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A Review on *Streptomyces spp*. as Plant-Growth Promoting Bacteria (PGPB)

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ABSTRACT

The bacteria *Streptomyces spp*. are known to be the most important and well-acknowledged microorganisms that produce secondary metabolites. Increasing population density has greatly influenced the demand for agricultural intensification, which is economically relevant to tackle. This review was conducted to evaluate the properties of microorganisms, specifically genus *Streptomyces* and its effect on the plant as growth promoting bacteria. It was found that a vast number of *Streptomyces* strains are capable of producing a wide variety of biologically active compounds, which helps plant growth. Various studies and research had shown that inoculation of *Streptomyces* on plants has resulted in increased in plant heights, leaf volume, roots volume, and stem weights. *Streptomyces corchorusii* strain UCR3-16 exhibited significant biocontrol potential against important rice fungal pathogens showing highest inhibition against *Rhizoctonia solani*. About 130 strains of *Streptomyces* were also evaluated against destructive soil-borne pathogens. Plant growth-promoting activities of *Streptomyces sp.*in sorghum and rice were also conducted. Some *Streptomyces* species are now being used agriculturally. In conclusion, these promising studies are suggested for more future research not just on *Streptomyces* but in different soil-dwelling microorganisms that could contribute to plant growth promotion.

Keywords: Plant-Growth Promoting Bacteria; *Streptomyces* spp.

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INTRODUCTION

Bacteria, the first form of cellular life on Earth, as of now existed 3.5 billion years ago, when the Earth itself was about 1 billion years old. Because of the development of photosynthesis by early bacteria, free oxygen appeared in the atmosphere about 2 billion years ago. This leads to new possibilities for living organisms to obtain energy. An explosion of bacterial diversity followed, and at that time a line of descent leading to present-day *Actinomycetes* was established; but the first true *Streptomycete* did not appear until about 450 million years ago, eventually giving rise to all to-day's *Streptomyces* species (de Lima et al., 2012). World plant biodiversity is the largest source of herbal medicine and still about 60-80% of the world population relies on plant-based medicines, which are being used since the ancient times as materials for curing different diseases. These natural compounds formed the base of modern drugs as people use today (Dias et al., 2012). The Plant Growth Promoting Bacteria works in different ways. These bacteria are equipped for settling atmospheric nitrogen, solubilizing phosphorus, and iron, and of delivering plant hormones. These microorganisms are equipped for settling environmental nitrogen, of solubilizing phosphorus, and press, and of delivering plant hormones, such as auxins, gibberellins, cytokinins, and ethylene. Moreover, they enhance a plant's resilience to stresses such drought, high salinity, metal toxicity, and pesticide load. At least one of these components may add to the acquired in plant development and improvement that are higher than ordinary for plants developed under standard development conditions (Bashan and De-Bashan, 2005). Plant growth promoting bacteria (PGPB) are characterized as free-living soil, rhizosphere, photosphere bacteria that, under a few conditions, are valuable for plants. The soil particularly rhizosphere microscopic organisms can strengthen plant development without a pathogen. These microbes have a place with different genera, including *Acetobacter*, *Achromobacter*, *Anahaena*, *Arthrobacter*, *Azoarcos*, *Azospirillum*, *Azotobacter*, *Bacillus*, *Burkholderia*, *Clostridium*, *Enterobacter*, *Flavobacterium*, *Frankia*, *Hydrogenopaga*, *Kluyvera*, *Microcoleus*, *Phyllobacterium*, *Pseudomonas*, *Serratia*, *Staphylococcus*, *Streptomyces*, and *Vibrio*. The benefits of soil bacteria include the solubilisation of minerals, fixation of nitrogen, and development of growth-promoting hormones. The latest research underscored the study of nitrogen-fixing bacteria indigenous to rhizospheres of cereal crops and other grasses (Beneduzi et al., 2012). As stated by the study of *Streptomycetes*: Characteristics and their antimicrobial activities, *Streptomycetes* are filamentous gram-positive bacteria that are found in a diversity of soil comprising composts, water and plants and in various environments (Hasani et al., 2014). It's shapes similarly like filamentous fungi growths. The morphological differentiation of *Streptomyces* involves the formation of a layer of hyphae that can differentiate into a chain of spores. The discovery and medicinal use of antibiotics in the 1950s have undoubtedly conferred one of the greatest benefits on mankind (Berdy, 2012). Interestingly, an unlimited source of novel substances with many therapeutic applications are from microorganisms producing secondary metabolites. These microorganisms possess diverse chemical structures and biological activities (Velayudham and Murugan, 2012). Many soil inhibiting bacteria like the genera of *Actinomycetes* are the most commonly distributed microbes (Garbeva et al., 2011). Among these genera, the most interesting property of *Streptomyces* is the ability to produce bioactive secondary metabolites, such as antifungal, antiviral, antitumor, anti-hypertensive, immunosuppressant, and especially antibiotics. The production of most antibiotics is species specific, and these secondary metabolites are important for *Streptomyces* species in order to compete with other microorganisms that come in contact, even within the same genre (de Lima et al., 2012).

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Streptomycetes are widely distributed in soils, especially in dry not too acidic, and rich in organic matter, they frequently exceed the combined counts of all other bacteria (Chen et al., 2017). They decompose plant and animal residues, for the addition of those residues to the soil will greatly increase the activity and size of the *Streptomycetes* population. It is still debatable whether *Streptomycetes* occur in soils primarily as vegetative mycelia or as spores (Waksman and Lechevalier, 1953). Researchers tried to unravel the problem of how *Streptomycetes* exist in soil by shaking soil samples with sand particles; the reason is that this might increase the propagule numbers by breaking the mycelium into several viable fragments if *Streptomycetes* were present mainly as mycelium. However, no growth in propagule numbers occurred, and Seipke, therefore, concluded that *Streptomycetes* were present, and probably persisted in the soil, as spores rather than as mycelium (Seipke et al, 2012). *Streptomycetes* have been found beneficial in associations with plants where they have enhanced plant growth and protected against pests, which have attracted the attention of researchers worldwide. *Streptomyces* has a potential to help them in the growth of a plant and considered that it is related to its secondary metabolic pathways, that interacts with the host plants and recent advances in which is why it is a plant growth-promoting mechanisms (Loyld, 1969). This genus *Streptomyces* contains a large diversity of species that have a high guanine and cytosine in its DNA, up to 75% of its genome. This genus produces different biologically active compounds; in relation with plant growth activity. The metabolic flexibility and universal behavior of *Streptomyces* species have enabled them to be isolated from different environments but some are not yet explored. Thus, given an opportunity to discover new bioactive compounds (McNeil and Brown, 1994). Since *Streptomyces* are mainly found in soil and they are known to produce different secondary metabolites that are beneficial in promoting plant growth. It could be concluded that *Streptomyces* sp. with a high amount of biologically active compounds also has high plant growth activities and soil enzyme production capability significantly improved growth and development. Thus, this promising beneficial effect of *Streptomyces* in plants gives the researchers the idea to promote and enhance the development of its properties.

METHODOLOGY

The research study was collected from different online resources of the literature review. In this case, databases such as NCBI, Science Direct, Elsevier, BMC Microbiology, and Springer are the main source of article reviews. These articles show that genus *Streptomyces* was one of the most promising bacteria and are potentially possesses biological compounds. Specifically, its symbiotic relationship with a plant as a growth promoting bacteria.

RESULTS AND DISCUSSION

The following results were based on the analysis of the researcher regarding how *Streptomyces* are able to promote and enhance plant growth through its natural occurrence. The researcher sought articles and studies to this review of related literature. On this part, different attributes and ways of how *Streptomyces* helps the plant were discussed, furthermore it includes experimental studies that scientists exhibited for concluding their statement for the significance of *Streptomyces* to plants. One of the study consulted was the "Biocontrol and plant growth promoting activities of a *Streptomyces corchorusii* strain UCR3-16 and preparation of powder formulation for application as biofertilizer agents for rice plant" it was discussed that rice is known to be the most widely used crop in the world. Hence, because of the used of agrochemical, it may harm the consumers and the environment. Among all

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bacterial communities, *Actinomycetes* have been reported to play an important role in the plant rhizosphere by secreting a wide range of antimicrobial products thus preventing growth of common root pathogens. *Actinomycetes*, especially *Streptomyces*, are prolific producers of secondary metabolites and are being used as BCAs to control soil-borne and seed-borne diseases of plants. This experimental study aims to know the biocontrol and plant growth promoting activities of *Streptomyces* chorchoussii strain UCR3-16. As the result showed that *Streptomyces corchorusii* UCR3-16 exhibited significant biocontrol potential against important rice fungal pathogens showing highest inhibition against *Rhizoctonia solani* (Table 1).

Table 1: *Streptomyces* strains with Potential Growth Promoting Property against Pathogenic Fungi/Bacteria

Species	Property	Target	Reference
Streptomyces chorhousii (Strain UCR3-16)	Biocontrol potential against rice fungal pathogens	The highest inhibition against *Rhizoctonia solani*	Tamreihao et al., 2016
Streptomyces anulatus (Strain CMJ581)	Wide-spectrum bio-active strains; Strong vitro activity	*Sclerotinia sclerotiorum* *Rhizoctonia solani* *Fusarium oxysporum* *Phythium ultimum* *Phytophthora sp.* *Thielaviopsis basicola* (Soilborne fungal pathogens)	Kunova et al., 2016
Streptomyces albidoflavus (Strain VT111I)			
Streptomyces cyanues (Strain ZEA 17I)			
PM1a	Potential act as Plant Growth promoting *Rhizobacteria* (PGPR)	Against Pcb (*Pectobacterium carotovorum* spp. *brasiliensis*) by dual-culture	Dias et al, 2017
PM3b		Efficient antagonism against Pcb by dual-culture	
PM5c		Against Pcb (*Pectobacterium carotovorum spp. brasiliensis*) by dual-culture	

[a]Potential to act as PGPR, as proposed by Dias MP.
[b]Isolate with efficient antagonism against Pcb by dual-culture
[c]It was the isolate that most promoted growth by direct interaction with Stm

The strain was also positive for different PGP traits. The strain could significantly enhance the growth and grain yield production of rice plants under pot conditions. The strain could enhance the growth of rice plants even under pathogen challenged conditions. The strain could be a promising agent for development as biofertilizers for major crops especially rice plants (Hara et al., 1988). Another research study in the "Selection of *Streptomyces* against soil-borne fungal pathogens by a standardized dual culture assay and evaluation of their effects on seed germination and plant growth". The researchers have interest on *Streptomyces* because it has a potential in agriculture as plant growth promoting bacteria and biological control agents because of its peculiar life cycle that leads in the production of secondary metabolites in synchronized with the development of aerial hyphae and sporulation that is commonly used to screen for a bacterial antagonist. One hundred and thirty *Streptomyces* strains were evaluated against six destructive soil-borne pathogens. The activity of strains varied from broad-spectrum to highly specific inhibition of individual pathogens. All strains inhibited at least one tested pathogen. Three strains, which combined the largest broad-spectrum with the highest inhibition activity, were selected for further characterization with four vegetable species. Among six fungal soil-borne

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pathogens against *Streptomyces* strains, there are best strains were able to to colonize the four vegetable crops and has the potential to be developed as a biological control and plant growth (Tamreihao et al., 2016) (Table 1). In the study about plant growth-promoting activities of *Streptomyces* spp. in sorghum and rice was conducted by Gopalakrishnan and team. Five strains of *Streptomyces*, isolated from herbal vermicomposting, CAI-24 (*Streptomyces tsusimaensis*), CAI-121 (*Streptomyces caviscabies*), CAI-127 (*Streptomyces setonii*), KAI- 32 (*Streptomyces africanus*), and KAI-90 (*Streptomyces spp*) were studied regarding their plant growth promotion potential on rice and sorghum, under different conditions; greenhouse condition and field condition. In sorghum under greenhouse condition, the *Streptomyces* strains enhanced all PGP parameters such as plant height, stem weight (except CAI-127), leaf area (except KAI-32), leaf weight, root length, root surface area (except CAI-121), root volume, and root dry weight over the control (Table 2.1).

Table 2.1: PGP Activities in Sorghum under greenhouse condition isolated from herbal vermicomposting

Species	PGP Parameters								Reference
	Plant Height	Stem Height	Leaf Area	Leaf Weight	Root Length	Root Surface Area	Root Volume	Root Dry Weight	
Streptomyces tsusimaensis (Strain CAI-24)	+	+	+	+	+	+	+	NR*	Gopalakrishnan et al., 2015
Streptomyces caviscabies (Strain CAI-121)	+	+	+	NR	NR	NR	+	NR	Gopalakrishnan et al., 2015
Streptomyces setonii (Strain CAI-127)	NR	NR	+	+	+	+	+	+	Gopalakrishnan et al., 2015
Streptomyces africanus (Strain KAI-32)	+	+	NR	+	+	+	+	+	Gopalakrishnan et al., 2015
Streptomyces spp (Strain KAI-90)	+	+	+	+	+	+	+	+	Gopalakrishnan et al., 2015

*NR means no result

Under field conditions in rice, the five *Streptomyces* strains significantly enhanced plant height, primary and secondary panicle number, panicle length (cm), stover and grain yield, total dry matter and test seed weight (g) over the control. Root length, root volume, and root dry weight were also found significantly enhanced in both the soil depths in all the *Streptomyces* strains (except CAI-24) inoculated plots over the control. Better growth and production of essential agronomical crops because of inoculation with PGP microorganisms were also reported on various studies. PGP microorganisms

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stimulate plant growth by changing the balance of hormones in the host plant and promoting mineral nutrient solubilisation and by fighting pathogenic microorganisms (Gopalakrishnan et al., 2015) (Table 2.2).

Table 2.2: Plant-Growth Promoting Activities in Rice under field condition isolated from herbal vermicomposting

Species	PGP* Parameters									Reference
	Plant Height	Primary and Secondary Panicle Number	Panicle Length	Stover and Grain yield	Total dry Matter	Test Seed Weight	Root Length	Root Volume	Root Dry Weight	
Streptomyces tsusimaensis (Strain CAI-24)	+	+	+	+	+	+	NR*	NR	NR	Gopalakrishnan et al., 2015
Streptomyces caviscabies (Strain CAI-121)	+	+	+	+	+	+	+	+	+	Gopalakrishnan et al., 2015
Streptomyces setonii (Strain CAI-127)	+	+	+	+	+	+	+	+	+	Gopalakrishnan et al., 2015
Streptomyces africanus (Strain KAI-32)	+	+	+	+	+	+	+	+	+	Gopalakrishnan et al., 2015
Streptomyces spp (Strain KAI-90)	+	+	+	+	+	+	+	+	+	Gopalakrishnan et al., 2015

*NR means no result

Sousa reviewed another study about Streptomyces. A better understanding of how the genus exhibit a range of traits that improve plant growth by using different mechanisms was the focus. The use of Plant Growth Promoting Bacteria is a good practice for sustainable agriculture and is one of the alternatives to pesticides and as fertilizer as well. Screening studies involve different experimental assays in the laboratory and greenhouse. Elite strains were tested under different environmental conditions and for different plant species and different genotypes of a target crop. Following the steps, few *Streptomyces* strains were used as biofertilizers, commercial bio-control have been developed to improve plant growth promotion. These *Streptomyces* species are now being used such as *Streptomyces lydicus*, *Streptomyces griseoviridis*, and *Streptomyces avermitilisas* biocontrol in several crops (de Jesus and Olivare, 2016). Another article characterizes *Streptomyces* as plant growth promoting Rhizobacteria and resistance promoting against some species of *Pectobacterium* especially *Pectobacterium carotovorum*, which are pathogenic to, plants. The article evaluated the ability of *Streptomyces* in promoting growth

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and providing defense-related metabolism of tomato plants, and the potential of *Streptomyces* on preventing the roots of the tomatoes to rot. By doing VOC profiling and direct plant, testing 2 species of plant have the potential to act as PGCPR. 2 species, PM1 and PM 5 was observed to activate enzyme peroxidase 3 days after plant infection and fast response of polyphenol oxidases was observe. The result shows that 2 species of *Streptomyces* namely PM 1 and PM 5 are great to plant growth promoter helping the roots to fight against some fungus that causes the plant roots to rot (Manteca and Sanchez, 2009) (Table 1). *Streptomyces* isolates' secondary metabolites were observed and analyzed regarding their ability to promote plant growth. Few isolates have been studied and some of them have potential to promote plant growth. As a result, all isolates shows chitinolytic activity which is a mechanism of control against phytopathogenic fungi with an exception to AC-92 which presents a cellulolytic activity which also helps the plant to be easily absorbed the organic matter and nutrients present in the soil. All isolates in total produced lipase, amylase, and catalase which play an important role in promoting plant growth (Dias et al., 2017) (Table 1). *Streptomyces* strains improved soil natural and mineral supplement qualities including microbial biomass carbon, dehydrogenase activity, and mineral supplement. The results showed that the six strains of *Streptomyces* sp., CAI-85, CAI-93 and KAI-180 were discovered better than CAI-155, CAI-140 and CAI-13, regarding their consequences for root and shoot advancement. With the use of electron microscopy micrographs had uncovered the accomplishment in colonization of the chickpea roots by each of the six strains. This examination additionally affirms the expansive range of Plant Growth Promotion exercises by the selected *Streptomyces* sp. Three strains are a potential contender for the discovery of novel secondary metabolites and their value can help in promoting the utilization of eco-accommodating biofertilizers. There is a need to do extra thorough research to exploit the capability of this PGP *Streptomyces* under various field conditions (multi-area trials), commercialization and move forward manageability in horticultural production (Hasani et al., 2014) (Table 3). A research article published in China reported data about growth promotion of *Streptomyces* among banana trees rhizosphere. An experiment was conducted for the reason that there's a heavy loss of agriculture due to plant diseases caused by fungi have become a threat to the global food security (Chen et al., 2017). The experiment starts from isolating *Streptomyces* sp. via serial dilution and checking the DNA using PCR, which they discovered to be 99.93% sequence similarity with *Streptomyces spectabilis* which has an antifungal activity against 11 plant pathogenic fungi. The isolate is named as CB-75, which is said to be a candidate for developing antifungal biocontrol agents. Upon testing it on the banana plant; two samples are grown the 1st one having a *Streptomyces* sp. help and the other one without, upon daily observation almost every part has improved not only in their sizes but also the chlorophyll content, root length and diameter, stem's weight and etc (Sousa et al., 2008) (Table 3).

CONCLUSION

From the various reviewed pieces of literature, we concluded that the natural soil-inhabiting bacteria *Streptomyces* could be an effective microorganism that naturally enhances plant development. Through this, the demand for agricultural supply can meet the needs of growing population. Therefore, a thorough study and exploration are suggested to meet the demand for the near future.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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Table 3: Six strains of *Streptomyces* sp. that affirms the expansive range of Plant Growth Promotion (PGP).

STRAINS of *Streptomyces spp.*	PGP in Rice reported previously (Gopalakrishnan et al. 2014)	Growth of *Mesorhizobium ciceri* on yeast extract mannitol agar (YEMA)	PGP in chickpea Rhizosphere	Potential candidates for the discovery of novel secondary metabolites	Reference
CAI-85	+	NR*	+	+	Sousa et al., 2008
CAI-93	+	NR	+	+	Sousa et al., 2008
CAI-13	+	NR	+	NR	Sousa et al., 2008
CAI-140	+	NR	+	NR	Sousa et al., 2008
CAI-155	+	NR	+	NR	Sousa et al., 2008
KAI-180	+	NR	+	+	Sousa et al., 2008

*NR means no result

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