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Potential of Plant Growth Promoting Traits by Bacteria Isolated from Heavy Metal Contaminated Soils

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Abstract Rhizobacteria can enhance biomass production and heavy metal tolerance of plants under the stress environment. The aim of this study was to collect soil samples from different industrial sites followed by their heavy metal analysis. After performing the ICP-AES analysis of soil samples from seven different sites, bacterial strains were isolated from the soil samples of most polluted (heavy metal) site. Phylogenetic analysis of isolates based on 16S rDNA sequences showed that the isolates belonged to four species: *Bacillus thuringiensis*, *Azotobacter chroococcum*, *Paenibacillus ehimensis* and *Pseudomonas pseudoalcaligenes*. Plant growth promoting activities; siderophore production, indole acetic acid production, HCN production, and phosphate solubilisation were assayed in vitro, and statistically analysis done by using ANOVA analysis and Tukey's Honestly Significant Difference test ($p \leq 0.05$). Plant growth-promoting characteristics of isolated strains were higher compared to the control *Pseudomonas fluorescens* (NICM 5096). In vitro study was performed to check resistance against two heavy metals of isolates. It was observed that isolated bacterial strains have higher heavy metal resistance as compared to control *E. coli* (NICM 2563). These isolates may cause pathogenic effects, so to avoid this risk, their antibacterial susceptibility was checked against eight antibiotics. Among the eight antibiotics, Ciprofloxacin-1 has shown higher inhibition against all the isolated bacterial strains.

Keywords Heavy metals · Rhizobacteria · Heavy metals accumulation · Plant growth promoting traits

Plant growth promoting rhizobacteria (PGPR) are the heterogeneous class of bacterial strains that can be found in the plant rhizosphere. PGPRs can improve plant growth by direct or indirect methods (Dell'Amico et al. 2008; Tica et al. 2011). The exact mechanism behind the improved plant growth is ambiguous (Dell'Amico et al. 2008; Tica et al. 2011). These PGPRs have a special ability to grow in heavy metal contaminated environment (Barakat 2011; Burd et al. 2000; Belimov et al. 2005). Heavy metals are regarded as serious pollutants in environment including agricultural soils (Wei and Yang 2010). Heavy metals contamination is the result of technological development, occurring at significant concentrations in the environment (Barakat 2011; Kishe and Machiwa 2003). Because of the environmental persistence, toxicity and ability to be incorporated into food chains, these industrial wastes including heavy metal are new threat and challenge (Forstner and Wittman 1983; Kumar et al. 2015a; Machiwa 1992). Same time, the pollution sources of heavy metals in environment are mainly derived from anthropogenic sources include mining, smelting, waste disposal, urban effluent, vehicle exhausts, sewage sludge, pesticides, fertilizers application (Kim et al. 1998; Kumar et al. 2013a, b, 2015b; Prasad et al. 2013; Wei and Yang 2010). Uses of rhizospheric microorganisms (bacteria/fungi etc.) are generally

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considered as safe, cost effective and reliable technique, for elimination of heavy metals from environmental compartments (Barakat 2011; Dell'Amico et al. 2008; Machiwa 1992; Tica et al. 2011). Rhizospheric bacteria can survive under the heavy metal contaminated sites, and can increase plant growth and metal tolerance (Dell'Amico et al. 2008; Tica et al. 2011).

Moreover, rhizospheric microorganisms can enhance biomass production and tolerance of plants to heavy metals in stress environment (Dell'Amico et al. 2008; Sheng and Xia 2006). In recent years, studies about rhizobacteria and their interactions with hyperaccumulating or accumulating plants have attracted the attention of several investigators (Barakat 2011; Barzanti et al. 2007; Dell'Amico et al. 2008; Idris et al. 2004; Sheng and Xia 2006). These bacteria can promote plant growth by producing siderophore production, indole acetic acid production, phosphate solubilisation and hydrogen cyanide production (Dell'Amico et al. 2008; Sheng and Xia 2006). Recent studies have revealed that these PGPRs could promote plant growth and protect plants against heavy metals toxicity in heavy metal-contaminated soils (Barakat 2011; Burd et al. 2000; Belimov et al. 2005; Dell'Amico et al. 2008; Idris et al. 2004).

The present study was designed to isolate rhizobacterial strains from the heavy metal contaminated areas, and screening of their multiple plant growth promoting activities. So, current study was divided into three main parts; (1) collection of different industrial soils to analyze concentration of heavy metals. (2) Isolation and characterization of rhizobacterial strains from most (heavy metals) polluted site. (3) Finally, in vitro analysis to check the antibiotic resistance, heavy metal resistance and plant growth-promoting characteristics of the best isolates.

Materials and Methods

Seven soil samples were collected from the industrial areas of the Jalandhar (India). Jalandhar is situated at Latitude 31.32560E and East Longitude 75.57920E, and at an elevation level of 228 m above the sea level. Soil was sieved through a 2-mm sieve (to remove any large debris) and thoroughly homogenized using a pestle and mortar. Heavy metals analysis was performed by using the inductively couple plasma emission spectroscopy (ICPES) having lower limit of detections 0.1 ng/g (Lakanen and Erviö 1971).

Serial dilution method was used for the isolation of rhizobacterial strains from the soil samples. For the identification of rhizobacteria strains, the colonies of isolates were inoculated on the specific agar. Four specific media were used as mentioned including their compositions. The growth media for PS1 was *Bacillus* isolation agar: Peptic digest of animal tissue (10.0 g/L), Meat extract (1.0 g/L), D-Mannitol (10.0 g/L), Sodium chloride (10.0 g/L), Agar (15.0 g/L), Phenol Red (0.025 g/L) (Anderson 1990). The growth media for PS2 was *Azotobacter* isolation agar: Potassium sulfate (0.1 g/L), Mannitol (20.0 g/L), Sodium Chloride (0.2 g/L), Calcium carbonate (5.0 g/L), Dipotassium phosphate (0.2 g/L), Magnesium sulfate (0.2 g/L), Agar (15.0 g/L) (Anderson 1990). The growth media for PS4 was *Rhizobium* isolation agar: Yeast extract (1.0 g/L), Mannitol (10.0 g/L), Sodium chloride (0.1 g/L), Magnesium sulfate (0.2 g/L), Dipotassium phosphate (0.5 g/L), Agar (20.0 g/L) (Deka and Azad 2006). The growth media for PS5 was *Pseudomonas* isolation agar: Peptone (20.0 g/L), Magnesium chloride (1.4 g/L), Potassium Sulfate (10.0 g/L), Irgasan (25 mg), Agar (13.6 g/L) (Anderson 1990).

Different biochemical tests, namely Indole test, Methyl Red test (MR), Catalase Test, Citrate Test were performed to confirm the identity of the rhizobacterial strains isolated on selected media as described by Aneja (1993).

Out of 24 isolates of site 4, the best four isolates were sent for 16 s rDNA analysis to Samved Biotech Pvt Ltd Ahmadabad, Gujarat. The selections of best isolates were made on the basis of qualitative analysis, i.e. the formation of single and healthy colonies. To confirm the identity of four isolates, a 1.5 kb 16 s rRNA gene fragmented was amplified from the total DNA of each isolate, and sequenced using the universal primers 27F (AGAGTTTGATCMTGGCTCAG) and 1492R (ACCTTGTTACGACTT) (Powell et al. 1987; Saiki et al. 1985; Watanabe and Baker 2000). Identified isolates were submitted to NCBI with an accession number. The extraction of DNA from bacterial isolates, PCR amplification, construction of 16S rDNA clone libraries, Sequencing and phylogenetic analysis were performed as per detailed procedures given by Sun et al. (2010).

To determine the antibiotic susceptibility, all the isolates were cultured on Muller-Hinton agar plates, and Kirby–Bauer disk diffusion method was used to check the sensitivity of the isolates to the eight antibiotics namely Bacitracin-8, Ciprofloxacin-1, Erthromycin-10, Fluconazole-25, Gentamicin-50, Penicillin-G-10, Tetracycline-10 and Vancomycin-30.

To determine the heavy metal resistance of isolates, the cultures were inoculated into liquid nutrient broth treated with 0, 50, 100, 250 ppm of $ZnCl_2$ and lead acetate, and incubated at 28°C in a rotator shaker for 48 h. Growth of samples and isolates was measured after 6 h by measuring optical density (OD) at 540 nm, and all the results were compared by taking *E. coli* (NICM 2563) as a control (Ahemad et al. 2012a, b, c).

Siderophore production of the isolated strains was checked by spreading cultures on King's B media having the following ingredients (g/L); Proteose peptone—20.00,

Dipotassium hydrogen phosphate—1.50, Magnesium sulphate heptahydrate—1.50, and Agar—20.00. The media was prepared with and without (50 mg/L) $FeCl_3$. The incubation was done at 28 ± 2°C for 48 h. The fluorescent pigment of the bacterial colonies was assessed using an ultraviolet lamp. Fluorescent pigment formed was considered as an indication of siderophore production (Teintze et al. 1981). For the quantitative analysis, solidifying agent agar was not used in King's B media. After the incubation for 48 h at 28 ± 2°C, broth was centrifuged at 5000 rpm for 15 min. The supernatant was used to check the siderophore production at 410 nm using distilled water as blank.

The ability of isolated strains to solubilize phosphate was evaluated qualitatively using Potato-Dextrose Yeast Extract Agar. Each bacterial culture was spot inoculated in the centre of the plate and incubated at 28 ± 2°C for 10 days. Phosphate solubilization was assessed by measuring the clear/halo zone. The halo zone was calculated by subtracting bacterial colony diameter from the total halo zone diameter (Freitas et al. 1997).

Isolates cultured on nutrient agar medium were supplemented with glycine (4.4 g/L). The production of cyanide was detected after the 48 h of inoculation, using picrate/Na_2CO_3 paper fixed to the underside of the Petridish lids which were sealed with parafilm before incubation at 28°C. A change from yellow to orange, red, brown, or reddish brown was recorded as an indication of weak, moderate, or strongly cyanogenic potential, respectively (Bakker and Schipper 1987).

Nutrient broth (50 mL) containing DL-Tryptophan was inoculated with 500 µL of 24 h old bacterial cultures and incubated in refrigerated incubator shaker at 30 ± 0.5°C and 180 rpm for 48 h in dark. The bacterial cultures were centrifuged at 10,000 rpm for 10 min at 4°C. Estimation of Indole acetic acid in the supernatants was done using Colorimetric assay. One millimeter of supernatant was mixed with 2 mL Salkowski reagent (1 mL $FeCl_3$ + 50 mL 35 % $HClO_4$). The mixture was incubated for 25 min at room temperature. Absorbance of the resultant pink color was measured at 530 nm using the UV–Visible Spectrophotometer. Appearance of pink color in test tubes indicates indole acetic acid (IAA) production (Loper and Schroth 1986).

To perform the above mentioned properties like heavy metal tolerance, siderophore production, Phosphate solubilization cyanide production, indole acetic acid production, biochemical tests etc., 10^4 cells from each isolate were spread on plates or inoculated into test tubes for each assay. Plant growth promoting activities of the four isolates were compared to a known plant growth promoting bacteria, *Pseudomonas fluorescens* (NICM 5096). All the experiments were conducted in three replicates using the same treatments. The difference among treatment means was compared by using ANOVA test at ($p \leq 0.05$) level. In order to compare the significant differences to the control, we performed a multiple range test with Tukey's Honestly Significant Difference test, where each combination (control vs. PS1, control vs. PS2, etc.) was compared.

Results

Results of heavy metals analysis of the seven sites are depicted in the Table 1. Site 4 was the most contaminated site (Table 1). Hence, site 4 was selected for further study. The details about the locations of the sites 1-7 are given in supplementary document (S1; Sampling Sites). Comparatively, higher heavy metal concentrations were observed for sites 1, 4, 6, and 7. Highest concentrations of Arsenic (As) were observed in the soil samples of sites 2, 4 and 7. Highest concentrations of Lead (Pb) and Cadmium (Cd) were observed in the soil samples of sites 4, 5, and 7. The maximum concentrations of Chromium (Cr), Copper (Cu), and Zinc (Zn) were observed in the soil samples of sites 1 and 4.

Qualitative identification of isolates were done by performing the biochemical tests namely gram staining, indole test, MR test, citrate test, and Catalase test. The detailed observations are represented in Table 2. The complete and confirmatory identifications of the isolates were done by using the 16 s rDNA analysis. The correct sizes were verified by colony PCR. 16 s rDNA analyses have confirmed following strains with GenBank accession numbers: *Bacillus thuringiensis* PS-1 (KC 355253.1), *Azotobacter chroococcum* PS-2 (JX913866.1), *Paenibacillus ehimensis* PS-4 (FN582330.1), and *Pseudomonas pseudoalcaligenes* PS-5 (AB109887.1).

In vitro antibiotic susceptibility analysis has shown high activity of inhibition or antibiotic ability of Ciprofloxacin-1 against four isolates (Fig. 1). Ciprofloxacin-1 has shown antibiotic ability against four isolates with an order; PS2 > PS5 > PS1 = PS4. Erthromycin-10 has shown good inhibition activity against PS2. Erthromycin-10, Gentamicin-50, and Vancomycin-30 have shown low inhibition against PS2, PS4, and PS5.

Heavy metal-tolerance activites of the isolates (PS1, PS2, PS4 and PS5) were determined against Zn and Pb only. In a 36 h experiment, isolates exhibited enhanced bioaccumulation of Zn and Pb up to 30 h compared to the control, *E. coli* (Fig. 2). It was observed that all the isolates were resistant against Zn and Pb up to 5000 ppm. Different concentrations (50, 100 and 250 ppm) of Pb and Zn were used to check the dose dependent effect of heavy metal ions. A 13 % and 8 % increase in the OD (at 540 nm) or

Table 1 Heavy metal analysis of soil samples of seven sites performed by ICPES

Heavy metal	Mean ($p \leq 0.05$) of conc. (ppm ± 0.05) of seven site with code						
	1	2	3	4	5	6	7
Arsenic	0.083	0.204	0.061	0.262	0.111	0.111	0.176
Cadmium	0.013	0.079	0.008	0.118	0.048	0.024	0.090
Chromium	0.094	0.120	0.125	0.130	0.049	0.077	0.053
Copper	145.1	74.45	17.37	147.5	8.104	2.969	9.400
Lead	7.727	12.77	8.773	32.38	6.799	2.406	8.387
Zinc	635.6	202.3	116.0	206.9	40.42	12.48	10.80

Table 2 Biochemical tests for of four isolates[a]

Isolates code	Grams staining	Indole test	MR test	Citrate test	Catalase test
PS1	+	+	+	+	+
PS2	−	+	+	+	+
PS4	+	+	+	+	−
PS5	−	−	−	+	+

[a] At 100 µL/plate or test tube of each isolate; + pass; − fail

MR Methyl red test

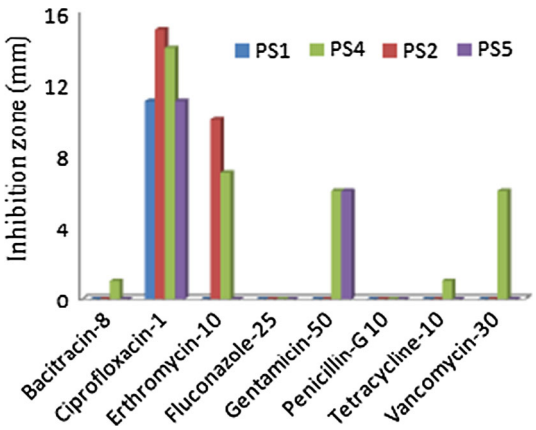

Fig. 1 Antibiotic susceptibility of isolates *Bacillus thuringiensis* (PS1), *Azotobacter chroococcum* (PS2), *Paenibacillus ehimensis* (PS4) and *Pseudomonas pseudoalcaligenes* (PS5) against eight antibiotics

increase in growth of *Bacillus thuringiensis* was observed with the addition of 250 ppm Zn and Pb. Similarly, 12 % and 8 % increase was observed with *Pseudomonas pseudoalcaligenes*. In the case of *Azotobacter chroococcum*, there was a 6 % decrease with zinc and an 11 % increase with lead. In contrast, 2 % increase was observed in case of Zn with *Paenibacillus ehimensis* but 24 % decrease observed with Pb.

Plant growth parameters namely siderophoric activity, indole acetic acid production, phosphate solubilisation and hydrogen cyanide production were observed quantitatively and qualitatively. Plant growth promoting activities of the four isolates were compared to a known plant growth promoting bacteria, *Pseudomonas fluorescens* (NICM 5096) (Table 3).

Compared to controls, siderophore production was significantly elevated at all three concentrations tested. The siderophore production was increased with the increase in the concentrations of isolates. At 100 ppm (of controls and isolates), an increase of 9 %, 11 %, 6 %, and 9 % was observed for PS1, PS2, PS4, and PS5 as compared to controls. Similarly, the indole acetic acid production was increased as concentration of strains increased as, PS1 (6 %), PS2 (9 %), PS4 (11 %) and PS5 (11 %). In HCN production study, increase in the HCN production was observed with the use of PS1, PS2 and PS5 as compared to controls, but almost same effect was observed in case of PS4. In phosphate solublisation study, there was 17 % (PS1) and 14 % (PS2) increase in phosphate solublisation was observed as compared with controls, but, a decrease in phosphate solublisation was observed with PS4 (22 %) and PS5 (8 %).

Discussion

Heavy metals analysis was the first and very important step in the current study, because as per our best knowledge it is the first heavy metal analysis study of the industrial and agricultural areas of the Jalandhar. As per a detailed review report on heavy metal exposure on agricultural soils and humans, “intake of heavy metals via the soil-crop system has been considered as the predominant pathway of human exposure to environmental heavy metals in agricultural area” (Wei and Yang 2010). The data of Charlesworth

Table 3 Plant growth promoting activities of four isolates

Isolates code	Conc. (ppm)	SA (mean)[a]	IAA (mean)[a]	HCN	PS (mm)[b]
C	10	0.41 ± 0.003	ND	ND	ND
	25	0.61 ± 0.004	(0.54 ± 0.006)	ND	ND
	100	0.84 ± 0.006	(0.72 ± 0.005)	++	(14 ± 0.007)
PS1	10	(0.47 ± 0.005)*	ND	ND	ND
	25	(0.69 ± 0.004)*	(0.57 ± 0.004)*	ND	ND
	100	(0.91 ± 0.007)*	(0.77 ± 0.005)*	+++	(17 ± 0.008)*
PS2	10	(0.49 ± 0.004)*	ND	ND	ND
	25	(0.71 ± 0.003)*	(0.59 ± 0.007)*	ND	ND
	100	(0.94 ± 0.005)*	(0.79 ± 0.005)*	+++	(16 ± 0.005)*
PS4	10	(0.44 ± 0.003)*	ND	ND	ND
	25	(0.68 ± 0.004)*	(0.64 ± 0.005)*	ND	ND
	100	(0.89 ± 0.006)*	(0.81 ± 0.004)*	++	(11 ± 0.004)*
PS5	10	(0.46 ± 0.002)*	ND	ND	ND
	25	(0.67 ± 0.005)*	(0.69 ± 0.006)*	ND	ND
	100	(0.92 ± 0.003)*	(0.81 ± 0.005)*	+++	(13 ± 0.005)*

ND Not determined; C. Pseudomonas fluorescens, *SA* Siderophoric activities, *IAA* Indole acetic acid activities, *HCN* Hydrogen cyanide production, *PS* Phosphate solubilization

* statistically significant ($p \leq 0.05$) versus control

[a] mean measured by comparing absorbance

[b] mean measured by scale due to hole formation

++ stand for light brown

+++ stand for deep brown color

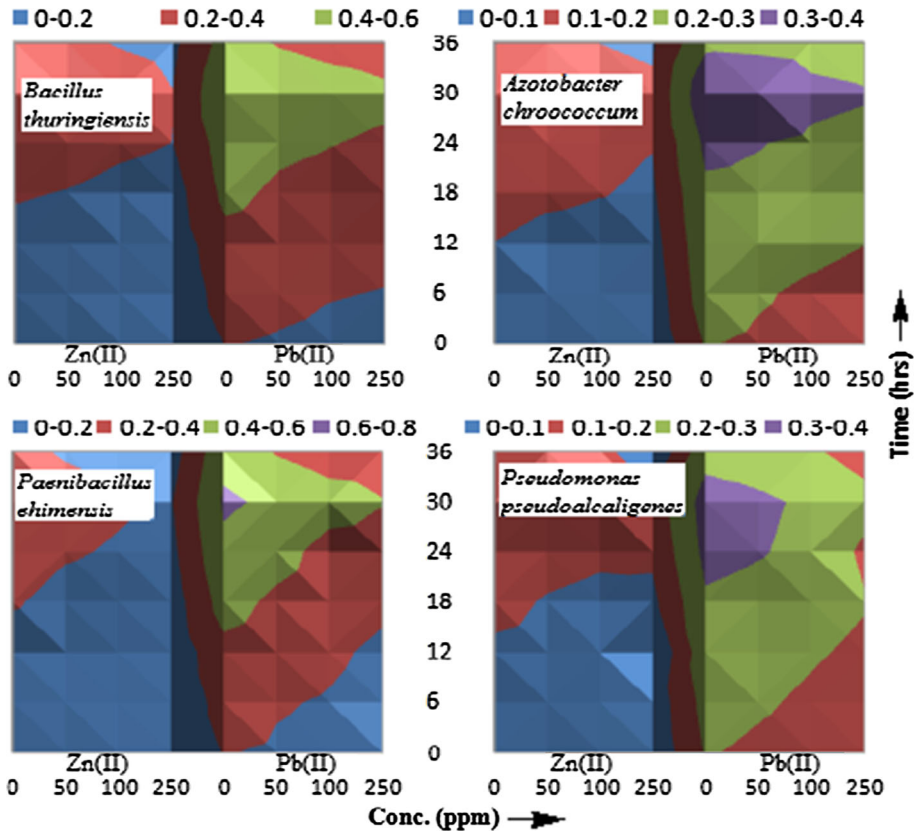

Fig. 2 Zinc and lead accumulating ability of isolates at 540 nm [Concentration (*X* axis) vs. Time (*Y* axis)]. Here, on *X* axis applied concentration levels (0 ppm or control, 50, 100 and 250 ppm) of isolates were mentioned, on *Y* axis time (0–36 h) is mentioned. The change in OD is mentioned by using *different colors* (*Navy Blue* 0–0.1, *Maroon* 0.1–0.2, *Light Green* 0.2–0.3, and *Purple* 0.3–0.4) (Color figure online)

et al. 2003" and "the results of the current study were significantly different from each other. Soils of all sites were contaminated with one or more heavy metals as; site 4 was contaminated with As, Pb, Cd, Cr, Cu, and Zn, site 1 with Cr, Zn, and Cu, and site 7 with As. Site 4 was the most contaminated site. Site 4 has contained Zn and Cu more than recommended and reported standards (Charlesworth et al. 2003; Kim et al. 1998; Leharne et al. 1992; Wei and Yang 2010). Spatially, the total concentrations of heavy metals have been related to industrial and residential activities (Kim et al. 1998; Leharne et al. 1992; Charlesworth et al. 2003). The fact behind the high concentrations of As, Pb, Cu, and Cr at all sites may be related to traffic pollution (Kim et al. 1998; Leharne et al. 1992; Wei and Yang 2010), because all these sites were closed to traffic area.

Isolation and characterization of different strains was the second and very important step in the current study, because recent studies have shown that strains isolated from the heavy metal contaminated sites having very good plant growth promoting activities (Dell'Amico et al. 2008; Idris et al. 2004; Rajkumar and Freitas). In current study, isolated strains showed increased plant growth promoting activities. Isolated strains may act as rhizobacterial strains, and may enhance the biomass production and tolerance of plants to heavy metals in the contaminated areas. In recent years, endophytic bacteria and their interactions with hyperaccumulating or accumulating plants have attracted the attention of several investigators (Barzanti et al. 2007; Idris et al. 2004). Endophytic bacteria promote plant growth by producing siderophores, indole acetic acid, hydrogen cyanide, nitrate, and enhancing phosphate solublisation etc. (Barzanti et al. 2007; Dell'Amico et al. 2008; Idris et al. 2004; Rajkumar and Freitas 2008). There are few heavy metal tolerant strains isolated by different authors as; *Streptomyces griseoluteus* strain (show decarboxylase activity), *E. splendens* and *C. communis* strains (show phytoremediation of copper-contaminated soils), *Brassica napus* strain (show cadmium tolerance) (Dell'Amico et al. 2008) and *Alyssum bertolonii* strain (show phytoremediation of nickel-contaminated soils) (Barzanti et al. 2007). It has been reported that plant growth-promoting bacteria could promote the growth and heavy metal uptake of plants (Sheng and Xia 2006; Rajkumar and Freitas 2008). Bacteria having the characteristics of producing IAA, siderophores, ACC deaminase, arginine decarboxylase may have the potential for the promotion of plant growth and heavy metal accumulation (Barzanti et al. 2007; Dell'Amico et al. 2008; Rajkumar and Freitas 2008; Sheng and Xia 2006).

Moreover, Irha et al. (2003) demonstrated that microorganisms are the most sensitive parameters for evaluating heavy metals toxicity. It was demonstrated that presence of heavy metals in soil decreased the indices of soil microbiological activity. Currently, the biological approaches for improving crop production are gaining strong status among agronomists and environmentalists following integrated plant nutrient management system. In this context, there is an ongoing rigorous research worldwide with greater impetus to explore a wide range of rhizobacteria possessing novel traits like heavy metal detoxifying potentials (Ma et al. 2011a; Wani and Khan 2010), pesticide degradation/tolerance (Ahemad and Khan 2012a, b, c), salinity tolerance, biological control of phytopathogens and insects (Hynes et al. 2008; Russo et al. 2008) along with the normal plant growth promoting properties such as, phytohormone (Ahemad and Khan 2012c), siderophore (Tian et al. 2009), hydrogen cyanate (HCN), and ammonia production, nitrogenase activity, phosphate solubilization (Ahemad and Khan 2012a, b, c) etc. Hence, diverse symbiotic (*Rhizobium*, *Bradyrhizobium*, *Mesorhizobium*) and non-symbiotic (*Pseudomonas*, *Bacillus*, *Klebsiella*, *Azotobacter, Azospirillum, Azomonas*), rhizobacteria are now being used worldwide as bioinoculants to promote plant growth and development under various stresses like heavy metals (Ma et al. 2011; Wani and Khan 2010).

Although, special attention has paid on the isolation of bacterial and fungal community compositions from contaminated soils in special environments, such as, pollutants and heavy metal contaminated soils (Idris et al. 2004; Barzanti et al. 2007). Not much information is available about the composition of bacterial communities present in the contaminated industrial area. Recent studies have revealed the higher tolerance, and applications in agriculture and industrial soils of the strains isolated from heavy metal rich habitats (Barzanti et al. 2007; Dell'Amico et al. 2008; Idris et al. 2004; Piotrowska-Seget et al. 2005; Rajkumar and Freitas 2008). The isolates recognized in present study have shown higher resistance against Zn and Cd, may these isolates can contribute towards phytoremediation and plant growth promoting traits on the soils under the stress of heavy metals including Cd and Zn.

Most of the commonly known heavy metal accumulators have a slow growth rate and low biomass. It has been reported that plant growth promoting bacteria could promote the growth and heavy metal uptake of plants (Sheng and Xia 2006; Rajkumar and Freitas 2008). Bacteria having the characteristics of siderophore production, indole acetic acid production, phosphate solubilisation and hydrogen cyanide production may have the potential for the promotion of plant growth and heavy metal accumulation (Dell'Amico et al. 2008; Jiang et al. 2008; Sheng et al. 2008). The current study showed that several of isolated strains examined possessed plant growth promoting characteristics (Table 1). Additionally, plant growth promoting bacteria are pathogenic and they can cause disease. So to avoid this risk on preliminary level, in current study antibacterial

susceptibility of all isolates was checked against eight antibiotics. It was observed that Ciprofloxacin-1 has higher inhibition against all the isolated bacterial strains. Hence, on the basis of initial studies, Ciprofloxacin-1 may use as against the pathogenic diseases, if these disease cause by the four isolates of current study.

Conclusion

In the current study, heavy metals analysis from seven industrial areas was assessed in conjunction with isolation of plant growth promoting bacterial strains from the most polluted areas. These isolated bacterial strains showed multiple heavy metal resistance and plant growth-promoting characteristics. These activities may allow the use of isolates for plant growth promotion and bacteria-assisted phytoremediation of chromium copper, arsenic, lead, zinc, and copper-contaminated soils. Future work will address the applications of selected bacteria in the phytoremediation of heavy metals and pesticides decomposition including the mechanisms involved.

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