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# Diversity, antifungal and plant growth promoting activity of actinomycetes from rhizosphere soils of medicinal plants

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ABSTRACT

A total of 202 actinomycete isolates were obtained from 25 medicinal plant rhizosphere soils. These isolates belonged to *Streptomyces* ($n$ = 175), *Saccharopolyspora* ($n$ = 13), *Micromonospora* ($n$ = 7), *Noardia* ($n$ = 3), *Pseudonocardia* ($n$ = 3) and *Actinomadura* ($n$ = 1) spp. The highest number and diversity of actinomycetes were isolated from *Curcuma longa* L. rhizosphere soil ($2.7 \times 10^5$/g). Eleven isolates displayed antagonistic activity against at least one of the eight phytopathogenic fungi tested. Fifty isolates exhibited indole-3-acetic acid (IAA) production in the range of 10.2-93.8 µg/ml. Forty seven isolates were able to solubilize phosphorus in the range of 0.02- 0.68 mg/ml. Seventeen isolates produced the amount of catechol-type siderophore ranging between 2.68-51.6 µg/ml. While all the 22 isolates produced hydroxamate-type siderophores ranging from 8.71-144.21 µg/ml. These results confirm that rhizospheric soils of medicinal plants represent an extremely rich reservoir for the isolation of significant diversity of actinomycetes that are potential sources for the discovery of biologically active compounds.

**Key words:** Actinomycetes, Antagonistic activity, Indole-3-acetic acid, Rhizosphere and Siderophores

Plant rhizosphere soil harbors various kinds of micro-organisms which turned out to be an unlimited source for potential drugs, agrochemicals and biocatalysts (Yarborough *et al.* 1993). In agriculture phytopathogenic fungi can cause plant diseases and much loss of crop yields for which chemicals like pesticides are used. However agrochemical treatment causes environmental pollution and decreased diversity of non-target organisms. The use of microorganisms to control plant pathogen is a suitable and ecofriendly alternative way of reducing use of chemicals in agriculture. Potential use of biocontrol agents as replacements or supplements for agrochemicals has increased in agriculture (Yang *et al*. 2007).

Actinomycetes are Gram-positive filamentous bacteria. They are the most widely distributed group of saprophytic soil inhabitants (Takizawa *et al*. 1993) and are prolific producers of diverse bioactive secondary metabolites (Kekuda *et al*. 2010). *Streptomyces*, a representative genus of actinomycetes that is mainly of terrestrial soil origin, has accounted for the production of 60% of antibiotics which are useful in agricultural industries (Mellouli *et al.* 2003, Fguira *et al*. 2005, Singh *et al*. 2006, Thakur *et al*. 2007), or plant growth promoting substances that have been developed for agricultural use originated from this genus (Ilic *et al*. 2007).

Actinomycetes are important producers of valuable metabolites, enzyme inhibitors commercially valuable enzymes like chitinases, cellulases, amylases etc. (Jog *et al*. 2012). Actinomycetes can protect roots by inhibiting the development of potential fungal pathogens by producing enzymes which degrade the fungal cell wall or producing antifungal compounds (Errakhi *et al*.2007) Actinomycetes can promote plant growth by producing promoters such as indole-3-acetic acid (IAA) to help growth of roots (El-Tarabily 2008) or produce siderophores to improve nutrient uptake (Tokala *et al*. 2002). However, the rate of discovery of new secondary metabolites has been decreasing, so the discovery of actinomycetes in unexplored sources increases the chance for the recovery of new secondary metabolites (Hayakawa *et al*. 2004).Active actinomycetes may be found in medicinal rhizosphere soils and may have the ability to produce new inhibitory compounds. Present studies was undertaken to isolate actinomycetes from rhizospheric soil of medicinal plants and evaluate their potential for antifungal and plant growth promoting activity.

## MATERIALS AND METHODS

Twenty five samples were collected from rhizosphere regions of five medicinal plants, e.g. *Curcuma longa* L.

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*Cymbopogon citrates, Mentha arvensis, Ocimum sanctum* and *Zingiber officinale* from herbal garden PAU, Faridkot and Ferozepur Distt. The samples were collected in polythene bags from a depth of 15 cm and transported to laboratory for immediate processing.

One gram of each sample was transferred to a 30 ml test tube and suspended in 9 ml of sterile normal saline by shaking for 2 minutes on a vortex mixer. Aliquots (0.1ml) from serial logarithmic dilutions of each suspension were pipetted onto the surface of duplicate Petri dishes containing either tryptic soy agar (TSA) or malt yeast extract agar (MYEA), both supplemented with cycloheximide (50µg/ml) to suppress fungal growth. The inoculum was spread evenly over the surface with glass applicator and incubated at 28° for 10 days. Counts from the duplicate plates of the respective media are expressed as the mean number of colony forming units (cfu)/gram.

Cultural and morphological characteristics, including presence of aerial mycelia, spore mass color, distinctive reverse colony color, color of diffusible pigments and spore chain morphology were used as identification characters (Yan 1992). Visual observation of both morphological and microscopic characteristics using light microscopy and Gram-stain properties were also performed. All morphological characters were observed on tryptic soy agar and the criteria used for classification and differentiations were according to Bergey's manual of systematic bacteriology. Biochemical screening: Physiological criteria such as ability to degrade casein, starch, esculin, tween 80, tyrosine, xanthine and hypoxanthine as substrates by the various actinomycete strains were also used for genus confirmation.

The actinomycete isolates were tested for their antagonistic activity against eight phytopathogenic fungi: *Aspergillus niger, Aspergillus flavus, Aspergillus oryzae, Helminthosporium oryzae, Fusarium oxysporum, Penicillium penophilum, Phytophthora dresclea,* and *Chaetomium globosum* by dual-culture in vitro assay (Khamna *et al.* 2009).

Phosphate solubilization test was conducted qualitatively by inoculating the actinomycetes isolates on National Botanical Research Institute's phosphate agar medium (NBRIP) containing $Ca_3(PO_4)_2$ according to Nautiyal (1999). The tested isolates were inoculated in NBRIP medium containing $Ca_3(PO_4)_2$ and incubated at 28°C for 7 days. The cultures suspensions were centrifuged at 3000 rpm for 30 min. Soluble phosphate in supernatants were determined according to Olsen and Sommers method (1982).

The production of IAA by 40 isolates was determined according to the method of Gordon and Weber (1951). The isolates were grown on yeast malt extract agar at 28°C for 5 days. Eight millimeter diameter agar discs were inoculated into 100 ml of yeast malt extract broth containing 0.2% L-tryptophan and incubated at 28°C with shaking at 125 rpm for seven days. Cultures were centrifuged at 11 000 rpm for 15 min. One milliliter of the supernatant was mixed with 2 ml of the Salkowski reagent. Development of pink color indicated IAA production. Optical density (OD) was taken at 530nm using a spectrophotometer. The level of IAA produced was estimated by comparison with an IAA standard.

The isolates were inoculated on Chrome azurol S (CAS) agar medium and incubated at 28ºC for 5 days (30). The colonies with orange zones were considered as siderophore producing isolates. The active isolates (width of orange zone on CAS plate > 20 mm) were cultured on glycerol yeast broth and incubated at 28ºC with shaking at 125 rpm for 10 days. Catechol-type siderophores were estimated by Arnow's method (1937) and hydroxamate-type siderophores were estimated by the Csaky test (1948).

## RESULTS AND DISCUSSION

### *Actinomycete isolates from rhizosphere soils*

The present study revealed that rhizospheric soil of medicinal plants harbor a variety of actinomycetes isolates.The highest number and diversity of actinomycetes were isolated from rhizosphere soils of *Curcuma longa* ($2.7 \times 10^5$/g) followed by *Cymbopogon citrates* ($2.37 \times 10^4$/g), *Ocimum sanctum* ($1.9 \times 10^4$/g), *Zingiber officinalis* ($1.4 \times 10^4$/g) and *Mentha arvensis* sp.($1.8 \times 10^3$/g) respectively. A total of 202 actinomycetes were isolated from rhizospheric soils of five medicinal plants, i.e. *Cymbopogon citrates, Zingiber officinale*, *Ocimum sanctum*, *Mentha arvensis* and *Curcuma longa*. Out of 202 isolates the majority ($n$ = 55) was recorded from *Curcuma longa* L. followed by *Ocimum sanctum* ($n$ = 47), *Mentha arvensis* ($n$ = 39), *Cymbopogon citrates* ($n$ = 32) and *Zingiber officinale* ($n$ = 29). About 86.6% of the isolates were identified as *Streptomyces* by morphological characteristics and 13.4% were identified as *Saccharopolyspora* sp. ($n$ = 13), *Micromonospora* sp. ($n$ = 7), *Noardia* sp. ($n$ = 3), *Pseudonocardia* sp. ($n$ = 3) and *Actinomadura* sp. ($n$ = 1). *Streptomyces* sp. was the dominant actinomycete isolated from all plant rhizosphere soils suggesting their wide distribution in association with plants in the natural environment. Which is consistent with the results reported by others (Thangapandian *et al.* 2007, Tamilarasi *et al.* 2008, Khamna *et al.* 2009).

The number and diversity of actinomycetes isolated from *Curcuma longa* rhizosphere was higher than from other rhizosphere soils. These results are supported by Khamna *et al.* (2009) who obtained 51 isolates of actinomycetes from *Curcuma mangga* rhizosphere soils. The rhizosphere represents a unique biological niche which supports abundant and diverse saprophytic microorganisms because of a high input of organic materials derived from the plant roots and root exudates (Merckx *et al.* 1987). Previous studies have shown that diversity of actinomycetes in rhizosphere soils is positively correlated to the level of organic matter and dependent upon the species of plant (Germida *et al.* 1998). It

is possible that root exudates from these plants might promote the growth of actinomycetes and antimicrobial compounds from the roots might decrease number of other soil bacteria and fungi so creating a greater diversity of these bacteria than other soils. Based on colony and cultural characteristics, various subgroups were identified among *Streptomyces* sp., the subgroup *S.griseofuscus* (*n* = 46) was most frequently isolated followed by *S.aureus* (*n* = 28) and *S.albosporus* (*n* = 27)*, S. flavus* (*n* = 25), *S. cinereus* (*n* = 19)*, S.viridis* (*n* = 16) and *S. globisporus* (*n* = 14).

*In vitro antagonism assay*

Eleven isolates were displaying atifungal activity against at least one of the eight phytopathogenic fungi tested. Out of eleven isolates tested for antifungal activity, ten were identified as *Streptomyces* sp. except one which was identified as *Saccharopolyspora* sp (Table 1). Five strains were isolated from *Mentha arvensis* rhizosphere and three from *Ocimum sanctum* rhizosphere soil. Plant root exudates stimulate growth of rhizospheric actinomycetes that are strongly antagonistic to fungal pathogens while the actinomycetes utilize root exudates for growth and synthesis of antimicrobial substances (Crawford *et al.* 1993).It is possible that exudates from the roots of *Mentha arvensis* and *Ocimum sanctum* might induce actinomycetes that show antifungal activity. *Streptomyces albosporus* Zb-8 was displaying antagonistic activity towards all the eight phytopathogenic fungi tested (Table 1). *Strptomyces flavus* Os-9 was showing antifungal activity against all the tested fungi except *Penicillium pinophilum.* Similar studies were carried by other workers. Thangapandian *et al.* (2007) reported that eight Streptomyces isolates obtained from medicinal plant rhizospheric soils showed antipathogenic activity. Khamna *et al.* (2009) found that 23 Streptomyces strains were active against at least one of the five pathogenic fungi. Alimuddin *et al.* (2011) found that fourteen of 17 isolates obtained from cajuput rhizosphere soil showed antagonistic property against *Candida albicans*, *Saccharomyces cerevisiae*, *Aspergillus flavus* and *Fusarium oxysporum*.

*Phosphate solubilisation*

Forty seven isolates were able to solubilize phosphate on NBRI-BPB medium were further evaluated for amount of phosphate solubilized. The amount of phosphate solubilized by the isolates ranged from 0.02-0.68 mg/ml (Table 2). The maximum amount of phosphate solubilization was shown by *Streptomyces aureus* Mt-10 (0.68 mg/ml). These results are in agreement with the observation of Hamdali *et al.* (2008) who reported high amount of phosphate solubilizing activity in *Streptomyces griseus* and *Streptomyces cavourensis* (0.58 and 0. 83 μg/ml respectively) and amount of phosphate solubilized by *Micromonospora aurantica* was reported to be 0.39 μg/ml. Microbial solubilization of mineral phosphate might be either due to the acidification of external medium or the production of chelating substances that increase phosphate solubilization. Hence, P-solubilzing actinomycetes play an important role in the improvement of plant growth.

*Indole acetic acid (IAA) production*

Fifty out of 202 isolates were observed to produce the phytohormone indole acetic acid. The actinomycete isolates were observed to produce IAA in range from 10.2 to 93.8 μg/ml (Table 2). *Streptomyces griseofuscus* Os-10 was observed to produce highest amount of IAA of 93.8 μg/ml. Our results are supported by Khamna *et al.* (2009) who reported that thirty-six of actinomycete isolates produced IAA, *Streptomyces* CMU-H009 isolated from lemongrass (*Cymbopogon citrates*) showed high ability to produce IAA.

Table 1 Antifungal activities of actinomycete isolates

| Actinomycete isolates | % inhibition* | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| *S.flavus* Cc-1 | 19.0 ± 0.1 | 55.5 ± 0.1 | 0 | 0 | 0 | 0 | 55.2 ± 0.1 |
| *S.griseofuscus* Cl-8 | 63.9 ± 0.2 | 64.0 ± 0.1 | 66.36 ± 0.2 | 58.4 ± 0. | 59.04 ± 0.1 | 0 | 54.3 ± 0.2 |
| *S.griseofuscus* Mt-4 | 59.07 ± 0.2 | 0 | 0 | 0 | 58.32 ± 0.1 | 15 ± 0.1 | 64.01 ± 0.1 |
| *S.flavus* Mt-6 | 64.0 ± 0.1 | 71.55 ± 0.2 | 59.1 ± 0.1 | 0 | 29.44 ± 0.1 | 13 ± 0.1 | 22.5 ± 0.2 |
| *Saccharoployspora* Mt-7 | 0 | 0 | 48.16 ± 0.2 | 0 | 39.16 ± 0.2 | 0 | 48.2 ± 0.2 |
| *S.flavus* Mt-9 | 0 | 39.5 ± 0.1 | 0 | 0 | 51.0 ± 0.1 | 21 ± 0.2 | 0 |
| *S.viridis* Mt-10 | 53.79 ± 0.1 | 0 | 50.21± 0.2 | 0 | 15.36 ± 0.2 | 57.72 ± 0.1 | 26.0 ± 0.2 |
| *S.griseofuscus*Os-7 | 19.1 ± 0.1 | 0 | 26.04 ± 0.1 | 0 | 56.44 ± 0.2 | 0 | 53.69 ± 0.2 |
| *S.flavus*Os-9 | 51.0 ± 0.1 | 46.2 ± 0.1 | 63.4 ± 0.1 | 46.22 ± 0.1 | 26.04 ± 0.2 | 20.35 ± 0.1 | 20.91 ± 0.1 |
| *S.griseofuscus* Os-10 | 0 | 0 | 22.58 ± 0.1 | 0 | 59.4 ± 0.1 | 15.9 ± 0.2 | 16.32 ± 0.1 |
| *S.albosporus* Zb-8 | 15.36 ± 0.2 | 58.46 ± 0.2 | 63.29 ± 0.1 | 12.88 ± 0.2 | 64.0 ± 0.1 | 24.0 ± 0.1 | 56.41 ± 0.1 |

[a] Average ± standard error from triplicate samples

1. *Aspergillus niger* 2. *Aspergillus flavus* 3. *Aspergillus oryzae* 4. *Helminthosporium oryzae* 5.*Fusarium oxysporum* 6. *Chaetomium globosum* 7. *Phytophthora dresclea*

Table 2 Production of IAA and phosphate solubilization by actinomycete isolates

| Actinomycete isolates | IAA production (mg/ml)[a] | Phosphate solubilization (mg/ml)[a] |
|---|---|---|
| *S. cinereus* Cl-1 | 14.4 ± 0.20 | 0.085 ± 0.0004 |
| *S.griseofuscus* Cl-2 | 35.8 ± 0.25 | 0.39 ± 0.012 |
| *S.cinereus* Cl-3 | 10.6 ± 0.15 | 0.13 ± 0.016 |
| *S.flavus* Cl-4 | 16 ± 0.20 | 0.45 ± 0.023 |
| *S.viridis* Cl-5 | 31.4 ± 0.20 | 0.13 ± 0.012 |
| *S.cinereus* Cl-6 | 43.6 ± 0.28 | 0.64 ± 0.0002 |
| *S.globisporus* Cl-7 | 29.2 ± 0.20 | 0.0036 ± 0.003 |
| *S.griseofuscus* Cl-8 | 53.2 ± 0.20 | 0.45 ± 0.017 |
| *Pseudonocardia* Cl-9 | 18.6 ± 0.20 | 0.13 ± 0.012 |
| *Pseudonocardia* Cl -10 | 24.8 ± 0.28 | 0.22 ± 0.008 |
| *S.viridis* Os-1 | 80.4 ± 0.20 | 0.13 ± 0.008 |
| *S.albosporus* Os-2 | 74.8 ± 0.36 | 0.26 ± 0.014 |
| *S.cinereus* Os-3 | 24.2 ± 0.30 | 0.44 ± 0.012 |
| *S.albosporus* Os-4 | 46.2 ± 0.26 | 0.14 ± 0.005 |
| *Nocardia* Os-5 | 40.7 ± 0.152 | 0.36 ± 0.012 |
| *S.flavus* Os-6 | 32 ± 0.32 | 0.18 ± 0.008 |
| *S.griseofuscus* Os-7 | 15 ± 0.20 | 0.48 ± 0.014 |
| *Micromonospora* Os-8 | 18 ± 0.30 | 0.32 ± 0.008 |
| *S.flavus* Os-9 | 23 ± 0.20 | 0.09 ± 0.015 |
| *S.griseofuscuss*Os-10 | 93.8 ± 0.30 | 0.19 ± 0.008 |
| *S.griseofuscus* Zb-1 | 19 ± 0.20 | 0.22 ± 0.014 |
| *S.flavus* Zb-2 | 17.8 ± 0.2 | 0.16 ± 0.008 |
| *S.albosporus* Zb-3 | 45.6 ± 0.30 | 0.13 ± 0.008 |
| *Actinomadura* Zb-4 | 24.6 ± 0.20 | 0 |
| *S.cinereus* Zb-5 | 23 ± 0.20 | 0.14 ± 0.005 |
| *S.cinereus* Zb-6 | 15 ± 0.20 | 0.28 ± 0.008 |
| *S.aureus* Zb-7 | 15.6 ± 0.28 | 0.11 ± 0.011 |
| *S.flavus* Zb-8 | 64.2 ± 0.2 | 0.02 ± 0.008 |
| *S.griseofuscus* Zb-9 | 40.4 ± 0.23 | 0.38 ± 0.011 |
| *S.albosporus* Zb-10 | 25.8 ± 0.15 | 0.32 ± 0.008 |
| *S.flavus* Cc-1 | 16.6 ± 0.11 | 0.26 ± 0.014 |
| *S.griseofuscus* Cc-2 | 25.0 ± 0.32 | 0.21 ± 0.014 |
| *S.globisporus* Cc-3 | 10.2 ± 0.25 | 0.42 ± 0.008 |
| *S.albosporus* Cc-4 | 21.0 ± 0.15 | 0.06 ± 0.005 |
| *S.griseofuscus* Cc-5 | 44.8 ± 0.10 | 0.19 ± 0.008 |
| *S.cinereus* Cc-6 | 25.6 ± 0.11 | 0.10 ± 0.03 |
| *S.aureus* Cc-7 | 19.2 ± 0.25 | 0.45 ± 0.012 |
| *S.flavus* Cc-8 | 41.8 ± 0.2 | 0.24 ± 0.008 |
| *S.albosporus* Cc-9 | 50.4 ± 0.41 | 0.40 ± 0.015 |
| *S.flavus* Cc-10 | 76.8 ± 0.56 | 0.25 ± 0.015 |
| *S.viridis* MT-1 | 15.2 ± 0.20 | 0.04 ± 0.003 |
| *S.griseofuscus* MT-2 | 23.0 ± 0.20 | 0.26 ± 0.011 |
| *S.flavus* MT-3 | 40.4 ± 0.56 | 0.12 ± 0.012 |
| *S.griseofuscus* MT-4 | 19 ± 0.20 | 0.004 ± 0.0003 |
| *S.albosporus* MT-5 | 50.4 ± 0.2 | 0.23 ± 0.012 |
| *S.flavus* MT-6 | 26.8 ± 0.30 | 0.10 ± 0.005 |
| *Saccharopolyspora* MT-7 | 33.6 ± 0.21 | 0.15 ± 0.005 |
| *S.globisporus* MT-8 | 23.4 ± 0.25 | 0.23 ± 0.012 |
| *S.flavus* MT-9 | 20.6 ± 0.31 | 0.097 ± 0.007 |
| *S.aureus* MT-10 | 45.8 ± 0.026 | 0.68 ± 0.115 |

[a]Average ± standard error from triplicate sample

*Streptomyces* from many crop rhizosphere soils have the ability to produce IAA and promote plant growth. It could be inferred that IAA, a plant growth hormone can promote plant growth in rhizosphere soils (El-Tarabily and Sivasithamparam 2006, Ramesh *et al*. 2012). The root exudates are natural sources of tryptophan for rhizospheric microorganisms which can enhance auxin biosynthesis in actinomycetes. It may be possible that high tryptophan will be present in root exudates of lemongrass and enhance IAA biosynthesis in *Streptomyces globisporus* Cc-3.

*Siderophore production*

Siderophore production was reported in 22 isolates. Seventeen isolates were observed to produce catechol type siderophore in range of 2.68-51.6 µg/ml while hydroxamate-type siderophore was produced by twenty two isolates in the range of 8.71-144.2 µg/ml (Table 3). The isolate *Streptomyces globisporus* Mt-8 from rhizospheric soil of *Mentha arvensis* produced maximum catechol type (51.6 µg/ml) and isolate *Streptomyces flavus* Cc-10 produced maximum hydroxamate type (144.21 µg/ml) siderophores on glycerol yeast broth. These results are supported by Khamna *et al.* (2009) who reported that *Streptomyces* CMU-SK 126 isolated from *C.mangga* rhizospheric soil exhibited high ability for

Table 3 Siderophore production by actinomycete isolates

| Actinomycete isolates | Hydroxamate (mg/ml ) | Catechol (µg/ml) |
|---|---|---|
| *S.flavus* Zb-2 | 103.21 ± 0.20 | 21.6 ± 0.20 |
| *S.aureus* Zb-7 | 22.3 ± 0.25 | 2.68 ± 0.22 |
| *S.albosporus* Zb-10 | 83.31 ± 0.11 | 12.25 ± 0.10 |
| *S.flavus* Mt-3 | 92.7 ± 0.20 | 32.8 ± 0.30 |
| *S.flavus* Mt-6 | 78.4 ± 0.25 | ND |
| *Saccharopolyspora* Mt-7 | 10.72 ± 0.22 | ND |
| *S.globisporus* Mt-8 | 82.96 ± 0.19 | 51.6 ± 0.20 |
| *S.viridis* Mt-10 | 124.58 ± 0.31 | ND |
| *S.viridis* Os-1 | 114.36 ± 0.22 | 43 ± 0.2 |
| *S.albosporus* Os-4 | 108.47 ± 0.32 | 29.4 ± 0.35 |
| *S.griseofuscus* Os-7 | 18.095 ± 0.08 | 25.5 ± 0.20 |
| *Micromonospora* Os-8 | 63.9 ± 0.20 | 28.2 ± 0.20 |
| *S.flavus* Os-9 | 85.7 ± 0.35 | 38.4 ± 0.20 |
| *S.griseofuscus* Os-10 | 102.64 ± 0.20 | ND |
| *S.flavus* Cc-1 | 130.66 ± 0.15 | 16.7 ± 0.30 |
| *S.albosporus* Cc-4 | 20.77 ± 0.40 | ND |
| *S.aureus* Cc-7 | 32.71 ± 0.20 | 21.11 ± 0.15 |
| *S.albosporus* Cc-9 | 129.32 ± 0.28 | 45.6 ± 0.20 |
| *S.flavus* Cc-10 | 144.21 ± 0.22 | 28.6 ± 0.10 |
| *S.griseofuscus* Cl-2 | 8.71 ± 0.18 | 16.1 ± 0.10 |
| *S.griseofuscus* Cl-8 | 64.17 ± 0.17 | 36.4 ± 0.20 |
| *S.cinereus* Cl-6 | 131.92 ± 0.25 | 12.4 ± 0.30 |
| CD ($P = 0.05$) | 3.13 | 0.87 |

* Average ± standard error from triplicate samples

ND-Not detected

siderophore production and produced catechol type (16.19 µg/ml) as well as hydroxamate type (54.9 µg/ml) siderophores. Microbial siderophores may also be utilized by plants as an iron source ( Wang *et al.* 1993).

Rhizosphere soil actinomycetes have to compete with other rhizosphere bacteria and fungi for iron supply and therefore siderophore production may be very important for their growth. Competition for iron is also a possible mechanism to control the phytopathogens in agriculture.

Present study revealed that rhizospheric soil from *Curcuma longa* provided a rich source of actinomycetes diversity. Production of phytohormone (IAA), siderophores, ability to solubilize phosphate as well as protection against plant pathogens by these acinomycetes may enhance the fitness and growth of the host and indirectly affect the harmful microbial population. Further investigations are required to understand the potential of these actinomycetes as biocontrol and plant growth promoting agents that may be useful in pharmacological and agricultural fields in future.

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