Cr (VI) Reduction by Indigenous Bacillus Species PB5 Isolated from Contaminated Soil of Abeokuta Ogun State, Nigeria

Parvaze Ahmad Wani, Adeosun Bukola Omozele, Idris Adegbite Wasiu and Kuranga Oluropo Jamiu

Department of Biological Sciences, College of Natural and Applied Sciences, Crescent University, Abeokuta, Ogun State, Nigeria

ABSTRACT

Chromium (VI) contamination has accelerated due to rapid industrialization worldwide. Aim of this study is to check the bacterial species for their tolerance towards chromium (VI), chromium (VI) reduction under various pH and further check whether these bacteria are reducing Cr (VI) under the influence of various metals, carbon source and protein denaturant. Bacterial strains were isolated from metal contaminated soils of Abeokuta. All of the isolates showed tolerance to chromium (VI). Among all the strains, only Bacillus species PB5 showed reduction of Chromium (VI). Maximum reduction (90%) of chromium (VI) was observed at pH 7 by Bacillus species PB5. Similarly, Bacillus species PB5 also reduced the chromium considerably at pH 6 (86%) and pH 8 (87.5%) at a concentration of 100 μg Cr mL⁻¹ after 120 h of incubation. Bacillus species PB5 also showed chromium (VI) reduction under various metals, protein denaturant and carbon source. There was maximum decrease in Cr (VI) reduction under the influence of PbCl₂ which was followed by ZnCl₂. Urea and citrate also decreased Cr (VI) reduction compared to control cells. Due to above properties strains could therefore be used as bioremediators of metals in soils contaminated with heavy metals.

Key words: Bacillus species, Chromium (VI) tolerance, antibiotic resistance, chromium (VI) reduction, carbon source, metals

INTRODUCTION

The contamination of chromium (VI) is mainly due to the use of Cr (VI) in leather, tanning, metallurgy, electroplating, textile and pigment manufacturing industries (Wang and Xiao, 1995; Pattanapipitpaisal et al., 2001a; Sultan and Hasnain, 2007). Chromium occurs either in trivalent or hexavalent which affect growth of microorganisms present in the environment (Ortegel et al., 2002). Hexavalent chromium is highly soluble in water, permeable through biological membranes and interacts with proteins and nucleic acids which makes it more toxic and carcinogenic than trivalent (Kamaludeen et al., 2003; Ackerley et al., 2006). Reduction of Cr (VI) leads to the formation of stables, less soluble and less toxic Cr (III). Reduction of toxic Cr (VI) to Cr (III) is thus a useful process for remediation of Cr (VI) affected environments (Jeyasingh and Philip, 2005). The reduction/detoxification of Cr (VI) by microbes is, however, inexpensive and environmentally safe approach and provides a viable option to protect the environment from chromium toxicity. The
reduction of Cr (VI) is reported in *Bacillus* (Nguema et al., 2014; Elangovan et al., 2006; Chaturvedi, 2011), *Pseudomonas* sp. (Wani and Ayoola, 2015; Rahman et al., 2007), *Escherichia coli* (Bae et al., 2005), *Microbacterium* (Pattanapipitpaisal et al., 2001b), *Ochrobactrum intermedium* (Faisal and Hasnain, 2005) and *Micrococcus* (Sultan and Hasnain, 2005).

Detoxification of chromium by microbes may occur directly or indirectly and is affected by pH, chromate concentration, incubation periods and the types of microbes involved. In the direct mechanism, microbes enzymatically (chromium reductases) reduce chromium (Soni et al., 2013; Losi et al., 1994) while in the indirect method, reductants or oxidants, such as H$_2$S, reduce chromium (DeFilippi and Lupton, 1992). Furthermore, in growing cultures with added carbon sources as electron donors and in cell suspensions, Cr (VI) reduction can be predominantly aerobic or anaerobic but generally not both. Interestingly, chromium reductases can catalyse reduction of Cr (VI) to Cr (III) anaerobically (Lovely and Phillips, 1994), aerobically (Cervantes et al., 2001) and also both anaerobically and aerobically (Marsh and McInerney, 2001). The Cr (VI) reductase may be present in the membrane fraction of the cells of PGPR, as found in *Pseudomonas fluorescens* and *Enterobacter cloacae* (Wang et al., 1990) and *Arthrobacter* species (Dey and Paul, 2013). The reduction of Cr (VI) to Cr (III) results in the formation of insoluble precipitate [Cr(OH)$_3$], which is easily removed from wastewater (Jeyasingh and Philip, 2005). The enzyme chromium reductase found in *P. ambigua* (Campos-Garcia et al., 1997) and *Bacillus* sp. (Wang et al., 1991) were purified and characterized. More recently, to clone a chromate reductase gene, novel soluble chromate reductase of *P. putida* was purified to homogeneity and characterized (Puzon et al., 2002). The reductase activity was NADH- or NADPH-dependent. Reduction of Cr (VI) by H$_2$S produced by the bacterial cells is found in soil environments which are rich in sulfate under anaerobic conditions (Losi et al., 1994). Hydrogen sulfide, produced in acid sulfate soil under reducing conditions, is easily precipitated as FeS in reduced soils (Eary and Rai, 1991) and sediments. Fe (II) and H$_2$S, both microbially produced, are effective reductants of Cr (VI) under reduced conditions as is the FeS (Karnachuk, 1995). Present study was therefore under taken to check the chromium (VI) reduction ability of the bacterial species under the influence of different environmental factors.

**MATERIALS AND METHODS**

**Collection of soil sample:** The soil samples for the isolation of Chromium (VI) resistant bacteria were collected from the contaminated soils of Abeokuta, Ogun state, Nigeria. Abeokuta is situated at 7.15° North latitude, 3.35° East longitude and 67 m elevation above the sea level.

**Isolation of bacteria:** Bacteria were isolated from the contaminated soil of Abeokuta on nutrient agar medium by spread plate technique (Holt et al., 1994). One milliliter of water sample was added to a flask containing 100 mL of normal saline solution and was serially diluted. A 10 μL of each suspension was spread plated on solid nutrient agar. Plates were incubated at 28±2°C for 24 h and the bacterial colonies were then purified and preserved on nutrient agar slants for further experiments.

**Morphological and biochemical characterization of bacterial species:** Morphological and biochemical characterization of the bacterial isolates were performed according to the Bergey's manual (Holt et al., 1994). Characteristics of catalase, urease, oxidase, starch hydrolysis, gelatin liquefaction, Voges-Proskauer (V.P.), Methyl Red (M.R.), indole production, H$_2$S production and the utilization of carbon/nitrogen sources were tested.
Evaluation of bacterial strains for chromium (VI) tolerance: The isolated bacterial strains were tested for their sensitivity/resistance to chromium (VI) by agar plate dilution method Holt et al. (1994) using nutrient agar. The freshly prepared agar plates amended with increasing concentration of chromium (0-1000 μg mL⁻¹) were spot inoculated (10 μL) with 10⁸ cells mL⁻¹. Plates were incubated at 28±2°C for 72 h and the highest concentration of heavy metals supporting growth was defined as the Maximum Resistance Level (MRL). Each experiment was replicated three times.

Determination of antibiotic resistance of the bacterial strains: To determine the resistance to antibiotics, the bacterial strains were tested for their sensitivity to thirteen different antibiotics. Their reactions to antibiotics were determined by the disc diffusion method. A 0.1 mL of the overnight grown broth culture was spread on the surface of nutrient agar. The antibiotic discs of known potency were then placed on the agar surface and then the plates were incubated at 28±2°C for 24 h. The zones of inhibition around the antibiotic discs were measured (in millimeter) against the following antibiotics that were used: tetracycline (10 μg), nitrofurantoin (300 μg), gentamycin (10 μg), Cloxacillin (5 μg), Cotrimoxazole (25 μg), Chloramphenicol (30 μg), Augmentin (30 μg), Amoxycillin (25 μg), Erythromycin (5 μg), Cefuroxine (30 μg), Ceftazidine (30 μg), Ciprofloxacin (5 μg), Nitrofurantoin (300 μg) and Ofloxacin (5 μg).

Chromium (VI) reduction by Bacillus species: To assess the effect of pH on hexavalent chromium [Cr (VI)] reduction in vitro, the Nutrient Broth (NB) was amended with 100 μg mL⁻¹ of Cr (VI) and the autoclaved medium was adjusted to pH 6, 7 and 8 with 1 M HCL or 1 M NaOH and incubated at 28±2°C for 120 h. For Cr (VI) reduction, 1 mL culture from each flask was centrifuged (6000 rpm) for 10 min at 10°C and Cr (VI) in the supernatant was determined by 1,5-diphenyl carbazide method (Eaton et al., 1992) upto 120 h. Briefly, the test samples were acidified (pH 1-2) and 1,5-diphenyl carbazide (50 μg mL⁻¹) was added and Cr (VI) concentration was detected by UV-VIS spectrophotometer at 540 nm.

Effect of metal ions, electron donors and protein denaturants on Cr (VI) reduction: To assess the effect of (0.1 mM each) metal ions (CuCl₂, ZnCl₂ and PbCl₂), electron donor (citrate) protein denaturants (urea) on hexavalent chromium [Cr (VI)] reduction in vitro, the Nutrient Broth (NB) was amended with 100 μg mL⁻¹ of Cr (VI) and CuCl₂, ZnCl₂, PbCl₂, citrate and urea. The autoclaved medium was adjusted to pH 7 with 1 M HCL or 1 M NaOH and incubated at 28±2°C for 120 h. After incubation, the bacterial culture solutions were centrifuged (6,000 rpm⁻¹ for 20 min at 4°C) and Cr(VI) concentration was measured as described above.

Data of three replicates were subjected to statistical analysis using sigma plot 12.0. The values indicate the Mean±SD of three replicates.

RESULTS AND DISCUSSION

Characterization of bacterial isolates: All the bacterial isolates were characterized based on morphological and biochemical tests and were all found to be Bacilli, gram negative, oxidase positive, urease positive, catalase positive, citrate positive and MRVP test positive. They also utilized different carbon sources. Based on the above properties strain PB1, PB3, PB4 and PB5 were characterized as Bacillus ssp. whereas PB2 Staphylococcus spp. and PB6 as Klebsiella ssp.
Evaluation of bacterial for Cr (VI) tolerance: In this study all the bacterial strains were checked for their resistance to Cr (VI) by agar plate dilution method (Fig. 1). Generally, bacterial strains showed a varied level of tolerance to Cr (VI). Among the bacterial strains, \textit{Klebsiella} spp. PB6 and \textit{Bacillus} spp. PB 5 showed highest tolerance to Chromium (VI) at a concentration of 1000 µg mL$^{-1}$. There are reports which showed the resistance of bacteria to Cr (VI) (Wani \textit{et al.}, 2015; Wani and Khan, 2013). There are many reports which showed varied level of tolerance by bacteria. This varied level of resistance could be due to the variation in growth conditions employed (Rajkumar \textit{et al.}, 2005). For example, \textit{Intrasporangium} sp. Q5-1 has shown a tolerance level of 17 mM to Cr (VI) (Yang \textit{et al.}, 2009) while as \textit{Bacillus} spp. PZ3 and \textit{Streptococcus} spp. The PZ4 showed highest tolerance to Chromium (VI) at concentration of 700 µg mL$^{-1}$ (Wani \textit{et al.}, 2015).

Resistance of the bacterial isolates to antibiotics: Resistance to antibiotics among different isolated metal-tolerant bacterial strains differed considerably (Table 1). Among the isolated bacterial isolates, 100% were resistant to ciprofloxacin and ofloxacin, 83.33% to Nitrofurantoin, Erythromycin, Cefuroxine and Ceftazidine, whereas 66.66% strains to Tetracycline. No strain was found to be resistant to Augumentin and Gentamycin (Table 1).

Effect of pH on Cr (VI) reduction: Chromium is an environmental pollutant released from various industries including tanneries, metal cleaning and processing, chromium plating, wood

Table 1: Resistant pattern of bacterial species to various antibiotics

| Antibiotics used | Concentrations (µg mL$^{-1}$) | No. of resistant isolates (%) |
|------------------|-------------------------------|------------------------------|
| Tetracycline     | 10                            | 4 (66.66)                    |
| Cloxacillin      | 5                             | 2 (33.33)                    |
| Chloramphenicol  | 30                            | 0 (0.00)                     |
| Nitrofurantoin   | 200                           | 5 (83.33)                    |
| Augumentin       | 30                            | 0 (0.00)                     |
| Gentamycin       | 10                            | 0 (0.00)                     |
| Cotrimoxazole    | 25                            | 3 (50.00)                    |
| Ampicillin       | 25                            | 2 (33.33)                    |
| Erythromycin     | 5                             | 5 (83.33)                    |
| Cefuroxine       | 30                            | 5 (83.33)                    |
| Ceftazidine      | 30                            | 5 (83.33)                    |
| Ciprofloxacin    | 5                             | 6 (100.00)                   |
| Ofloxacin        | 5                             | 6 (100.00)                   |

Fig. 1: Maximum tolerance level of different bacterial isolates to chromium (VI)
processing and alloy formation. Chromium [Cr (VI)] is the most toxic and carcinogenic (Kamaludeen *et al*., 2003) due to its high solubility, rapid permeability and their intracellular proteins and nucleic acids (Reeves *et al*., 1983). The reduction of Cr (VI) leads to the formation of stable, less soluble and less toxic Cr (III) and is thus, a useful process for remediation of Cr (VI) affected environments (Thacker *et al*., 2007). Thus detoxifications of chromium by bacterial strains is thus a good technique to clean the environment from chromium. Therefore, the present study was designed to determine the Cr (VI) reducing ability of the metal tolerant strains.

Among all the strains, only one strain *Bacillus* spp. PB5 showed chromium reducing ability under *in vitro* conditions as this strain was highly resistant to chromium (VI). This study was carried out to access the effect of different pH values on the reduction of Cr (VI).

The effect of different pH values on the reduction of chromium (VI) is shown in Fig. 2. Maximum reduction (90%) of chromium (VI) was observed at pH 7 by *Bacillus* sp. PB5. Similarly *Bacillus* spp. PB5 also reduced chromium considerably at pH 6 (86%) and pH 8 (87.5%), respectively, at a concentration of 100 μg Cr mL⁻¹ after 120 h of incubation.

Present study is in correlation with the study of Yang *et al*. (2009) who also observed considerable reduction of chromium. Cr (VI) reduction under various pH and different concentrations of Cr (VI) was also observed by Wani *et al*. (2015), who observed maximum reduction of Cr (VI) at pH 7.0 and 100 μg mL⁻¹ of chromium.

**Effect of metal ions, electron donors and protein denaturants on Cr (VI) reduction:** The effect of different metal ions, electron donor and protein denaturant on the reduction of chromium (VI) is shown in Fig. 3. Maximum effect on Cr (VI) reduction by *Bacillus* sp. PB5 was shown by PbCl₂, followed by ZnCl₂ whereas less effect was shown by CuCl₂. Citrate and urea also showed decrease in chromium reduction but urea showed more effect on reduction as compared to citrate. This study has concluded that nutrient broth is best for Cr (VI) reduction in comparison to citrate. Metal ions have been known to affect chromate reductase activity. Ohtake *et al*. (1990) reported that Cu²⁺ inhibit the chromate reductase activity of *Enterobacter cloacae* whereas Park *et al*. (2000) found reduction in soluble chromate reductase activity in *Pseudomonas putida*. In another study Pal *et al*. (2013) also found reduction in soluble chromate reductase activity in *B. sphaericus* AND 303. Metal ions may affect microbial Cr (VI) reduction in two ways: destruction of cells (decrease in cell growth) and inhibition of enzymes responsible for Cr (VI) reduction. Metal ions may absorb on to cell walls or complex with enzymes responsible for Cr (VI) reduction.

Fig. 2: Effect of pH on Cr (VI) reduction ability of *Bacillus* species PB5 after 120 h of growth in nutrient broth
Citrate has shown decrease in the Cr (VI) reduction compared to control. It has shown a Cr (VI) reduction of 74% and decreased Cr (VI) reduction by 16% compared to control. Similar decrease in Cr (VI) by citrate compared to control has been shown by Soni et al. (2013). In another study Yang et al. (2009) found decrease in chromium (VI) reduction by NADH, methanol and ethanol compared to control. In this study we found decrease in Cr (VI) reduction by acetate possibly because Cr (VI) reductase enzyme of strain PB5 is not acetate dependent. Urea has shown decrease in Cr (VI) reduction compared to control. Similar decrease in Cr (VI) reduction by urea has been studied by Soni et al. (2013).

CONCLUSION
This study concludes that the bacterial strain not only tolerated metal ions and antibiotics but also reduced chromium (VI) under different pH, protein denaturant, carbon source and metals. Due to multifarious properties expressed by the bacterial strain, this strain could therefore be used as bioremediator of metals in soils contaminated with heavy metals. Therefore, the findings of this study would help in developing appropriate conditions for the treatment of contaminated effluents/soils. In future we can study the role of chromium reductase enzyme for the reduction of Cr (VI) to Cr (III).

REFERENCES
Ackerley, D.F., Y. Barak, S.V. Lynch, J. Curtin and A. Matin, 2006. Effect of chromate stress on Escherichia coli K-12. J. Bacteriol., 188: 3371-3381.
Bae, W.C., H.K. Lee, Y.C. Choe, D.J. Jahng and S.H. Lee et al., 2005. Purification and characterization of NADPH-dependent Cr(VI) reductase from Escherichia coli ATCC 33456. J. Microbiol., 43: 21-27.
Campos-Garcia, J., G. Martinez-Cadena, R. Alvarez-Gonzalez and C. Cervantes, 1997. Purification and partial characterization of a chromate reductase from Bacillus. Rev. Latinoam. Microbiol., 39: 73-81.
Cervantes, C., J. Campos-Garcia, S. Devars, F. Gutierrez-Corona, H. Loza-Tavera, J.C. Torres-Guzman and R. Moreno-Sanchez, 2001. Interactions of chromium with microorganisms and plants. FEMS Microbiol., 25: 335-347.
Chaturvedi, M.K., 2011. Studies on chromate removal by chromium-resistant Bacillus sp. isolated from tannery effluent. J. Environ. Protect., 2: 76-82.

DeFilippi, L.J. and F.S. Lupton, 1992. Bioremediation of soluble Cr (VI) using sulfate reducing bacteria in Allied Signal Research. Proceedings of the National R and B Conference on the Control of Hazardous Materials, San Francisco, February 4, 1992, pp: 1-138.

Dey, S. and A.K. Paul, 2013. Evaluation of in vitro reduction of hexavalent chromium by cell-free extract of Arthrobacter sp. SUK 1201. Br. Microbiol. Res. J., 3: 325-338.

Eary, L.E. and D. Rai, 1991. Chromate reduction by subsurface soils under acidic conditions. Soil Sci. Soc. Am. J., 55: 676-683.

Eaton, A.D., L.S. Clesceri and A.E. Greenberg, 1992. Standard Methods for the Examination of Water and Wastewater. APHA/AWWA/WEF., Washington, DC., USA., Pages: 981.

Elangovan, R., S. Abhipsa, B. Rohit, P. Ligy and K. Chandraraj, 2006. Reduction of Cr(VI) by a Bacillus sp. Biotechnol. Lett., 28: 247-252.

Faisal, M. and S. Hasnain, 2005. Bacterial Cr(VI) reduction concurrently improves sunflower (Helianthus annuus L.) growth. Biotechnol. Lett., 27: 943-947.

Holt, J.G., N.R. Kreig, P.H.A. Sneath, J.T. Staley and S.T. Williams, 1994. Bergeys Manual of Determinative Bacteriology. 9th Edn., Williams and Wilkins, New York, USA.

Jeyasingh, J. and L. Philip, 2005. Bioremediation of chromium contaminated soil: Optimization of operating parameters under laboratory conditions. J. Hazrad. Mater., 1: 113-120.

Kamaludeen, S.P.B., M. Megharaj, A.L. Juhasz, N. Sethunathan and R. Naidu, 2003. Chromium-microorganism interactions in soils: Remediation implications. Rev. Environ. Contaim. Toxicol., 178: 93-164.

Karnachuk, O.V., 1995. Influence of hexavalent chromium on hydrogen sulfide formation by sulfate-reducing bacteria. Microbiology, 64: 262-265.

Losi, M.E., C. Amrhein and W.T. Frankenberger Jr., 1994. Environmental biochemistry of chromium. Rev. Environ. Contam. Toxicol., 136: 91-121.

Lovely, D.R. and E.J.P. Phillips, 1994. Reduction of chromate by Desulfovibrio vulgaris and its C3 cytochrome. Applied Environ. Microbiol., 60: 726-728.

Marsh, T.L. and M.J. McInerney, 2001. Relationship of hydrogen bioavailability to chromate reduction in aquifer sediments. Applied Environ. Microbiol., 67: 1517-1521.

Nguema, P.F., Z. Luo and J.J. Lian, 2014. Enzymatic chromium (VI) reduction by cytoplasmic and cell membrane fractions of chromate-reducing bacterium isolated from sewage treatment plant. Int. J. Biol., 6: 64-76.

Ohtake, H., E. Fujii and K. Toda, 1990. Reduction of toxic chromate in an industrial effluent by use of a chromate reducing strain of Enterobacter cloacae. Environ. Technol., 11: 663-668.

Ortegel, J.W., E.D. Staren, L.P. Faber, W.H. Warren and D.P. Braun, 2002. Modulation of tumor-infiltrating lymphocyte cytolytic activity against human non-small cell lung cancer. Lung Cancer, 36: 17-25.

Pal, A., S. Datta and A.K. Paul, 2013. Hexavalent chromium reduction by immobilized cells of Bacillus sphaericus AND 303. Braz. Arch. Biol. Technol., 56: 505-512.

Park, C.H., M. Keyhan, B. Wielinga, S. Fendorf and A. Matin, 2000. Purification to homogeneity and characterization of a novel Pseudomonas putida chromate reductase. Applied Environ. Microbiol., 66: 1788-1795.

Pattanapipitpaisal, P., N.L. Brown and L.E. Macaskie, 2001a. Chromate reduction by Microbacterium liquefaciens immobilised in polyvinyl alcohol. Biotechnol. Lett., 23: 61-65.
Pattanapipitpaisal, P., N.L. Brown and L.F. Macaskie, 2001b. Chromate reduction and 16S rRNA identification of bacteria isolated from a Cr(VI)-contaminated site. Applied Microbiol. Biotechnol., 57: 257-261.

Puzon, G.J., J.N. Petersen, A.G. Roberts, D.M. Kramer and L. Xun, 2002. A bacterial flavin reductase system reduces chromate to a soluble chromium(III)-NAD$^+$ complex. Biochem. Biophys. Res. Commun., 294: 76-81.

Rahman, M.U., S. Gul and M.Z.U. Haq, 2007. Reduction of chromium (VI) by locally isolated *Pseudomonas* sp. C-171. Turk. J. Biol., 31: 161-166.

Rajkumar, M., R. Nagendran, K.J. Lee and W.H. Lee, 2005. Characterization of a novel Cr$^{6+}$ reducing *Pseudomonas* sp. with plant growth-promoting potential. Curr. Microbiol., 50: 266-271.

Reeves, M.W., L. Pine, J.B. Neilands and A. Balows, 1983. Absence of siderophore activity in *Legionella* species grown in iron-deficient media. J. Bacteriol., 154: 324-329.

Soni, S.K., R. Singh, A. Awasthi, M. Singh and A. Kalra, 2013. *In vitro* Cr(VI) reduction by cell-free extracts of chromate-reducing bacteria isolated from tannery effluent irrigated soil. Environ. Sci. Pollut. Res., 20: 1661-1674.

Sultan, S. and S. Hasnain, 2005. Chromate reduction capability of a gram positive bacterium isolated from effluent of dying industry. Bull. Environ. Contam. Toxicol., 75: 699-706.

Sultan, S. and S. Hasnain, 2007. Reduction of toxic hexavalent chromium by *Ochrobactrum intermedium* strain SDCr-5 stimulated by heavy metals. Biores. Technol., 98: 340-344.

Thacker, U., R. Parikh, Y. Shouche and D. Madamwar, 2007. Reduction of chromate by cell-free extract of *Brucella* sp. isolated from Cr(VI) contaminated sites. Bioresour. Technol., 98: 1541-1547.

Wang, P.C., K. Toda, H. Ohtake, I. Kusaka and I. Yabe, 1991. Membrane-bound respiratory system of *Enterobacter cloacae* strain HO1 grown anaerobically with chromate. FEMS Microbiol. Lett., 78: 11-15.

Wang, P.C., T. Mori, K. Toda and H. Ohtake, 1990. Membrane-associated chromate reductase activity from *Enterobacter cloacae*. J. Bacteriol., 172: 1670-1672.

Wang, Y.T. and C. Xiao, 1995. Factors affecting hexavalent chromium reduction in pure cultures of bacteria. Water Res., 29: 2467-2474.

Wani, P.A. and M.S. Khan, 2013. Nickel detoxification and plant growth promotion by multi metal resistant plant growth promoting *Rhizobium* species RL9. Bullet. Environ. Contam. Toxicol., 91: 117-124.

Wani, P.A. and O.H. Ayoola, 2015. Bioreduction of Cr (VI) by heavy metal resistant *Pseudomonas* species. J. Environ. Sci. Technol., 8: 122-130.

Wani, P.A., I.O. Zainab, I.A. Wasiu and K.O. Jamiu, 2015. Chromium (Vi) reduction by Streptococcus species isolated from the industrial area of Abeokuta, Ogun State, Nigeria. Res. J. Microbiol., 10: 66-75.

Yang, J., M. He and G. Wang, 2009. Removal of toxic chromate using free and immobilized Cr(VI)-reducing bacterial cells of *Intrasoporangium* sp. Q5-1. World. J. Microbiol. Biotechnol., 25: 1579-1587.