*ISBN: 978-93-90847-97-6*

# 3. The Salubrious Role of Actinomycetes Towards Plant Growth: A Step Towards Sustainable Agriculture

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***Abstract:***

*Sustainable agriculture implies the use of environmentally benign processes to increase crop productivity. Microbes nourish the soil and increase nutrient availability for crops without distorting the environment. Actinomycetes are a group of prokaryotic gram-positive bacteria that have been linked to increased agricultural productivity by producing a wide range of growth promoting compounds that aid in the growth of agricultural crops while also acting as a biocontrol agent. Besides actinomycetes have the ability to follow both direct as well as indirect ways to promote plants growth. They are capable to produce growth inducing compounds that assist in $N_2$ fixation, indole 3-acetic acid production (IAA), phosphate solubilizations, siderophore production, etc. The actinomycetes are also competent to reduce the biotic as well as abiotic stresses and protect the crops from harmful pathogens. Furthermore, actinomycetes are known to elute certain growth promoting compounds that not only assist in growth and development of the crops but also enable them to withstand harsh environmental conditions like drought, salinity, waterlogging etc. In the present chapter, we intend to discuss on the significant role of actinomycetes in enhancing soil health, suppressing pathogens, and increasing crop production by their direct and indirect mechanisms. Furthermore, we will briefly discuss the current applications and benefits of using actinomycetes for sustainable agriculture.*

***Keywords:*** *Sustainable agriculture, crop productivity, actinomycetes, biocontrol agent.*

## 3.1 Introduction:

The copy warned the Little Blind Text, that where it came from it would have been rewritten with declining soil nutrition, conventional agriculture is struggling to meet the food needs of growing population around the world. However to restore depleting soil nutrition, reliance on the use of harmful and toxic chemical fertilizers have also increased. (Djebaili *et al.*, 2020).

The excessive use of toxic chemical fertilizers thus enter into the food cycle which eventually led to development of many human diseases and ecological disparity. The natural way to replenish the soil nutrition is a slow and time consuming process which thus impact the overall food production. (Abbamondi *et al.,* 2016). The burgeoning of the human population has led to the rise in the food demand, in contrary to inadequate supply of food (Djebaili *et al.,* 2020; Hamedi *et al.,* 2015). To bridge the gap between the supply and demand of the food a sustainable approach towards agriculture is the most pressing need. Though to some extent the need has been fulfilled by the genetically modified crops (GMO) but required to supplement with chemical fertilizers for their growth (Dalal *at al.,* 2014; Rojas e*t al.,* 2014). Therefore, an eco-friendly and sustainable approach is required to scale up the crop production using microbes that are capable of supplementing the plants with a plethora of growth regulators and defence towards pathogen (Gopalakrishnan *et al.,* 2015).

In the late 1970s, Kloepper and co-workers coined the term plant growth-promoting rhizobacteria (PGPR) to describe isolated bacteria from the rhizosphere (Kumar and Jacob, 2019). Furthermore, De Bary (1866) have coined the term "Endophyte" for the microorganisms that are present inside the plant tissue. (Compant *et al.,* 2012).

Actinomycetes, also called Actinobacteria, are consider to be an intermediate group between fungi and bacteria. The name Actinomycetes was derived from Greek word *aktis* (a ray) and *mykes* (fungus) due to its close morphological resemblance to fungus. They are free living bacteria characterized by tough powdery and pigment forming colonies (Srinivasan *et al.,* 1991).

The rhizospheric and endophytic actinomycetes have a wide range of natural bioactive chemicals that provide plants with different nutrients, hormones required for their growth. The bioactive compounds also protects the plant from any phytopathogens.

The rhizospheric and endophytic actinomycetes possesses an arsenal of various natural bioactive compounds. The bioactive compounds from actinomycetes provides the plants with required nutrition for their growth, various hormones necessary for developments in plants and the antibiotics required to fight against phytopathogens. (Qin *et al.* 2015; Shan *et al.,* 2018).

Plant Growth promoting Actinobacteria (PGPA) have the ability to induce various mechanisms to supress the harmful pathogens by production of lytic enzymes, siderophores, antibiotics and various biometabolities. Also PGPA assist the plant to overcome various abiotic stress such as water scarcity, heavy metal toxicity, depletion of soil nutrition, salinity etc. by several mechanisms. The various PGPA mechanisms comprises of regulating the ethylene level in plants by production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, Nitrogen fixation, siderophore production etc. (Anwar *et al.,* 2016). Thus, in this chapter we are going to discuss about the PGP activity of the actinomycetes, its antagonist activity against wide variety of plant pathogens and the biometabolities that support the growth and development in plants.

## 3.2 Actinomycetes and Its Role as Plant Growth Promoters (Pgps):

Plant growth is governed by various biotic and abiotic factors (Figure 1) that impact the total crop production. To overcome these obstacles use of synthetic fertilizers has increased over the past few years which had led to different environmental pollutions. Actinomycetes are ubiquitous groups of microorganisms that are widespread in diverse ecosystems around the world. (Djebaili *et al.,* 2020).

They are the active producer of various economically important bioactive compounds. They covers 70 to 80 % of the commercially available antibiotics. (Srinivasan *et al.,* 1991; Lacey 2008). Other antibiotic producing genus includes *Micromonospora*, *Actinomadura*, *Streptoverticillium* and *Thermoactinomycetes* (Colquhoun *et al.,* 1998, Waksman, 1954).

Actinomycetes occur both as rhizospheric bacteria and as endophytic bacteria. They are an excellent source of biometabolities which promote plant growth and ensure its good health using its direct and indirect PGP traits (as shown in Figure 2). Furthermore, actinomycetes assist the plant growth by production of phytohormones such as indole-3-acetic acid (IAA) (Franco-Correaa *et al.,* 2010; Rungin *et al.*, 2012). Moreover, actinomycetes exhibits antagonist activity against a wide range of plant pathogens by production of beneficial enzyme such as chitinase, ACC deaminase, wide range antimycotics and antibiotics. Moreover, they also have the ability for phosphate solubilization, HCN production and nitrogen fixation (Sreevidyaa *et al.*, 2016; Chukwuneme *et al.*, 2020).

It has also been reported that strains of various genera belonging to Actinobacteria have the ability to produce IAA. Report suggest various actinobacterial strains such as VAI-7; VAI 40; SAI 13; SAI 29, *S. pseudovenezuelae* (MG547870), *A. arilaitensis* (MG547869) and *Streptosporangium becharense* SG1 are excellent producers of indole-3-acetic acid (IAA). (Sreevidyaa *et al*., 2016; Chukwuneme *et al.*, 2020; Boukaya *et al.*, 2018).

As an endophytes, actinomycetes grow a symbiotic association with the host plant and internalize the tissue without harming the host. Furthermore, endophytic actinomycetes have played a significance role in plant growth by supressing various phytopathogens and secreting various beneficial biometabolities. Endophytic actinomycetes such as *Streptomyces mutabilis* NBRC $12800^T$, *Streptomyces cyaneofuscatus* JCM $4364^T$, *Streptomyces asterosporus* NRRL B-$24328^T$ have been investigated to eliminate plant disease such as damping of *R. solani, Fusarium* root rot along with additional biological activities and PGP traits (Goudjal *et al.*, 2013; Goudjal *et al.*, 2016). Actinomycetes are able to produce Polyamines (PAs) which are a low molecular weight bioactive compounds and reported to produce by both animal as well as plants. Two variant of the actinomycetes strains of *Streptomyces griseoluteus* had been studied which includes PNPM (Polyamine non-producing mutant strain) and wild type isolate (WT). The PNPM was incapable to promote plant growth whereas when WT variant was used it showed significant plant growth due to the activation of various plant growth regulators that includes IAA, $GA_3$. (Nassar *et al.,* 2003). So the study provides an important link between the Polyamines that supports the PGRs traits. Actinomycetes are therefore an indispensable part of future sustainable agriculture.

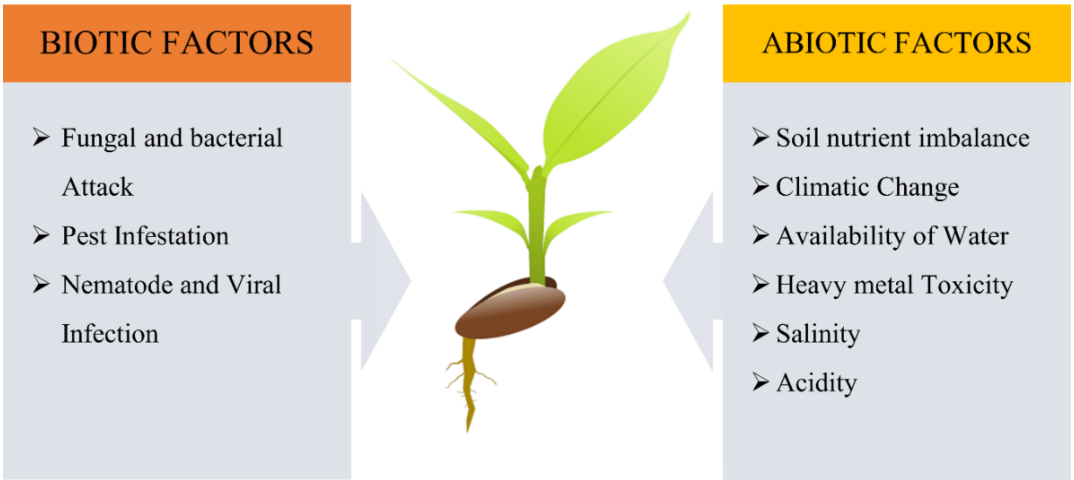


**Figure 3.1: Schematic illustration for biotic and abiotic stress in plants.**

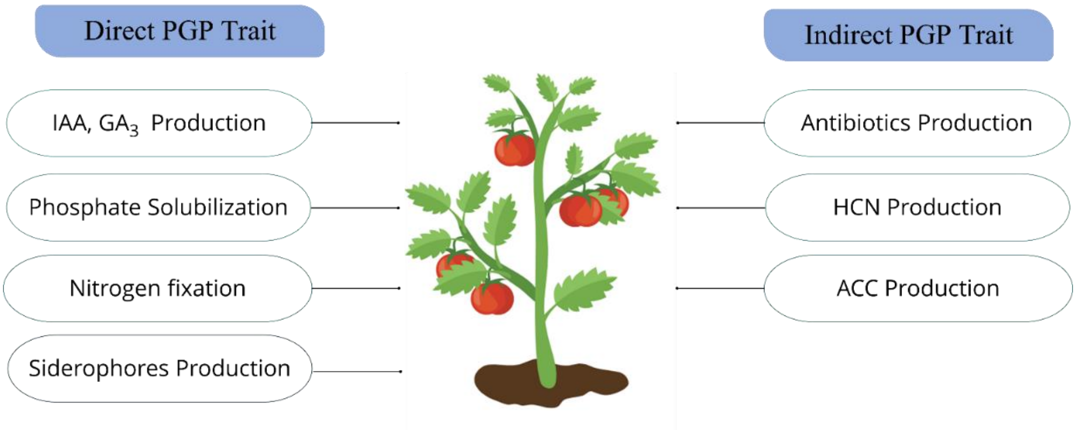


**Figure 3.2: Schematic diagram for the direct and indirect PGP traits.**

## 3.3 Actinomycetes Traits as Plant Growth Promoter:

### 3.3.1 Indole-3-Acetic Acid (Iaa) Production:

Auxin is one of the most important plant hormones essential its growth and development. Auxin is required to regulate physiological process such as ontogeny, organogenesis, vascular differentiation, and root and shoot formation, fruit ripening etc. Among all phytohormones of the Auxin class, indole-3-acetic acid (IAA) is the most common naturally occurring hormone involved in plant growth and development. IAA producing strains have been successfully isolated from both the rhizospheric soil as well as from different parts of plants (Kudoyarova *et al.*, 2019; Canellas and Olivares, 2014). Lasudee *et al.* (2018), reported to have isolated IAA producing actinomycetes strain *S. thermocarboxydus*, from the spores of *Funneliformis mosseae* an Arbuscular mycorrhizal fungi (AMF).

The AM fungi and the actinomycetes formed a symbiotic relationship that had also benefited the host plant. *S. thermocarboxydus* showed excellent PGP traits when inoculated with Thai jasmine rice under low soil nutrition and induced drought stress. (Lasudee *et al.*, 2018).

Jog *et al.* 2014, isolated five strains of *Streptomycetes sp.* from both the rhizospheric soil and roots tissues of *Triticum aestivum* which were capable to produce PGPs traits including IAA, phytase etc. (Jog *et al.*, 2014). Therefore, along with other PGP traits, IAA helps the plant resist stress and improve plant growth.

### 3.3.2 Gibberellins Production:

Gibberellins are naturally occurring phytohormones belonging to the class of diterpenoid which play a pivotal role in healthy modification of plants. Gibberellins improves the growth of plant tissue along with cell elongation. (Vandenbussche *et al.*, 2007). Solans *et al.*, (2011) reported to isolate saprophytic actinomycetes from the actinorhizal plant (*Ochetophila trinervis)*.

The isolated actinomycetes belongs to the genus *Streptomyces, Actinoplanes* and *Micromonospora*. The roots of *O. trinervis* were inoculated with different genera of actinobacteria separately and in combination to establish the co-inoculation effect on the plant growth. The result revealed the development of intense root hairs with different shapes. The presence of Gibberellic Acid ($GA_3$) was confirmed in the study using GCMS analysis. (Solans *et al.*, 2011). According to Nassar *et al.* (2003) the variant WT of actinomycetes strain *Streptomyces griseoluteus* have been reported to produce number of plant growth regulator including gibberellic acid ($GA_3$). $GA_3$ was found significantly in the root and the shoot of *Phaseolus vulgaris* L. (Nassar *et al.*, 2003). Therefore $GA_3$ produced by the actinomycetes strains have significant effect in plant growth promotion and overall health.

### 3.3.3 Phosphate Solubilization by Actinomycetes:

Phosphorus is an essential nutrient for the plant growth and development and are naturally present in the soil. Microbes have the ability to solubilize the mineral form of phosphorus making it freely available for plants. (Romero-Perdomo *et al.*, 2021). Actinomycetal strains belonging to the genus *Streptomyces* have been reported to possess the ability to solubilize the phosphate from the soil.

The strains isolated from the rhizospheric region of *T. repens* were reported to solubilize inorganic phosphate from the soil. Actinomycetes able to solubilize phosphate in the soil with the help of phosphatase enzyme. The strains MCR26, MCR9 and MCR24 showed a correlation and synergistic effect with the Arbuscular mycorrhizal (AM) *Glomus mosseae* in terms of plant growth and Phosphate acquisition. (Franco-Correaa *et al.*, 2010). Minima *et al.*, (2018) have also reported to isolate a total of 191 number of actinomycetes strains from the roots and stem of Rice plant (*Oryza sativa* L.) majority of which were capable of solubilizing phosphate belongs to the genera of *Streptomyces*. Other actinomycetes genera involve in solubilizing phosphate are *Actinomadura*, *Actinomycetospora*, *Kribbella*, *Microbispora*, *Nocardia* and *Pseudonocardia* (Mingma *et al.*, 2018).

### 3.3.4 Nitrogen Fixation:

Nitrogen is considered to be a vital element required by plants for their normal growth and development. The Nitrogen is the main constituent found in chlorophyll, thus is an imperative element in the development of photosynthetic components in the plant cell. (Bassi *et al.*, 2018). Franco-Correa *et al.*, (2010) reported that actinomycetes with the nitrogen fixing ability can grow on N-Free media indicating the ability to fix Nitrogen (Franco-Correaa *et al.*, 2010). The various strains of actinomycetes capable of fixing N includes *Frankia sp.*, *Streptomyces thermoautotrophicus* UBT1 (Valdés *et al.*, 2005).

Furthermore, studies suggests that bacteria belong to the group *Frankia* when inoculated with the actinorhizal plants in a nutrient deficient environment improves the plant growth and development. (Diagne *et al.*, 2013). Therefore, actinomycetes are an invaluable source for nitrogen fixation, thus supporting plant growth promotion (PGP).

### 3.3.5 Siderophore Production:

Siderophore are low molecular weight organic compounds with metal chelating activity. The name Siderophore was derived from Greek word meaning '*iron carrier'* and have a high specific affinity towards iron. Many microorganisms are able to produce siderophores which in return help them to acquire iron as a source of nutrients from the environment. (Ahmed *et al.*, 2014). According to Rungin *et al.* (2012), actinomycetes strain Streptomyces *sp.* GMKU 3100 which is able to produce siderophore has induced the root and shoot growth of rice and mungbean plants. Literature studies suggest that siderophore producing actinobacteria develop antagonist activity against phytopathogens (Rungin *et al.*, 2012). The two *Streptomyces* strains UPMRS4 and UPMRS28 isolated from the rhizospheric soil of both healthy and blast infected rice plants has also been reported to produce siderophores (Awla *et al.*, 2017). Dimkpa *et al.*, have successfully isolated a Nickle resistant strain *Streptomyces acidiscabies* E13 which have the ability to produce siderophore under nickel stress. The *S. acidiscabies* E13 produce hydroxamate siderophore such as DFOB, DFOE and Cch in the presence of Ni and absent of Fe in the media. (Dimpka *et al.* 2008). Verma at *al.*, (2010) studied the three *Streptomyces* strains isolated from the root of *Azadirachta indica* that were capable to produce siderophore and have exhibited antagonistic activity against *Alternaria alternate* (Verma *et al.*, 2011) Therefore, actinomycetes are an excellent source for the production of siderophores and plays a vital role as plant growth promoters.

### 3.3.6 Antibiotics Production:

Actinomycetes are the biofactories for the production of numerous bioactive metabolites. Control of phytopathogens by production of antibiotics is one of the PGP trait of actinomycetes. Both the endophytic as well as rhizospheric actinobacteria are reported to have showed antagonistic activity against bacterial and fungal strains. Samac *et al.,* (2003) reported the antibiotic producing strain of actinomycetes that was able to colonise *Medicago sativa* L. plants and inhibits the growth of *Phoma medicaginis* var. *medicaginis.* (Samac *et al., 2003*). Similarly, *Streptomyces philanthi* RM-1-138 which has been reported to inhibit the growth of fungal pathogen *R. solani*. *Streptomyces violaceusniger* strain YCED-9 have also showed antagonist activity against a broad range of fungal pathogens. The strain produce polyene-like compounds similar to guanidylfungin A, nigericin, and geldanamycin

(Trejo-Estrada *et al.*, 1998). Thus, antibiotics produced by actinomycetes can be incorporate in near future as biologically control agent (BCA) in agricultural practice thus eliminating the use of harmful pesticides.

### 3.3.7 Hcn Production:

Hydrogen cyanide (HCN) is a volatile secondary metabolites. As reported the HCN is a toxic compounds use to counter the phytopathogens of plants. Goudjal Y *et al.*, 2016, isolated HCN producing *Streptomyces sp.* strain from roots of *S. nigrum*. The strain has further been reported to show antagonistic activity against pathogenic fungi such as F. *oxysporum* f. sp. *radicis* lycopersici, *F. solani* and *F. oxysporum*, (Goudjal *et al.*, 2016). Other reported actinobacterial strains equipped with HCN production are *Streptomyces sp.* UPMRS4 and *Streptosporangium becharense* SG1 (Awla *et al.*, 2017; Boukaya *et al.*, 2018). Therefore, HCN is an essential candidate that promotes growth and protects the plant from unwanted microbial attacks.

### 3.3.8 1-Aminocyclopropane-1-Carboxylic Acid (ACC) Deaminase Activity by Actinomycetes:

ACC (1-aminocyclopropane-1-carboxylic acid) deaminase activity is one of the crucial activity involving the growth and development of the host plant. ACC which is an immediate precursor for the ethylene production are secreted by plants root exudates under abiotic and biotic stress condition (Zarei *et al.*, 2020). According to the Chukwuneme *et al.*, (2020) when ACC gets cleaved to ACC Deminase it release α-ketobutyrate and ammonia in the process which can be measured to determine the ACC deminase activity. In the study it was observed *Streptomyces pseudovenezuelae* was the highest producer of deminase activity (0.903 ± 0.024 μmol αKB mg−1 h−1). Other actinobacterial strains includes *A. arilaitensis* , *Streptomyces indiaensis*, *M. oxydans*, *Streptomyces spp*., *S. werraensis* and *S. luteogriseus* respectively (Chukwuneme *et al.*, 2020).

The Actinomycetes strain *S. thermocarboxydus* isolated from the spores of *F. mosseae* an Arbuscular mycorrhizal fungi (AFM) that are used widely in horticulture as a bioinoculant. The Actinomycetes strain is capable to produce ACC deminase when grown on DF salt medium supplied with ACC as sole nitrogen source. Furthermore, the ACC deminase equipped bacteria provides the host plant to withstand in water deficient environment. The strain *S. thermocarboxydus* produce both ACC and IAA which synergistically induce growth promotion in Rice (*Oryza sativa*) KDML105 under induced drought stress. (Lasudee *et al.,* 2018)

## 3.4 Conclusion and Future Applications:

The book chapter has unequivocally exemplified the multifunctionality of actinomycetes in the field of sustainable agriculture. Actinomycetes possess diverse sets of plant growth promoting traits without exerting any negative impact into the environment. Actinomycetes have also exhibited the symbiotic relation between the bacteria and the Arbuscular Fungi which will revolutionized the agriculture sector by providing multifarious ways to resolve issues related to crop improvement. The literature study suggest that the plant growth promoting actinomycetes can be used as a bioinoculant to improve crop yields as well as induce disease resistant capabilities to the plant. Using bioinoculant as a substitute for chemical fertilizer will reduce the environmental pollution and its harmful impact in humans. Also actinomycetes plays a major role in strengthening the plant to withstand various abiotic and biotic stress. Thus, actinomycetes is the future for sustainable agriculture.

| **Actinomycetes Strains** | **Isolation source** | **Plant Growth promoting Trait** | **PGPR Trait on inoculated Plant** | **References** |
|---|---|---|---|---|
| *Streptomyces mutabilis* NBRC 12800T and *Streptomyces cyaneofuscatus* JCM 4364T | Plants root of Cleome Arabica; *Astragallus armatus* | Antifungal*;* Biocontrol of *R. solani* damping-off | *R. solani* | Goudjal *et al.,* 2013 |
| *Streptomyces sp.* strains VAI-7;VAI 40; SAI 13; SAI 29 | Herbal vermicompo st | IAA-Production | Chickpea. | Sreevidyaa *et al.*, 2016 |

| **Actinomycetes Strains** | **Isolation source** | **Plant Growth promoting Trait** | **PGPR Trait on inoculated Plant** | **References** |
|---|---|---|---|---|
| *Streptomyces lydicus* DSM 40002T | Oryza sativa L. | Antifungal; siderophores and solubilize phosphate | Thai Jasmine Rice | Mingma *et al.*, 2018 |
| Streptomyces sp. GMKU 3100 | Roots of Oryza sativa L. cv. KDML105 | Siderophore production; Phosphate solubilization and IAA production | *Vigna radiata* (L.) CN72) and *Oryza sativa* L. cv. KDML105 | Rungin *et al.*, 2012 |
| *Streptomyces sp.* UPMRS4 | Rhizospheres soil of both healthy and blast disease infected rice | Biocontrol of rice blast disease (*Pyricularia oryzae*); siderophore production; Phosphate solubilizing; (HCN) | MR219 rice variety | Awla *et al.*, 2017 |
| *S. pseudovenezuelae* (MG547870) and *A. arilaitensis* (MG547869) | rhizosphere soil of maize plantations | IAA; Siderophore; phosphate solubulization and ACC production | Maize plants | Chukwuneme *et al.*, 2020 |
| *Streptosporangium becharense* SG1 | Saharan soil from Béchar | Antagonist activity aganist Root rot disease caused *by Fusarium culmorum*; Promote | durum wheat | Boukaya *et al.*, 2018 |

| **Actinomycetes Strains** | **Isolation source** | **Plant Growth promoting Trait** | **PGPR Trait on inoculated Plant** | **References** |
|---|---|---|---|---|
| | | growth of durum wheat; IAA production; Phosphate solubilisation; HCN; Siderophore | | |
| *Streptomyces spp.* | Herbal vermicompost | Antifungal Activity; Biocontrol of *Fusarium oxysporum* wilt of chick pea; IAA production; Siderophore Production | Sorghum and rice | Gopalakrishnan *et al.* 2013 |
| *Streptomyces acidiscabies* E13 | - | IAA; Siderophore production; Promote growth of Cowpea under the presence of nickel contamination by binding iron and nickel | Cowpea (*Vigna unguiculata* L.) | Dimpka *et al.* 2008 |
| *S. thermocarboxydus* isolate S3 | Spores of *Funneliformis mosseae* CMU-RYA08 | PGP Properties; IAA production and ACC deaminase activity; Phosphate | Thai jasmine rice (O. sativa and Mung beans (Vigna radiata) | Lasudee *et al.*, 2018 |

| **Actinomycetes Strains** | **Isolation source** | **Plant Growth promoting Trait** | **PGPR Trait on inoculated Plant** | **References** |
|---|---|---|---|---|
| | | solubilizing; Siderophore | | |
| *Streptomyces spp.* | Rhizosphere Soil samples *Trifolium repens* L. | Nitrogen fixation; Phosphate solubilization; $N_2$ Fixation | Clover plants | Franco-Correaa *et al.* 2010 |
| *Streptomyces asterosporus* NRRL B-24328$^T$ | *S. nigrum* | Antagonist activity against *Frl* root rot; HCN; Siderospore; IAA; Phosphate Solubulization; β-1,3-glucanase activities | Tomato seedlings. | Goudjal *et al.*, 2016 |
| *Streptomyces spp.* | Moroccan phosphate mines Soil | Phosphate solubilization; IAA production | Wheat plant (*Triticum durum* L.) | Hamdali *et al.* 2008 |
| *Streptomyces spp.* | Rhizophere and roots of *Triticum aestivum* | IAA, siderophore production; Phosphate solubilization; | *Triticum aestivum* (wheat) | Jog *et al.* 2014 |
| *Streptomyces griseoluteus* WT | rhizosphere soil of Phaseolus vulgaris | IAA production; $GA_3$ | Bean (Phaseolus vulgaris L.) | Nassar *et al.* 2003 |

| **Actinomycetes Strains** | **Isolation source** | **Plant Growth promoting Trait** | **PGPR Trait on inoculated Plant** | **References** |
|---|---|---|---|---|
| *Streptomyces sp.*, *Nocardia sp*., *Nocardiopsis sp.*, *Spirillospora sp.*, *Microbispora sp.* and *Micromonospora sp.* | Leaves, branches, and roots of mandarin root stocks and trees | Phosphate-solubilizing activity, IAA production | Mandarin seedlings | Shutsrirung *et al.*,2013 |
| *Streptomyces sp.* | Root of Azadirachta indica A. Juss. (Meliaceae), plants | IAA, siderophore production; Phosphate Solubulizing; Antagonistic activity aganist *Alternaria alternata* | Tomato (*Solanum lycopersicum*) | Verma *et al.* 2011 |
| *Frankia sp.; Streptomyces sp.; Actinoplanes sp.* and *Micromonospora sp.* | Isolated from rhizosphere and rhizoplane of *Ochetophila trinervis* | IAA; $GA_3$; Zeatine | *O. trinervis* and Alfalfa plants | Solans *et al.*,2011 |

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