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Research Article

Bioremediation of Lead and Chromium from Wastewater by Pseudomonas Putida and Bacillus Subtilis Isolated from oil Contaminated soil: A Comparative Study

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Abstract

This study investigated the bioremediation potential of Pseudomonas putida and Bacillus subtilis, isolated from oil-contaminated soil, for removing lead and chromium from synthetic wastewater. The bacteria were identified using biochemical tests and 16S rDNA sequencing. Maximum tolerance levels to chromium and lead were determined for multiple isolates of each species. Bioremediation experiments were conducted over 8 days using pure cultures of each bacterium and a mixed culture. P. putida showed higher tolerance and removal efficiency for both metals compared to B. subtilis. The mixed culture demonstrated synergistic effects, achieving 93.6% chromium removal and 91.6% lead removal after 8 days, outperforming the individual cultures. This study highlights the potential of using P. putida and B. subtilis, particularly in combination, for effective bioremediation of chromium and lead from contaminated wastewater. Further optimization of growth conditions and metabolic pathways could enhance the heavy metal removal efficiency of these bacterial species.

Key Words: microbiome; physical health; mental health

Introduction

Heavy metals such as lead and chromium are common contaminants in industrial and municipal wastewaters, posing serious threats to the environment and public health due to their toxic nature, non-biodegradability, and accumulative behaviors (Al-Enezi, Hamoda, and Fawzi 2004). These metals can enter wastewater through industrial discharges, household chemicals, and various anthropogenic activities like metal finishing, paint manufacturing, and electroplating (Dongre 2021).

Interestingly, while chromium in its trivalent form ($Cr3^{+}$) is vital for metabolism in small quantities, its hexavalent form (Cr6+) is highly toxic, carcinogenic, and mutagenic (Laxmi and Kaushik 2020). Similarly, lead, even in small amounts, can cause acute health disorders when ingested beyond stringent levels (Feng et al. 2018). Both metals can bioaccumulate in the food chain, ultimately affecting human health through contaminated water and food sources (Sharifuzzaman et al. 2016). Various methods have been developed for the removal of heavy metals from wastewater, including ion exchange, membrane filtration, chemical precipitation, and adsorption (Muchie and Akpor 2010).

Biological approaches, such as bioremediation, are emerging as eco-friendly alternatives to physicochemical metho (Laxmi and Kaushik 2020). Bioremediation using microorganisms has emerged as a promising, cost-effective, and environmentally friendly approach for removing heavy metals from contaminated environments. Microbes possess various mechanisms for metal sequestration, enabling them to have high metal biosorption capacities (Kulshreshtha et al. 2014). This method is considered safer, cleaner, and more effective than traditional physicochemical approaches for decontaminating sites polluted with a wide range of contaminants (Ayangbenro and Babalola 2017). Bioremediation presents a viable alternative to conventional heavy metal removal techniques, offering a sustainable solution to environmental pollution. As research in this field continues to evolve, bioremediation is poised to play a crucial role in environmental protection and sustainable development (Fouda-Mbanga et al. 2024).

Pseudomonas putida is a highly versatile bacterium with remarkable metabolic capabilities, enabling it to adapt to various environmental niches and effectively degrade a wide range of pollutants, including heavy metals. The genome sequences of several *P. putida* strains have revealed their

diverse metabolic activities and ability to thrive in contaminated environments (Wu et al. 2011).

Chromate reductase enzymes play a crucial role in bacterial resistance to hexavalent chromium (Cr (VI)) by facilitating its reduction to the less toxic trivalent chromium (Cr (III)). These enzymes are widely distributed among various bacterial species and are considered a key strategy for detoxifying Cr(VI) (Ghosh, Jasu, and Ray 2021).Interestingly, the efficiency of chromate reduction varies among different bacterial strains. For instance, Lactobacillus strains have been reported to completely reduce 32 ppm of Cr(VI) within 6 to 8 hours, making them faster in Cr(VI) reduction than any other known bacteria (Mishra et al. 2012) .

Similarly, *Escherichia coli* FACU demonstrated a chromate reductase specific activity of 361.33 µmol/L of Cr(VI) per min per mg protein (Mohamed et al. 2020).

Chromate reductase enzymes are essential for bacterial chromium detoxification and bioremediation. These enzymes not only protect the bacteria from Cr (VI) toxicity but also offer potential applications in environmental cleanup. The development of immobilized enzymatic systems (Robins et al. 2013). *Bacillus subtilis* has indeed been extensively studied for its ability to sequester heavy metals through biosorption and bioaccumulation. Multiple studies have demonstrated its effectiveness in removing various heavy metals from contaminated environments. *Bacillus subtilis* has shown significant potential for heavy metal removal through biosorption, which is a cell surface phenomenon [15]. The biosorption process is influenced by factors such as pH, temperature, and contact time. Optimal conditions for B. subtilis include a pH range of 5.0-6.0 and a contact time of 30 minutes (Lorestani, Merrikhpour, and Cheraghi 2020). B. subtilis has also demonstrated the ability to bioaccumulate heavy metals intracellular (Jin et al. 2023).

The effectiveness of *Bacillus subtilis* in removing heavy metals, coupled with its adaptability to various environmental conditions, highlights its potential as a sustainable solution for addressing heavy metal contamination in different environments. The integration of these bacterial species into bioremediation processes offers a sustainable and eco-friendly alternative to conventional chemical methods. Ongoing research continues to explore the genetic and biochemical pathways involved in metal resistance and detoxification, aiming to optimize bioremediation strategies for industrial applications.

The main goal in this study is to investigate *Pseudomonas putida* and *Bacillus subtilis* bioremediation activity for lead and chromium under experiment operation conditions.

Materials And Methods

Samples Collection and bacteria isolation and identification

Soil sample was collected from contaminated site with oil from Refining and Petrochemical Company, Al-Dora, Baghdad, Iraq to isolate bacteria.

Using the spread plate method, bacteria were separated from the oil-contaminated soil and placed on nutrient agar medium. A flask holding nine milliliters of regular saline solution was filled with one gram of soil sample, which was then serially diluted. Each suspension was spread out and plated in 10 µL on solid nutrient agar. Following a 24-hour incubation period at 35°C, the bacterial colonies were isolated and maintained on nutrient agar slants for subsequent investigations.

To identify isolated colonies of heavy metal-tolerant bacteria, characteristics such as their elevation, shape, and superficial forms were noted, also biochemical testing and Gram staining(Singh and Hiranmai 2021).

Extraction of DNA and PCR amplification and sequencing of 16S rDNA

The targeted bacterial DNA was extracted by Macrogen Universal Kit according to the reported procedure (Macrogen Company Korea). The 16S rRNA genes were PCR-amplified from the genomic DNA using the bacterial Macrogen universal primer for *Pseudomonas putida* and *Bacillus subtilis* as shown in Table 1.

Pseudomonas putida			
Primer	type	type	Sequence
518F	Universal	Forward	5'CCAGCAGCCGCGGTAATACG-3'
800R	Universal	Reverse	5' TACCAGGGTATCTAATCC -3'
Bacillus subtilis			
Primer	type	type	Sequence
27F	Universal	Forward	5′AGAGTTTGATCMTGGCTCAG -3'
1492R	Universal	Reverse	5′-TACCTTGTTACGACTT -3'

Table 1: Primers of 16S rDNA used in the study.

Inoculum preparation

For every isolate and the consortium, a standardized bacterial-saline medium suspension was created. The bacterial cells from each isolate were pelleted by centrifugation at 4000 rpm for 15 min at 4oC using an Eppendorf Centrifuge, after each isolate was grown for 24 hours in nutrient broth. After two rinses, the pellet was resuspended with 0.85% NaCl to yield an OD600nm of 0.5. To create the consortium culture, each single isolate was mixed in an equal portion and topped off with 0.85% NaCl. This resulted in an end reading of OD600nm 0.5, which, according to the spread plate method, corresponds to roughly $1*10^7$ CFU per ml. Every experiment that came after it started with this culture (Wong et al. 2015)

Evaluation of bacterial strains for chromium and lead tolerance:

Using nutrient agar and the agar plate dilution method (Bergey 1994), the resistant to chromium and lead (Cr (VI) and $PbCl_2$) of the isolated bacterial strains was assessed. Spot inoculation (10 µL) of 108 mLG1 cells was performed on freshly prepared agar plates amended with increasing concentrations of Chromium (0-1400 µg/mL) and Lead (0-1000 µg/mL). The Maximum Resistance Level (MRL) was determined by incubating plates at 35°C for 72 hours, during which time the highest concentration of heavy metals that supported growth was found. Three copies of each experiment were conducted.

Chromium and lead reduction by bacterial isolates:

A 15-minute autoclave sterilization at 121 degrees Celsius was used on the wastewater. 100 ml of the sterilized wastewater was added to each of the seven 120 ml sterile conical flasks. The first flask (Control) was left uninoculated, while the second and third were infused with 20µl of a 24-hour nutrient broth culture of *Bacillus subtilis* and *Pseudomonas putida*, respectively. Two different cultures of the bacteria were added to the fourth flask for inoculation. An atomic absorption spectrophotometer was used to measure the concentrations of lead and chromium after the experiment was allowed to stand for 24 hours. When comparisons between the values obtained before and after treatment were made, percentage reductions of heavy metals were found. One milliliter of each flask's culture was centrifuged (6000 rpm) for ten minutes at 10°C in order to reduce lead and chromium. The amount of Cr (VI) in the supernatant was then measured using the 1,5-diphenyl carbazide method (Federation 1999).

For eight days, the flasks were incubated on a New Brunswick gyratory shaker. Samples were taken out every two days so that the atomic absorption spectrophotometer could be used for analysis.

Results and discussion

Table 2 presents the results of biochemical tests performed on bacterial isolates from oil-contaminated soil. These tests are crucial for identifying and differentiating between *Bacillus subtilis* and *Pseudomonas putida*. *B. subtilis*: Gram-positive (G+ve) bacilli (rod-shaped). This indicates that *B. subtilis* has a thick peptidoglycan layer in its cell wall, which retains the crystal violet stain during the Gram staining process. Furthermore, *P. putida*: Gram-negative (G-ve) rods. This confirms that *P. putida* has a thinner peptidoglycan layer and an outer membrane, which doesn't retain the crystal violet stain.

Both *B. subtilis* and *P. putida* isolates are motile. This indicates that both species possess flagella, enabling them to move in their environment, which can be important for accessing nutrients and escaping adverse conditions in the soil. *B. subtilis* is Positive for spore formation. This means that *B. subtilis* can form endospores, Nevertheless, *P. putida* is Negative for spore formation. *P. putida* does not form endospores. Both *B. subtilis* and *P. putida* are catalase-positive. This indicates both species produce the enzyme catalase, which breaks down hydrogen peroxide (a toxic byproduct of aerobic metabolism) into water and oxygen. This allows them to survive in oxygen-rich environments. *B. subtilis* is Negative for oxidase. This means it lacks the enzyme cytochrome oxidase, which is part of the electron transport chain. *P. putida*: Positive for oxidase. This indicates the presence of cytochrome oxidase. This is a crucial test for differentiating between these two genera. *Pseudomonas* are generally oxidase-positive, while *Bacillus* are oxidase-negative.

Both *B.subtilis* and *P.putida* are positive for gelatin hydrolysis. This indicates that both bacteria produce gelatinase, an enzyme that breaks down gelatin, which provides them with nutrients. *B. subtilis* was positive for starch hydrolysis. It produces amylase, an enzyme that breaks down starch. But *P. putida* was Negative for starch hydrolysis Both *B. subtilis* and *P. putida* were positive for Simmons Citrate utilization. This indicates that both bacteria can use citrate as their sole carbon source, demonstrating their metabolic versatility. *B. subtilis* was Negative for fluorescence. It does not produce fluorescent pigments. While, *P. putida* was fluorescence due to fluorescent pigments generation.

Error! Reference source not found. depicts the maximum tolerance levels of *Pseudomonas putida* to chromium and lead. *P. putida* showed the highest tolerance to chromium, with maximum tolerance levels ranging from 600 to 1200 µg/ml. Tolerance to lead was significantly lower, ranging from 100 to 400 µg/ml. Tolerance levels varied across the 6 isolates (P1 to P6), with P2 and P3 exhibiting the highest chromium tolerance at 1200 and 1000 µg/ml respectively. Lead tolerance was relatively consistent across isolates, staying below 400 µg/ml. This data indicates that the *Pseudomonas putida* isolates tested have a much greater capacity to tolerate chromium compared to lead in their environment. The substantial variability in chromium tolerance between isolates also suggests genetic diversity in chromium resistance mechanisms within this bacterial species.

The maximum tolerance levels of *Bacillus subtilis* isolates to the heavy metals chromium and lead was measured by the agar plate dilution method can be dispatched in Figure 1. Chromium tolerance ranged from 100 to 1000 µg/ml across the 8 isolates (B1 to B8). Lead tolerance was significantly lower, ranging from 100 to 400 µg/ml. The highest chromium tolerance was seen in isolates B5 and B7, at 1000 µg/ml each. Lead tolerance was relatively consistent across isolates, mostly staying below 300 units. *Bacillus subtilis* isolates demonstrated a greater capacity to tolerate chromium compared to lead. The substantial variability in chromium tolerance across isolates suggests genetic diversity in chromium resistance mechanisms within this bacterial species.

The data presented in Table 3 shows the reduction of chromium and lead concentrations in a heavy metal synthetic water sample using a pure culture of Bacillus subtilis over an 8-day period. The initial chromium concentration was 1000 µg/ml, which decreased by 5.5% to 945 µg/ml by day 2. The chromium level was further reduced by 29.5% to 705 µg/ml on day 4, 43% to 570 µg/ml on day 6, and 50.8% to 492 µg/ml on day 8. The initial lead concentration was 300 µg/ml, which decreased by 3.3% to 290 µg/ml on day 2, 31.3% to 206 µg/ml on day 4, 45.3% to 164 µg/ml on day 6, and 56.6% to 130 µg/ml on day 8. The Bacillus subtilis culture demonstrated a greater capacity to reduce lead levels compared to chromium over the 8-day period.

Recent finding by Wrobel highlighted that Bacillus subtilis can effectively remove various heavy metals, including chromium and lead, through biosorption and intracellular accumulation.(Wróbel et al. 2023) Additionally, (Tarangini et al. 2009) reported that optimizing growth conditions and metabolic pathways in Bacillus subtilis can further enhance its heavy metal removal efficiency

Error! Reference source not found. presents the bioremediation of chromium and lead by a *Pseudomonas putida* culture in a heavy metal synthetic water sample over 8 days. The initial chromium concentration was 1200 µg/ml, decreasing by 20.4% to 955 µg/ml on day 2, 46.4% to 643 µg/ml on day 4, 73.1% to 323 µg/ml on day 6, and 82.5% to 210 µg/ml on day 8. The initial lead concentration was 500 µg/ml, reducing by 36.2% to 319 µg/ml on day 2, 46% to 270 µg/ml on day 4, 73.4% to 133 µg/ml on day 6, and 81% to 95 µg/ml on day 8. The *P. putida* culture demonstrated greater capacity to remove lead compared to chromium, with lead decreasing over 81% and chromium 82.5%.

it was found *P. putida* can effectively biosorb and accumulate chromium (Olaya-Abril et al. 2024), while Ruparelia and Patel (2024) reviewed bacterial mechanisms for metal bioremediation, including *Pseudomonas*. Optimizing growth conditions and metabolic pathways in P. putida can further enhance its heavy metal removal efficiency (Abbasi et al. 2024).

The bioremediation of chromium and lead in a heavy metal synthetic water using a mixed culture of *Pseudomonas putida* and *Bacillus subtilis* can be demonstrated in **Error! Reference source not found.**. The initial chromium concentration was 1000 µg/ml, decreasing by 32.6% to 674 µg/ml on day 2, 59.8% to 402 µg/ml on day 4, 84.3% to 157 µg/ml on day 6, and 93.6% to 64 µg/ml on day 8. The initial lead concentration was 300 µg/ml, reducing by 45.3% to 164 µg/ml on day 2, 57.7% to 127 µg/ml on day 4, 74.7% to 76 µg/ml on day 6, and 91.6% to 25 µg/ml on day 8. The mixed culture demonstrated greater capacity to remove chromium compared to lead, with chromium decreasing over 93% and lead 91.6%.

Papers reported that bioremediation potential can be enhanced when of *Pseudomonas-Bacillus* consortia was applied for heavy metals removal. Kumar (2024) found the synergistic interactions between these bacteria improve metal biosorption and intracellular accumulation. Similarly Alotaibi, Khan, and Shamim (2021) reported that optimizing growth conditions and metabolic pathways in mixed cultures can further enhance heavy metal removal efficiency.

The results of DNA extraction, PCR amplification, and 16S rDNA sequencing for Pseudomonas putida and Bacillus subtilis are as follows: DNA was successfully extracted from the bacterial samples using the Macrogen Universal Kit. PCR amplification of the 16S rRNA genes was performed using specific universal primers for each bacterial species. For Pseudomonas putida, the universal forward primer 518F (5'-CCAGCAGCCGCGGTAATACG-3') and the universal reverse primer 800R (5'-TACCAGGGTATCTAATCC-3') were used. These primers amplified a region of approximately 282 base pairs within the 16S rRNA gene. For Bacillus subtilis, the universal forward primer 27F (5'-AGAGTTTGATCMTGGCTCAG-3') and the universal reverse primer 1492R (5'-TACCTTGTTACGACTT-3') were employed. This primer pair amplified a larger region of approximately 1465 base pairs within the 16S rRNA gene. The PCR products were successfully amplified and visualized using gel electrophoresis, confirming the presence of the expected DNA

fragments for both bacterial species. The amplified 16S rDNA sequences were then purified and sent for sequencing to determine the exact nucleotide composition of the amplified regions.

Biochemical test	*B. subtilis*	*P. putida*
Gram Staining	G+ve bacilli	G-ve rods
Motility	motile	motile
Spore formation	+	-
Catalase	+	+
Oxidase	-	+
Gelatin hydrolysis	+	+
Starch hydrolysis	+	-
Simmons Citrate	+	+
Fluorescence	-	+

Table 2: Results of Biochemical tests of bacterial isolated from oil contaminated soil (8 isolates of *B. subtilis* and 6 isolates of *P. putida*)

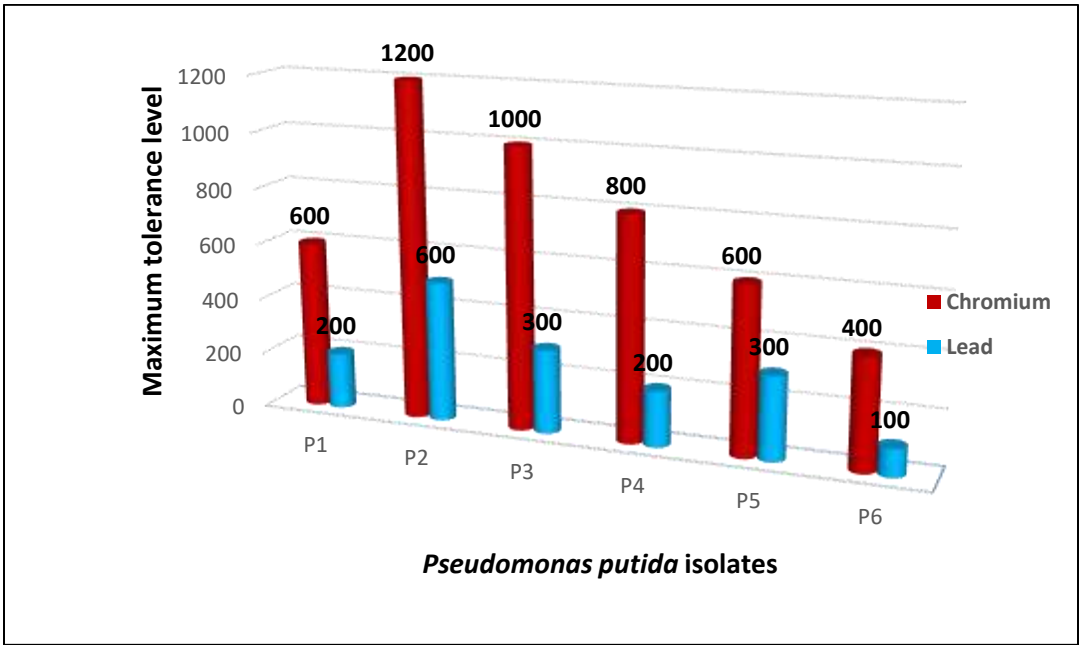

Figure 1: Maximum tolerance level of Pseudomonas putida isolates to chromium and Lead by agar plate dilution metho

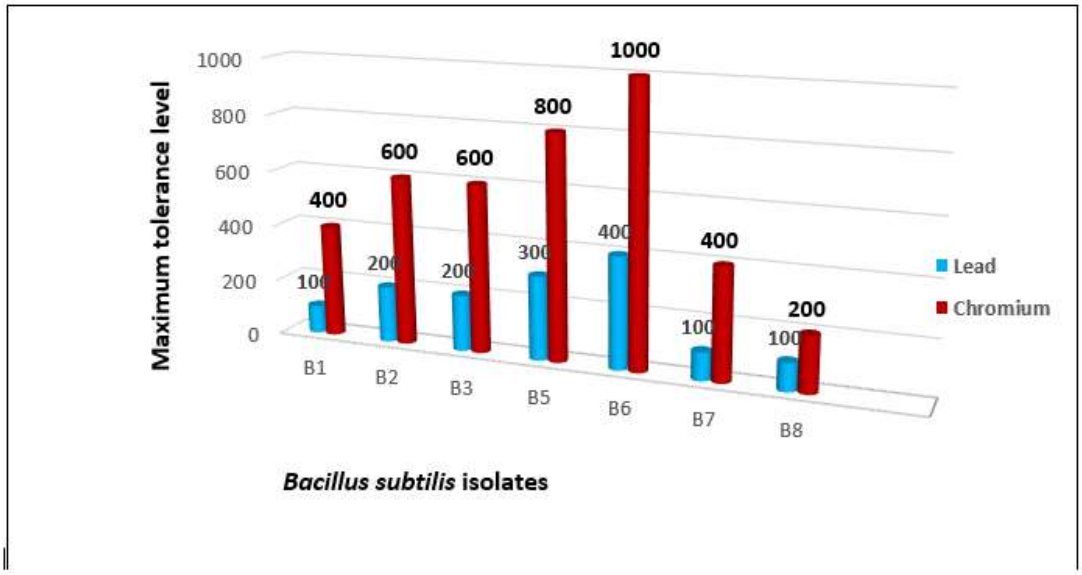

Figure 1: Maximum tolerance level of Bacillus subtilis isolates to chromium and Lead by agar plate dilution method.

Heavy metal	Initial Concentration (µg/ml)	Day 2 (reduction %)	Day 4 (reduction %)	Day 6 (reduction %)	Day 8 (reduction %)
Chromium	1000	945 (5.5%)	705 (29.5%)	570 (43%)	492 (50.8%)
Lead	300	290	206	164	130 (56.6%)

Table 3: Reduction of Chromium a nd Lead in heavy metal synthetic water using a pure culture of Bacillus subtilis

Heavy metal	Initial Concentration (µg/ml)	Day 2 (reduction %)	Day 4 (reduction %)	Day 6 (reduction %)	Day 8 (reduction %)
Chromium	1200	955	643	323	210 (82.5%)
Lead	500	319	270	133	95 (81%)

Table 4: Bioremediation of Chromium and Lead in heavy metal synthetic water using a pure culture of Pseudomonas putida

Heavy metal	Initial Concentration (µg/ml)	Day 2 (reduction %)	Day 4 (reduction %)	Day 6 (reduction %)	Day 8 (reduction %)
Chromium	1000	674	402	157	64 (93.6%)
Lead	300	164	127	76	25 (91.6%)

Table 3: Bioremediation of Chromium and Lead in heavy metal synthetic water using a mixed culture of Pseudomonas putida and Bacillus subtilis.

References

1. Abbasi, M., I. Khan, A. Rehman, A. Hayat, M. Ur Rehman, T. A. Shah, A. A. Khan, et al. (2024). "Bioremediation of Heavy Metals Contaminated Soil by Using Indigenous Metallotolerant Bacterial Isolates." Applied Ecology and Environmental Research 22 (2): 1623-1648.
2. Al-Enezi, G, M F Hamoda, and N Fawzi. (2004). "Ion Exchange Extraction of Heavy Metals from Wastewater Sludges." Journal of Environmental Science and Health, Part A 39 (2): 455-464.
3. Alotaibi, Badriyah Shadid, Maryam Khan, and Saba Shamim. (2021). "Unraveling the Underlying Heavy Metal Detoxification Mechanisms of Bacillus Species." Microorganisms 9 (8).
4. Ayangbenro, Ayansina Segun, and Olubukola Oluranti Babalola. (2017). "A New Strategy for Heavy Metal Polluted Environments: A Review of Microbial Biosorbents." International Journal of Environmental Research and Public Health 14 (1): 94.
5. Bergey, David Hendricks. (1994). Bergey's Manual of Determinative Bacteriology. Lippincott Williams & Wilkins.
6. Dongre, Rajendra Sukhjadeorao. (2021). "Chromium & Lead as Soil Pollutants: Insights on Toxicity Profiles and Their Remediation." Journal of Advanced Biotechnology and Bioengineering 9:1-16.
7. Federation, Water Environment. (1999). "Standard Methods for the Examination of Water and Wastewater Part 1000 Standard Methods for the Examination of Water and Wastewater."
8. Feng, J-J, L Jia, Q-Z Liu, X-L Chen, and J P Cheng. (2018). "Source Identification of Heavy Metals in Sewage Sludge and the Effect of Influent Characteristics: A Case Study from China." Urban Water Journal 15 (4): 381-387.
9. Fouda-Mbanga, Bienvenu Gael, Tarisa Velempini, Kriveshini Pillay, and Zikhona Tywabi-Ngeva. (2024). "Heavy Metals Removals from Wastewater and Reuse of the Metal Loaded Adsorbents in Various Applications: A Review." Hybrid Advances, 100193.
10. Ghosh, Sreejita, Amrita Jasu, and Rina Rani Ray. (2021). "Hexavalent Chromium Bioremediation with Insight into Molecular Aspect: An Overview." Bioremediation Journal 25 (3): 225-251.
11. Jin, Li, Cordelia Rampley, Yosef Abebe, Gianbattista Bussi, Trang Quynh To, Duane Ager, and Paul G Whitehead. (2023). "Assessing Heavy Metal Contamination Using Biosensors and a Multi-Branch Integrated Catchment Model in the Awash River Basin, Ethiopia." Water 15 (23): 4073.
12. Kulshreshtha, Arpita, Ranu Agrawal, Manika Barar, and Shilpi Saxena. (2014). "A Review on Bioremediation of Heavy Metals in Contaminated Water." IOSR Journal of Environmental Science, Toxicology and Food Technology 8 (7): 44-50.
13. Kumar, Deepak. (2024). "Effective Bioremediation of Heavy Metals for Environmental Sustainability Approach Using Bacillus Subtilis HIB2 and Pseudomonas Aeruginosa HIB11 Isolated from Hindon River," 1-16.
14. Laxmi, Vidya, and Garima Kaushik. (2020). "Toxicity of Hexavalent Chromium in Environment, Health Threats, and Its Bioremediation and Detoxification from Tannery Wastewater for Environmental Safety." Bioremediation of Industrial Waste for Environmental Safety: Volume I: Industrial Waste and Its Management, 223-243.
15. Lorestani, Bahareh, Hajar Merrikhpour, and Mehrdad Cheraghi. (2020). "Assessment of Heavy Metals Concentration in Groundwater and Their Associated Health Risks near an Industrial Area." Environmental Health Engineering and Management Journal 7 (2): 67-77.
16. Mishra, Ritesh, Vartika Sinha, Ambrose Kannan, and Raj K Upreti. (2012). "Reduction of Chromium-VI by Chromium Resistant Lactobacilli: A Prospective Bacterium for Bioremediation." Toxicology International 19 (1): 25.
17. Mohamed, Mahmoud S M, Nagwa I El-Arabi, Ahmed El-Hussein, Shereen Abu El-Maaty, and Abdelhadi a Abdelhadi. (2020). "Reduction of Chromium-VI by Chromium-Resistant Escherichia Coli FACU: A Prospective Bacterium for Bioremediation." Folia Microbiologica 65:687-696.
18. Muchie, Mammo, and O B Akpor. (2010). "Remediation of Heavy Metals in Drinking Water and Wastewater Treatment Systems: Processes and Application." International Journal of Physical Sciences 5 (12): 1807-1817.
19. Olaya-Abril, Alfonso, Karolina Biełło, Gema Rodríguez-Caballero, Purificación Cabello, Lara P. Sáez, Conrado Moreno-Vivián, Víctor Manuel Luque-Almagro, and María Dolores Roldán. (2024). "Bacterial Tolerance and Detoxification of Cyanide, Arsenic and Heavy Metals: Holistic Approaches Applied to Bioremediation of Industrial Complex Wastes." Microbial Biotechnology 17 (1): 1-22.
20. Robins, Katherine J, David O Hooks, Bernd H A Rehm, and David F Ackerley. (2013). "Escherichia Coli NemA Is an

Efficient Chromate Reductase That Can Be Biologically Immobilized to Provide a Cell Free System for Remediation of Hexavalent Chromium." PloS One 8 (3): e59200.

21. Ruparelia, Jayeshkumar R., and Hiren K. Patel. (2024). "Harnessing the Chromium Reduction Potential of Pseudomonas Aeruginosa JRHM33: A Comprehensive Study on Bioinformatics, Phenotype Microarray, and CCD-RSM Optimization." Heliyon 10 (15): e35650.
22. Sharifuzzaman, S M, Hafizur Rahman, S M Ashekuzzaman, Mohammad Mahmudul Islam, Sayedur Rahman Chowdhury, and M Shahadat Hossain. (2016). "Heavy Metals Accumulation in Coastal Sediments." Environmental Remediation Technologies for Metal-Contaminated Soils, 21-42.
23. Singh, Snigdha, and R. Y. Hiranmai. (2021). "Monitoring and Molecular Characterization of Bacterial Species in Heavy Metals Contaminated Roadside Soil of Selected Region along NH 8A, Gujarat." Heliyon 7 (11): e08284.
24. Tarangini, K., Arvind Kumar, G. R. Satpathy, and Vikas Kumar Sangal. (2009). "Statistical Optimization of Process Parameters for Cr (VI) Biosorption onto Mixed Cultures of Pseudomonas Aeruginosa and Bacillus Subtilis." Clean - Soil, Air, Water 37 (4–5): 319-327.
25. Wong, Kok Kee, Brid Quilty, Ainon Hamzah, and Salmijah Surif. (2015). "Phenol Biodegradation and Metal Removal by a Mixed Bacterial Consortium." Bioremediation Journal 19 (2): 104-112.
26. Wróbel, Monika, Wojciech Śliwakowski, Paweł Kowalczyk, Karol Kramkowski, and Jakub Dobrzyński. (2023). "Bioremediation of Heavy Metals by the Genus Bacillus." International Journal of Environmental Research and Public Health 20 (6).
27. Wu, Xiao, Sebastien Monchy, Safiyh Taghavi, Wei Zhu, Juan Ramos, and Daniel van der Lelie. (2011). "Comparative Genomics and Functional Analysis of Niche-Specific Adaptation in Pseudomonas Putida." FEMS Microbiology Reviews 35 (2): 299-323

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