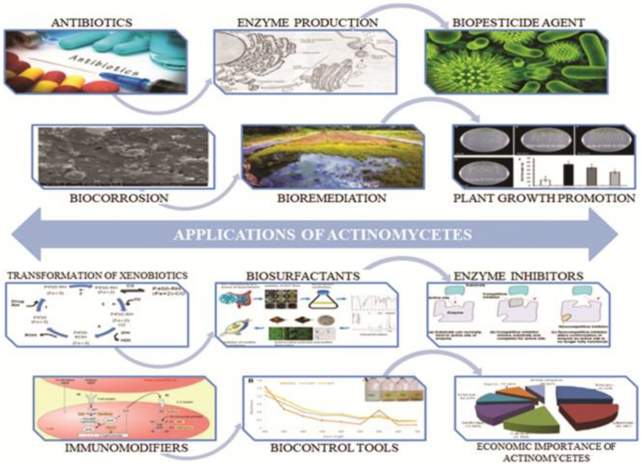

Fig. 2 — Biotechnological applications of actinomycetes

Role of Actinomycetes in Biocorrosion

An electrochemical reaction between the environment and a material takes place which alters the properties of the material and impairs its function, called as corrosion[84]. Microbial corrosion or microbial induced corrosion is another name of biocorrosion.

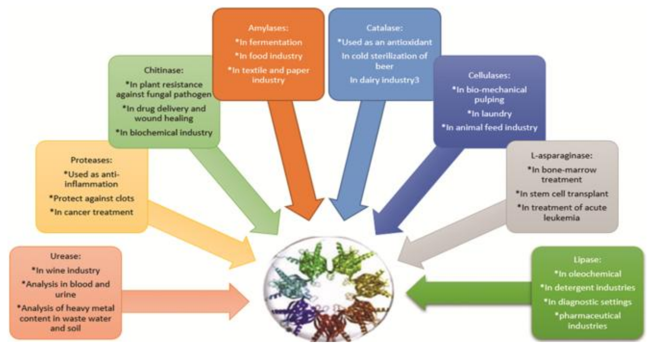

Fig. 3 — Applications of enzymes produced from actinomycetes

Table 3 — Antibiotics produced by actinomycetes

Actinomycetes species	Name of antibiotics	Action of antibiotics	References
Streptomyces venezuelae	Chloramphenicol	Typhoid, typhus, whooping cough, atypical pneumonia, bacterial urinary infections	61
S. fradiae	Neomycin, Fosfomycin	Antibacterial against Gram-negative bacilli and some Gram positive bacteria	62
S. griseus	Streptomycin	Meningitis, pneumonia, tuberculosis and local infections	63
S erythreus	Erythromycin	Typhoid, common pneumonia, diphtheria, whooping cough	64
M. inyonensis	Mutamicin and netilmicin	Used in the treatment of Gram negative aerobic infections	65
M. inositole	Sisomicin	Conjunctivitis, keratitis and shows greatest activity against Gram positive bacteria	66
S. nashvillensis	Tetrodecamycins	Shows antimicrobial activity against Gram positive bacteria	67
Micromonospora	Micromonohalimanes A, B	Malaria and fungal infections	68

Table 4 — Enzymes produced by actinomycetes

Sl. No.	Enzymes	Actinomycetes sp	Optimum temperature and pH	References
1	Cellulase	*Streptomyces ruber*	6 and 37°C	69
		Thermobifida halotolerans	7 and 45°C	70
2	Protease	*S. pactum*	75 and 40°C	71
		S. thermoviolaceus	65 and 65°C	72
3	Keratinase	*Actinomadura keratinilytica*	10 and 70°C	73
4	Amylase	*S. erumpens*	9 and 45°C	74
		Thermobifida fusca	6 and 60°C	75
5	Xylanase	*Streptomyces* spp	9 and 50°C	76
		Actinomadura sp	4 and 70°C	77
6	Lipase	*S. exfoliates*	6 and 37°C	78
		N. alba	7 and 30°C	79
7	Chitinase	*S. thermoviolaceus*	6 and 60°C	80
		Nocardiopsis prasina	7 and 55°C	81
8	Pectinase	*S. lydicus*	65 and 45°C	82

This is an electrochemical process in which microbe's starts, facilitate, or accelerate a corrosion reaction on a metal surface[85]. A wide range of microorganisms are found in almost each and every area of oil production and these microbes are mainly isolated from water injection plants, drilling mud, and live reservoir cores[86-88].

Bioremediation by Actinomycetes

In our daily life, petroleum hydrocarbons are broadly used as chemical compounds and fuel. Due to the excessive use of petroleum and its products, it becomes the universal contaminants of large soil surfaces and ultimately it is measured as a most important environmental problem[89]. The hydrocarbons degraded in the environment by many ways, in which one mechanism is bioremediation, by which they can be removed from the environment. The use of soil microbes to degrade pollutants to non-toxic substances is called bioremediation[90]. Actinomycetes have immense potential for bioremediation of soils which are contaminated by organic pollutants, thus play a significant role in recycling of organic carbon and degradation of complex polymers [91].

Actinomycetes as Plant Growth Promoting Agents

Actinomycetes are the major components of rhizospheric microbial population and are useful in soil nutrient cycling and plant growth promotion[92]. Actinobacteria are commonly resided in rhizosphere due to their interactions with plants and such type of interactions is possible since they are behaving as plant growth-promoting rhizobacteria (PGPR). As PGPR, actinomycetes acquired an essential mechanism that favors growth and development of plants. Actinobacteria improves the accessibility of natural resources, synthesized plant growth regulators, and are able to inhibit phytopathogens[93]. Actinomycetes are also used for direct and indirect mechanisms to influence the plant growth and protection[94].

Role of Actinomycetes for Transformation of Xenobiotics

Transformation of xenobiotics is defined as the structural modification of components foreign to an organism's metabolism, which occurs in its environmental niche. The majority chemical reactions that occur during the transformation of xenobiotics are oxidative, reductive, hydrolytic, dehydration and condensation. Actinobacteria can perform a diversity of microbial conversions of organic compounds in a significant manner that includes complicated process of biodegradation of pollutants in soil and water. *Nocardia* and *Streptomyces* species have capability to carry out extremely selective chemical modifications of complicated compounds of natural and synthetic origin. *Nocardia* strains have been established to degrade aromatic hydrocarbons by hydroxylation. Actinomycetes have the ability to hydroxylate aliphatic chains of hydrocarbons in the terminal and subterminal position and subsequently followed by shortening of the transformed chains. Actinomycetes have ability to degrade positive pesticides. The herbicide, dalapon, 2, 2-dichloropropionic acid was degraded by *Nocardia* strains isolated from soil[95].

Actinomycetes as Biosurfactant

A surface-active molecule which is produced by living cells, mainly by microorganisms, is called as biosurfactant. The term biosurfactant has been used to refer any compound i.e., synthesized by microbes having several influences on interfaces. The evaluation of biosurfactants is carried out through surface tension measurements. The term's surfactant and emulsifier are frequently used interchangeably. Biosurfactants comprises a lot of benefits on their chemically synthesized counterparts. They are very specific, biodegradable and non-toxic. They are helpful at extreme conditions of temperature, pH and salinity and easy to synthesize from cheaper and renewable feed stocks. Actinomycetes play major role in production of bioemulsifiers. Trehalose dimycolates produced by *Rhodococcus erythropolis* has been extensively studied by Wagner and his group[96-98].

Actinomycetes as Enzyme Inhibitors

Actinomycetes also synthesize various enzyme inhibitors of low molecular weight. The first low molecular weight enzyme inhibitor was produced by a *Streptomycetes* strain[99]. Since then, more than 60 enzyme inhibitors have been reported which includes leuprptins, antipain (inhibit papain), plasmin, trypsin, chymotrypsin, and cathepsnin B. In the treatment of cancer, the enzyme inhibitors are finding possible role like streptonigrin, retrostatin and revistin from *Streptomyces* species that inhibit reverse transcriptase. Alistragin found in culture filtrates of *Streptomyces roseoviridis* which inhibits carboxypeptidase B. Phosphoramiden, inhibits metallo proteases and is produced by *S. tanashiensi*[100].

Actinomycetes as Immunomodifiers

From the culture filtrates of actinomycetes, low molecular weight compounds have been isolated, which enhance the immune response; these agents are called "immuno-modifiers". The inhibitor of enzymes which are situated on the cell surface, are involved in immunity and may bind to such cells and expands immune responses. Immunosuppressive agents such as FR-900506 reported by Fujisawa Pharmaceutical Company, produced by *Streptomyces tsukubaensis*[101] shows stronger inhibition against interleukin-2 production, mixed lymphocyte reaction, interferon, cytotoxic T-cells and platelet activating factor-C induction[102].

Actinomycetes as Biocontrol Tools

Now a day's actinomycetes are widely used as biocontrol agents. The major example of biocontrol agent is *Streptomyces griseoviridis* strain K61. *Streptomyces* strains also have important applications in the agricultural field through their biological control potential against phytopathogens, particularly against phytopathogenic fungi[103].

Actinomycetes used in Nitrogen Fixation

The *Frankia* family (species of actinomycetes) works in a symbiotic relationship with many non-leguminous plants as nitrogen fixing bacteria. *Frankia* is the first identified endophytic actinomycetes which fix nitrogen to form actinorrhizae[104]. The natural nitrogen cycle relies on nitrogen fixing bacteria like those found in the *Frankia* family of actinobacteria to supply the fixed nitrogen. About 15% of the world's nitrogen fixed naturally in symbiotic relationships between various species of the *Frankia* and their host plants that is able to fix N_2 (even in free-living conditions) by developing a vesicle, which is a spherical cell devoted to nitrogen fixation[105].

Role of Free Living Actinobacteria in Carbon Cycling

The free-living actinomycetes also contribute to carbon cycling in environments that are enriched in decaying plant material, compost, and manure etc[106]. Actinomycetes are enriched in the full suite of enzymes necessary to deconstruct plant biomass, in comparison of most other phyla of bacteria[107]. It majorly includes chitin, which is a structural polymer in the cell wall of fungi and in the exoskeletons of invertebrates. Actinobacteria, like *Streptomyces* and *Arthrobacter* species, have the ability to degrade chitin with the help of chitinase enzyme[108-109].

Actinobacteria in Bioenergy

It has been surveyed in 2013, that fossil fuels (petroleum, coal and natural gas) supplied 80% of the world's energy[110]. Negative climate impacts of this data are that burning of fossil fuels generates tremendous amount of pollution and thereby driven worldwide interest in research regarding sustainable, economical production of fuels from other biodegradable sources[111-112]. Plants and many microbes capture the energy of the sun via photosynthetic carbon dioxide fixation. Microbes are even engineered to produce fuels in specific environments in an economical way[113-115]. However, to develop a sustainable biofuel industry, microbes are needed to convert plant biomass into soluble sugars and to transform these sugars into a wide range of desirable compounds[116], and in both these tasks actinobacteria have profound potential and thereby producing energy using agro-industrial wastes.

Application of Actinobacteria in Nanotechnology

Inorganic materials are fabricated by actinobacteria by any of the method; extracellular or intracellular by delicate method in nanoscale dimensions. In the recent years, fungal infections become very common and also silver nanoparticle appeared as a potential antifungal agent. For the antifungal activity, synthesized gold nanoparticles were tested by the means of well diffusion method against *Microsporum gypseum* (10 ± 0.47 mm) and *Trichophyton rubrum* (13 ± 1.03 mm). Chemotaxis can be increased in the early phase reaction with the help of gold nanoparticle. Silver nanoparticle bring into being for the disruption of biofilm formation with the help of nanobiotechnology that permit for the competent utilization of the anti-fouling behavior of silver in the form of silver nanoparticles. Karthik *et al*. reported that biogenesis of silver nanoparticle from marine actinobacteria using *Streptomyces* sp. LK3 illustrate larvicidal activity against *Rhipicephalus microplus* and *Haemaphysalis bispinosa*[117-118].

Anti-cancer Properties of Actinobacteria

In the recent years, cancer becomes one of the most important reasons for the human death with more than 10 million per year. With the minimum costs and side effects, nanotechnology proposes assets of tools to analyze and treat cancer. Manivasagan *et al* (2013) reported that by means of novel *Nocardiopsis* sp. MBRC-1 which was isolated from the marine sediments samples from Busan, South Korea are used for the biosynthesis of nanoparticle. The shape and size of the particle are spherical and 45 ± 0.15 nm, respectively. The biosynthesized silver nanoparticles shows evidence of healthy antimicrobial activity against fungi and bacteria and also demonstrate *in vitro* cytotoxic effect against the HeLa (human cervical cancer) cell line with an IC_{50} value of 200 mg/ml[119].

Economic Importance of Actinomycetes

Actinomycetes gained the maximum importance in recent years as producer of therapeutic substances. They have capability to synthesize the metabolites which obstruct the development of bacteria and so are called antibiotics. Actinomycetes become more or less harmless when introduced into the human or animal body but are harmful to bacteria. Antibiotics have in modern time have great therapeutical and industrial value. Actinomycetes, as a producer of many industrially important substances, the past decade has seen considerable interest in the successful use in chemotherapy of streptomycin, chloromphenicol, aureomycin and terramycin, all are metabolites of the actinomycetes. It has stimulated the search for new actinomycetes and new antibiotics among the actinomycetes.

Conclusion

Actinomycetes are ubiquitously present in natural environments like in soil, water and dead remains of plants and animals. But the research studies on actinomycetes are very limited especially in terms of microbial habitats of rhizospheric soil. Actinomycetes serve as a promising source for natural products, antibiotics, enzymes and many other commercially important secondary metabolites. Thus actinomycetes play a vital role in pharmaceuticals, agriculture, biorefineries, food, textile, pulp and paper to get rid of various challengeable problems. And also it helps in promoting the plant growth in field condition, so it is highly considered as an important area for future research. Progress should be made to isolate novel actinomycetes from rhizospheric habitats to obtain new secondary metabolites that can be used for multiple types of biotechnological applications.

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