



Cadmium (Cd) and Lead (Pb) Uptake Potential and Surface Properties of *Aeromonas* spp. Isolated from Soil of Local Mining Site

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Authors' contributions

This work was carried out in collaboration among all authors. Author UBI contributed with conventional microbiological procedures. Author SY carried out molecular analysis. Author IY aided in interpretation of statistical data. Author AHK contributed in heavy metal uptake assay. All authors read and approved the final manuscript.

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ABSTRACT

Aim: In this study, *Aeromonas* spp. isolated from soil of local mining sites were assessed for their tolerance to some heavy metals and their capability for its uptake.

Materials and Methods: The bacteria were isolated from soil of local mining site in Bagega District of Zamfara State in Nigeria. Maximum Tolerable Concentration (MTC) was employed to screen for metal tolerance of the bacteria to Cadmium (Cd) and Lead (Pb) via Agar Plate Method technique. DNA Extraction and 16sRNA Gene Sequence Analysis was carried out to identify the isolates and sequences were compared to those in NCBI database using Basic Local Alignment Search Tool (BLAST).

Results: Similarly, isolates identified were further characterized and validated by subjecting them to 16sRNA gene sequence analysis. Similarity search indicated a close genetic relatedness to *Aeromonas* spp. in NCBI database. The *Aeromonas* spp. Identified showed maximum tolerance to Pb at 27ppm and Cadmium at 24ppm. Bioaccumulation assay carried out revealed *Aeromonas* sp.

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BDL2 to take up Pb by as high as 70%. Biosorption capacity of their respective dried biomass assayed showed higher Pb uptake at 95.9% for *Aeromonas* sp. BDL2. Statistical analysis revealed a significant difference ($P \leq 0.05$) between the isolates and their respective biomass in the uptake Pb and Cd. Surface examination different bands indicated the presence of carboxyl, amine, amides, sulfates and other aromatic groups and significant shifts of surface molecules.

Conclusion: *Aeromonas* sp. BDL2 identified in this study exhibited higher tolerance to Pb. Surface molecules and their positional properties revealed the presence of hydroxyl, carboxyl, amine and amide group ligands with significant shifts after accumulation and biosorption experiment suggesting interaction between these surface molecules and heavy metal ions.

Keywords: Biosorption; bioaccumulation; uptake; soil.

1. INTRODUCTION

As our societies had gradually grown wealthier, it has created more diverse pollutants with no effective remediation measure in place. Population growth, urbanization and industrialization will in no distant future outperform the reduction strategies in place in the control of hazardous wastes being generated by human activities. Reference [1] reported heavy metals and metalloids to be widespread and of great concern, as they have both direct and indirect consequences on both human health, soil habitat and microbiota. Microorganisms' uptake heavy metals actively (bioaccumulation) and/or passively (adsorption). As maintained by Dixit et al. [2] that microbial cell walls, which mainly consist of polysaccharides, lipids and proteins, offer manyfunctional groups that can bind heavy metal ions and these include carboxylate, hydroxyl, aminoand phosphate groups. Among various microbe-mediated methods, the biosorption process seemsto be more feasible for large scale application compared to the bioaccumulation process, becausemicrobes will require addition of nutrients for their active uptake of heavy metals, which increases thebiological oxygen demand or chemical oxygen demand in the waste.

Microbes are adapted to thrive in 'adverse conditions' of high acidity/alkalinity/toxicity and high temperature. They can develop 'biological resistance' against any toxic substance in the environment due to special 'jumping genes' [3]. Hence while a number of them may be killed due to high toxicity, some resistant microbes survive and are cultured for further use. Under favorable conditions of growth e.g. pH, temperature and moisture and adequate supply of nutrients like vitamins, magnesium, manganese, copper, sulfur, potassium, phosphorus and nitrogen, microbes can biodegrade/biotransform the complex hazardous organic chemicals into

simpler and harmless ones. After the use of 'super bug' in cleaning up oil spills, there has been several successful stories of microbial technique in clean-up of contaminated lands and soils [4]. Whilst microbial remediation (bioremediation) is a well established technology for the removal of organic soil contaminants, the use of microorganisms to transform inorganic contaminants like heavy metals is still being investigated. Environmentalists are viewing microbes as an 'eco-friendly nanofactories' for metal remediation through biotechnological applications employing microbes, such as yeast, bacteria, algae, diatoms and actinomycetes, also there are bacteria which can also ingest the most toxic 'cyanide' from water [4].

2. MATERIALS AND METHODS

2.1 Isolation of Bacteria

Bacteria employed in this study were isolated from soils of local mining sites in Bagega District (11.8648°N, 6.0024°E) of Anka Local Local Government Area of Zamfara State, Nigeria. A sterilized Soil Core Sampler was used to obtain a representative sample from depth of 0-10 cm of the soil in those locations. Samples collected were moved to laboratory immediately in tightly sealed container in order to preserve the soil biological properties. Soil samples were sieved with 0.5 mm Sieve employing standard microbiological procedures. Serial dilution of the soil was carried out and spread plating was employed using a Nutrient Agar medium. All analysis carried out were in triplicates.

2.2 Preparation of Stock Solution

Stock solution of Lead acetate ($Pb(C_2H_3O_2)_2$) (1.6 g) and Cadmium (II) Chloride ($CdCl_2$) (1.63 g) were dispensed in 1000ml of distilled water to obtain 1000ppm. Working solutions of 0, 1, 2, 4, 8, 16, 32, 64ppm prepared and used in further

assays. The pH of the solutions was adjusted using 0.1 M H₂SO₄ and 0.1M NaOH. Relevant measures, such as use of standard, positive and negative controls where necessary, strict cleaning and sterilization of glassware's were absolutely observed [5,6].

2.3 Bacterial Biomass Production

Biomass of each of the tolerant species was harvested after growing the cultures in a nutrient broth (NB) medium. For each of the isolates, biomass was obtained from a 72h culture by centrifugation using Selecta Centromix Centrifuge Model 220 at 10000rpm for 15 minutes. Pellets were washed twice with deionized water and dried at 80°C for 15 minutes [7].

2.4 Screening for Cd and Pb Tolerance by the Bacteria

To identify the suitability of the isolates, Maximum Tolerable Concentration (MTC) which is defined as the highest concentration of heavy metal which bacteria can tolerate, was employed to screen for metal tolerance of the bacteria to Cd and Pb. This was achieved via Agar Plate Method in which varying concentrations of the heavy metals (0, 1, 2, 4, 8, 16, 32 and 64ppm) were prepared and incorporated into the Nutrient Agar Medium as described by [8] and adopted by [9-11]. Prepared inoculum (0.1ml) of the isolate standardized using McFarland standard was spread plated into each of the varying heavy metal supplemented Nutrient Agar media and incubated at 30°C for 48 hours.

2.5 Characterization and Identification of Isolates

The following tests and analysis were carried out to determine the morphological and biochemical characteristics of the isolates. These are Gram's Staining [12], Spore staining [13], Catalase test [12], Oxidase test [12], Starch hydrolysis test [12], Nitrate reduction test, Triple sugar iron test [13], Urease Production Test [13], Methyl Red Reaction Test [13], Voges-Proskauer test [13], Indole Production Test [13], Citrate utilization and Motility Test [13].

2.6 DNA Extraction and 16sRNA Gene Sequence Analysis

The Extraction of the DNA was carried out using the DNeasy blood and tissue kit (Qiagen Ltd.,

West Sussex, U.K). Amplification of the DNA was performed by PCR using the universal bacterial primers 16srRNA Bact1442-Forward; (5'-AGAGTTGATCCTGGCTCAG-3') and 16srRNA1492-R (5' GGTTACCTTGTTACGACTT-3'). The final PCR mixture (50µl) consisted of 0.4 µM of each primer, 250 µM of each of dNTP, 1U DynazymeTaq DNA polymerase (Finnzymes Reagents, Thermo Fisher Scientific, Inc. Finland), 1 x PCR Dynazyme buffer with final MgCl₂ concentration of 1.5 mM and 1µl of the template DNA solution. The temperature program consisted of an initial denaturation at 95° C for 1 min, 30 cycles (94°C for 30 s, 60°C for 30 s, 72°C for 1 min) and a final extension step at 72°C for 8 min. PCR products were purified by 0.8% agarose gel electrophoresis followed by extraction with QIAquick Gel Extraction Kit (Qiagen, Hilden, Germany). Purified PCR products were sequenced (GATC-Biotech, Konstanz, Germany) using PCR primers and analyzed using BLASTn search [14].

2.7 Sequence and Phylogenetic Analysis

The 16SrRNA gene sequences of the isolates were compared to the sequences in the public databases using Basic Local Alignment Search Tool (BLAST). Multiple Sequence Alignment was done using MUSCLE. The 16S rRNA gene sequences with high similarity to those determined in the study were retrieved and added to database and aligned with Mega 7 [15]. Phylogenetic trees were constructed by the Neighbour-Joining method [16] with MEGA 7 package.

2.8 Cd and Pb Uptake Assay

A Batch Equilibrium Method (a traditional method of determining metal uptake) as described by Khodaverdilo and Samadi [17] was used to determine the uptake of Cd and Pb by the bacteria. A standardized inoculum of 0.5ml was dispensed into a 100 ml of Nutrient Broth supplemented with 12ppm of each heavy metal for 72 hours with shaking. Similarly, harvested dried biomass obtained from equal volume of inoculum was dispensed into 100 ml distilled water (with 1% Nitric Acid) supplemented with 12ppm of Cd and Pb and incubate for 72 hours on a rotary shaker at 160 rev/min. Biomass was thereafter separated by centrifugation and the supernatant was analyzed for residual metal concentration by Atomic Absorption Spectrophotometry (AAS). The percentage metal uptake was calculated as follows:

$$\text{Percentage Uptake} = \frac{\text{Heavy metal utilized}}{\text{Heavy metals added}} \times 100 \quad [18]$$

2.9 Determination of Surface Characteristics of Biosorbents

Fourier transform infrared spectroscopy (FT-IR) was carried out on the isolates before and after metals uptake experiments to determine surface molecules of the bacteria. Pellets of each of the isolates was obtained and pressed unto a 16mm diameter mould. FT-IR spectra was recorded with a resolution of 1cm⁻¹ in the 4000 to 400 cm⁻¹ wave region [9,16].

3. RESULTS

3.1 Characterization of Isolates

Morphological and biochemical characterization of the isolates was presented in Table 1. Similarly, isolates identified were further characterized and validated by subjecting them to 16sRNA gene sequence analysis. Similarity search performed using BLASTn indicated a close genetic relatedness to *Aeromonas* spp. in

NCBI database as shown in Table 2. Phylogenetic relationship constructed was presented in Fig. 1.

3.2 Maximum Tolerable Concentration Assay

The *Aeromonas* spp. Identified showed maximum tolerance to Pb at 27ppm and Cadmium at 24ppm as indicated in Fig. 2.

3.3 Heavy Metal Uptake Assay

Bioaccumulation assay carried out revealed BDL2 to take up Pb by as high as 70% with BDK1 following closely at 69% as shown in Fig. 3 although statistical analysis using Anova revealed no significant difference (P≥0.05) between the isolates. Biosorption capacity of the respective biomass assayed showed higher percentage of Pb uptake by the bacterial biomass at 94.5 and 95.9% for BDK1 and BDL2 respectively. Statistical analysis employed revealed a significant difference (P≤0.05) between the isolates and their respective biomass in the uptake Pb and Cd.

Table 1. Morphological and biochemical characterization of isolates

	BDK1	BDL2
Gram Reaction	-ve	-ve
Arrangement	Rods	Rods
Motility	+ve	-ve
Spores	+ve	-ve
Starch	+ve	+ve
Catalase	+ve	+ve
Oxidase	+ve	+ve
Indole	+ve	+ve
VP	-ve	-ve
Citrate	+ve	-ve
Urease	+ve	+ve
Gelatin	+ve	-ve
Nitrate Reduction	+ve	+ve
Glucose	+ve	+ve
Lactose	+ve	+ve
Sucrose	+ve	+ve
H ₂ S	-ve	-ve
Mannitol	+ve	+ve
Gas	-ve	-ve

Table 2. Molecular characterization of isolates indicating closest hits

Isolate code	Best hit match	% Query	% Identity	Accession no.
BDL2	<i>Aeromonas jandaei</i>	95	84.92	LC361001.1
	<i>Aeromonas veronii</i>	95	84.92	MF16714.1
BDK1	<i>Aeromnassobria</i>	65	95.17	LC194875.1
	<i>Aeromonas hydrophila</i>	65	95.05	MN865804.1

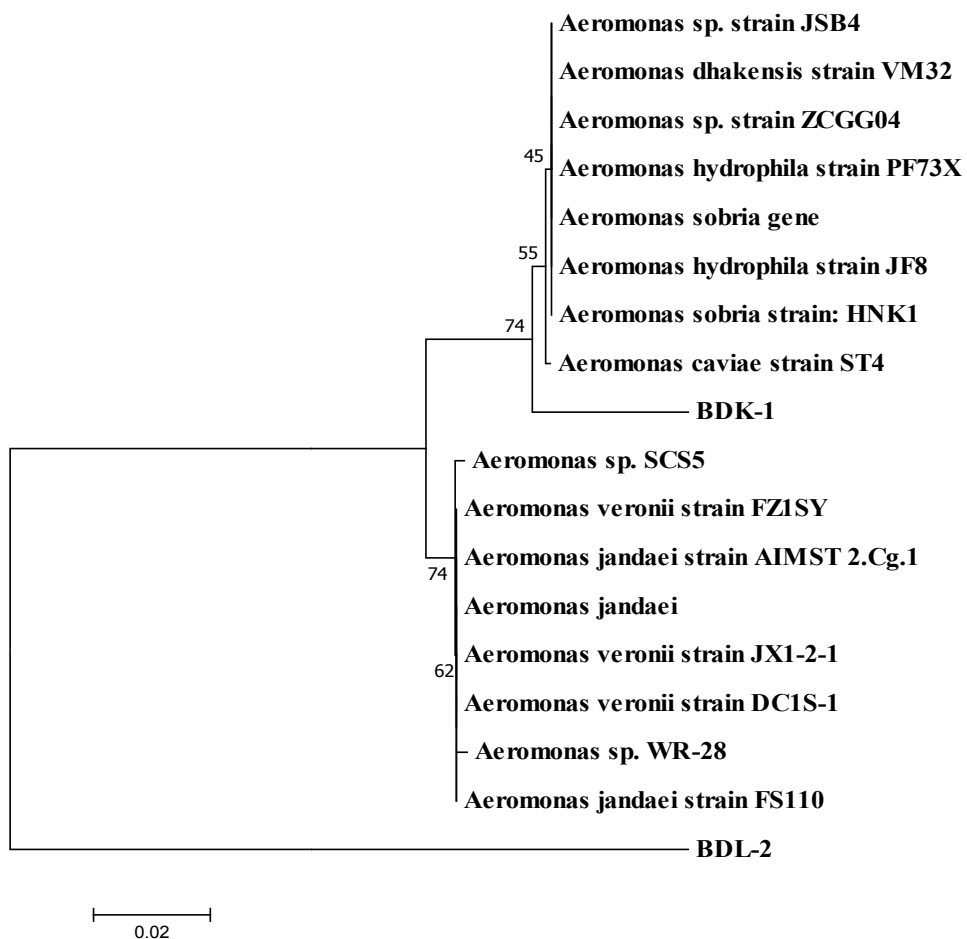


Fig. 1. Phylogenetic tree based on 16SrRNA sequence strain BDK1 and BDL2 using neighbor joining method (Bootsrap values were ran at 1000 replications)

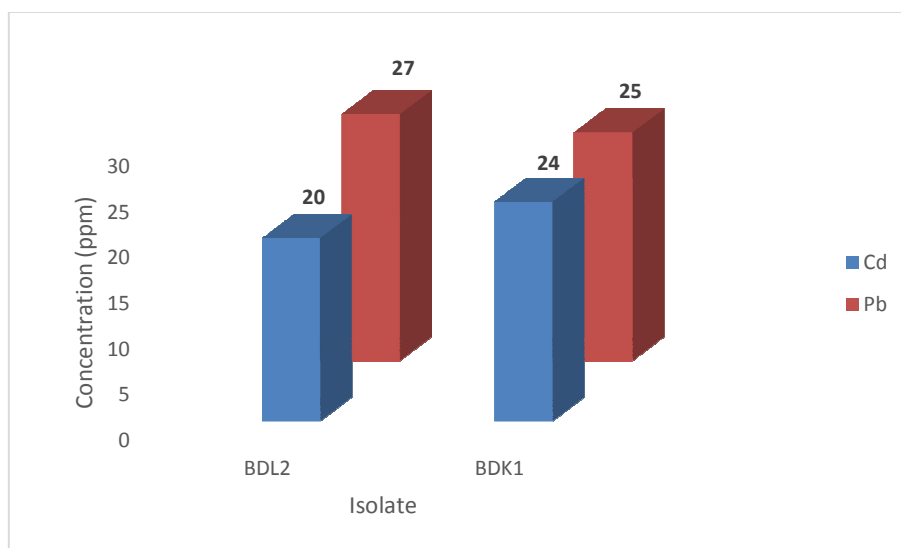


Fig. 2. Maximum tolerable concentration of Pb and Cd by isolates

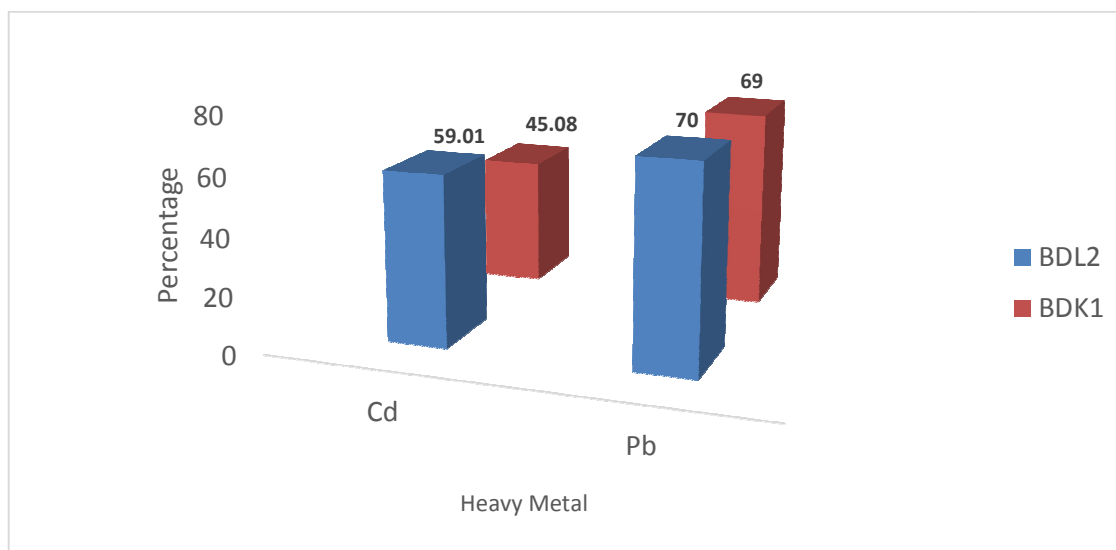


Fig. 3. Bioaccumulation of cadmium and lead by the isolates

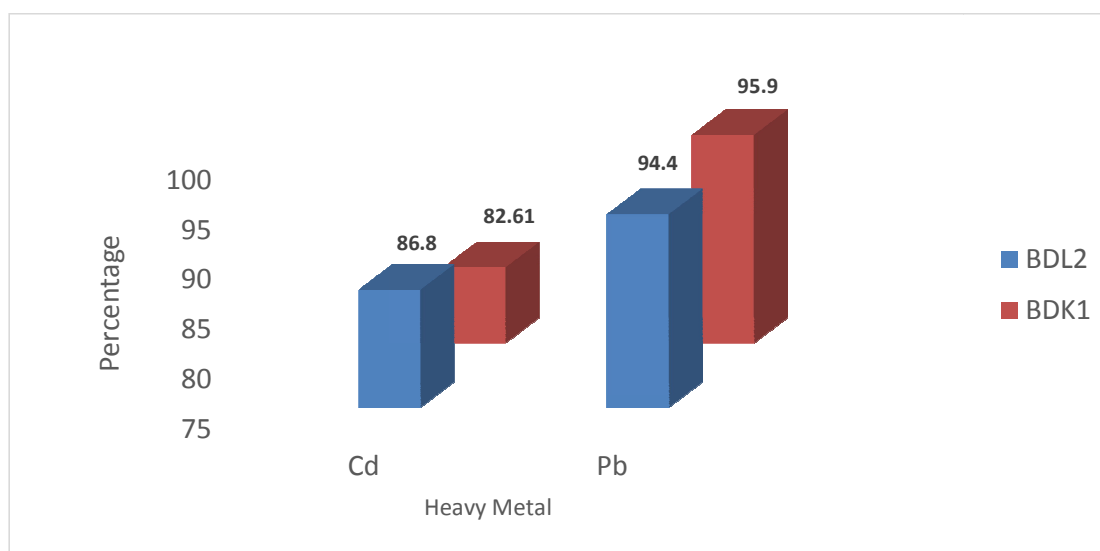


Fig. 4. Biosorption of cadmium and lead by the biomass

3.4 Determination of Surface Molecules Properties

The surface properties of all the isolate and their respective biomass were carried out using Fourier Transform Infra-Red spectroscopy to ascertain functional groups position prior and after heavy metal accumulation experiments. Wavelengths at different bands recorded indicated the presence of carboxyl, amine, amides, sulfates and other aromatic groups in the isolates as indicated in Figs. 5 to 8 prior to

and after Cd and Pb uptake by both the isolate and biomass of the bacteria.

4. DISCUSSION

In this study, *Aeromonas* spp. identified were capable of tolerating between 20-27ppm of Cd and Lead metals respectively. Metal tolerant qualities that might be inherent in these bacteria and possibly adaptation to their primary environment might have contributed to their adaptation. It was reported how several bacteria

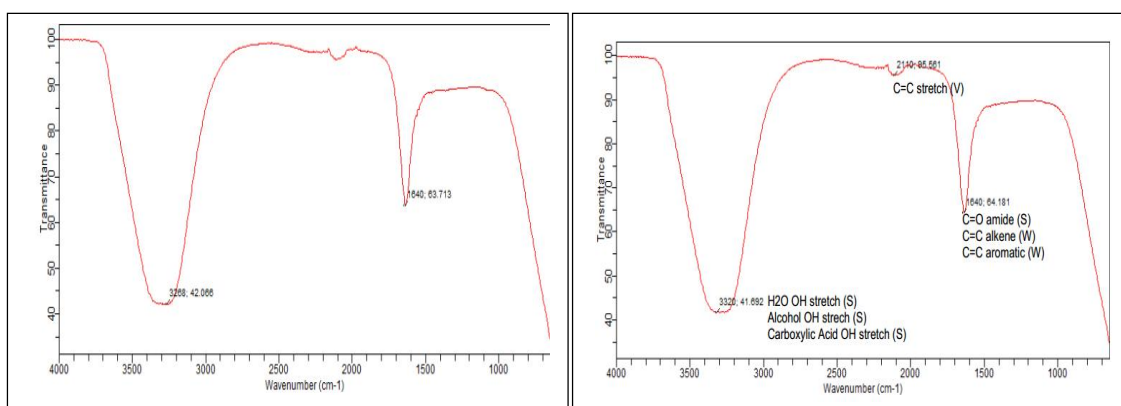


Fig. 5. Surface molecules of *BDL2* before and after accumulation assay

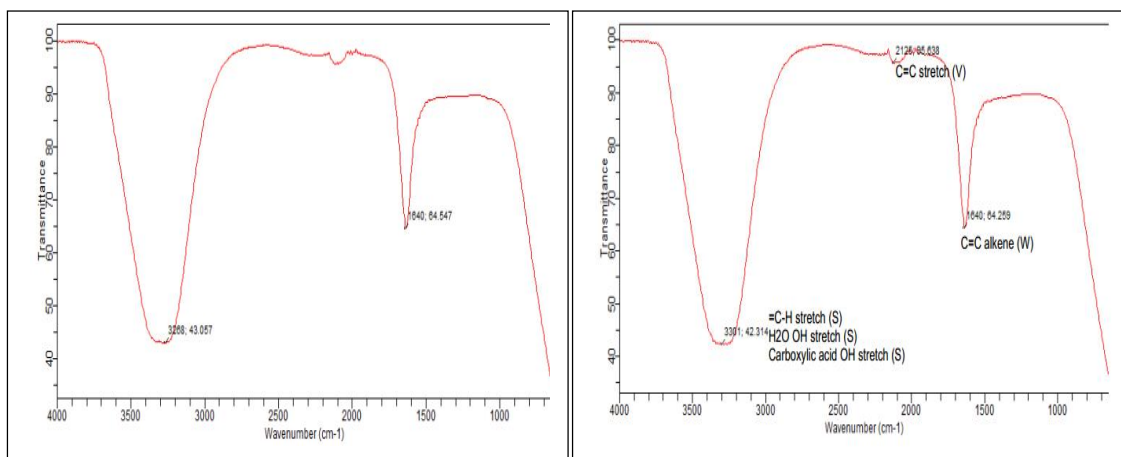


Fig. 6. Surface molecules of *BDK1* before and after accumulation assay

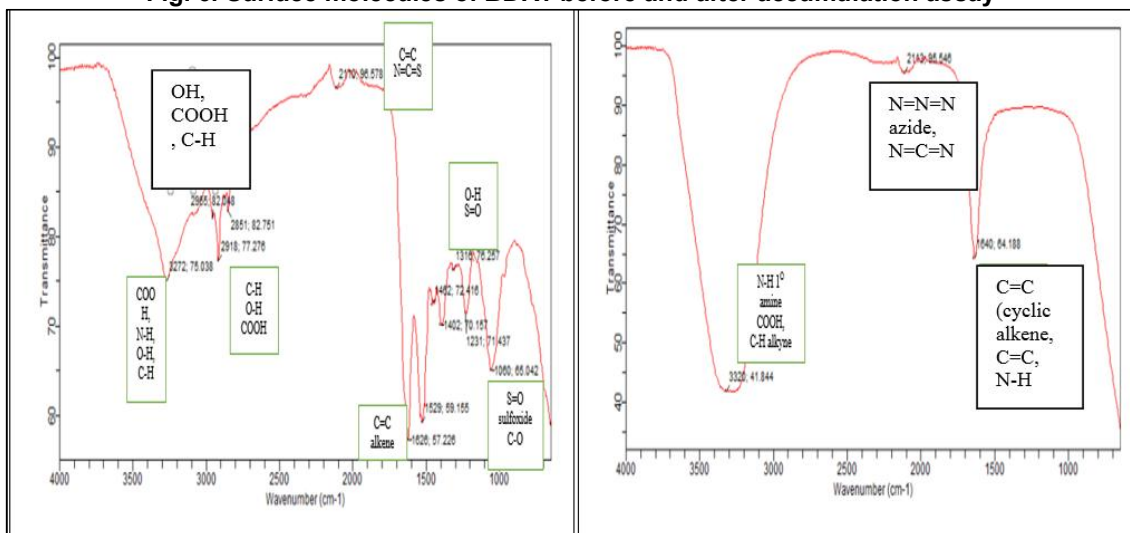


Fig. 7. Surface molecules of *BDL2* biomass before and after biosorption assay

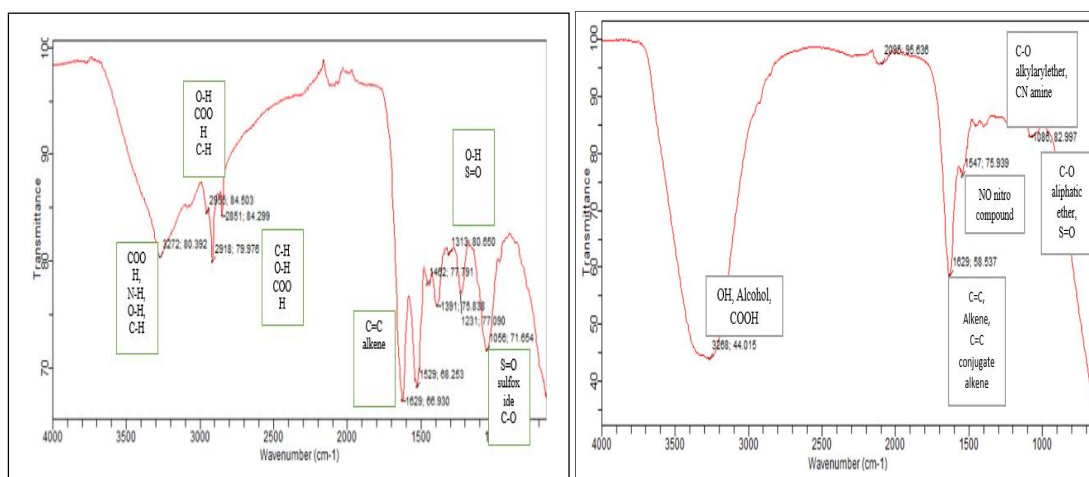


Fig. 8. Surface molecules of *BDK1* biomass before and after biosorption assay

species were found to be persistent in metal contaminated soils and other similar environments [19-21]. Studies have showed some bacteria can withstand high metal concentrations as reported by [22-24] reported that some bacteria to have the capability of tolerating from as low as 2ppm to as high as 100ppm in concentrations of heavy metals. Contrary to the findings in this study, tolerance to individual heavy metals observed by Marzan et al. [25] where bacterial isolates were shown to withstand 1900ug/ml of Pb metal which is lower than what was recorded in this study can be attributed to the originating source of the bacteria might have played an important role in the level of tolerance or otherwise as several studies showed those obtained from sludge to have higher tolerant capability to those obtained from soil component [25-27] reported the isolation of highly Pb tolerant bacteria from Pb contaminated soil. Similar findings recorded in this study were reported by Neethu et al. [28] where 3ppm of Pb was identified as the range of concentration that inhibited bacterial growth. The HTL of *Aeromonas* spp. to Cadmium as observed in this study was 24ppm. Cadmium was a naturally occurring heavy metal and a potential bacterial toxicant having antagonistic effect. Studies by Oaikhena et al. [29] had reported tolerance of some bacterial isolates to a maximum of 0.9ppm of cadmium. Findings in this research are similar to that of Smrithi and Usha [30] who reported similar values in terms of cadmium tolerance by bacterial isolates.

The bacteria identified in this study showed capability of accumulating heavy metals with

Aeromonas sp. *BDL2* having the uptake capacity of up to 70% for Pb. Affinity of bacteria to metals is widely reported [31,22]. The processes leading to this phenomena can be metabolic and non-metabolic as surface molecules can adsorb various ionic compounds which might be as a result of the opposite charge existing between them. The observation recorded in this study agreed with that of Sofu et al. [32] who reported the removal and uptake of heavy metals by bacterial isolates to a near 100% level. To further corroborate the findings in this study, Shamim [33] reported about 90.4% uptake of Pb by Gram negative *Pseudomonas* sp. in biosorption of heavy metals studies. But contrary to this study, Congeevaram et al. [34] reported an extremely low uptake of Pb at 0.41% by *Stenotrophomonas* sp. in their study of heavy metal resistance by bacteria and fungal isolates. This variation might have resulted due to differences in genetic make-up and also adaptability of habitats.

The ability of harvested *Aeromonas* spp. biomass to biosorb Cd and Pb assessed showed *Aeromonas* sp. *BDK1* exhibiting highest biosorption capacity of 95.5%. There was significant difference ($P \leq 0.05$) in uptake between isolates and their resultant biomass. The high uptake recorded in the biomass might have been an indication of increase in surface to volume ratio of the biomass to its isolates. Similarly, it is indicative of preservation of cell wall related ligand and other active sites even after harvesting. Similar studies by [35-37] have reported higher biosorption capacity in bacterial biomass in comparison to immobilized or living bacterial cells by a difference of up to 50%

capacity. In agreement to the findings recorded in this research, Velasquez and Dussan [38] reported biomass of *Bacillus* sp. to biosorb higher percentage of heavy metals than living isolates. Functional groups properties on the surface of each of the isolates and biomass before and after heavy metal accumulation and biosorption experiment were assessed. The Fourier Transform Infra Red Spectroscopy (FTIR) was taken from the range of 4,000 to 1000cm³ wavelength. Hydroxyl, Carboxylic, Amide, Aromatic, and other ketone linkages were evident in all the isolates. Findings from this research revealed that peaks observed at between 3200 to 3400 is indicative of the presence of hydroxyl, alcoholic and carboxylic stretches. Presence of these group of surface molecules were reported by Oves et al. [9]. Similarly, findings by [39-40] corroborated this study by reporting that hydroxyl and carboxyl groups as well as nitrogen based bioligands including amide and sulphonamides were involved in the binding of Pb. Further studies by Qiao et al. [41] reported the presence of these groups in their study of bio-immobilization of lead by *Bacillus* biomass characteristics of *Bacillus* spp. obtained from contaminated soil samples. Furthermore, peaks measured at between 2000 and 2200 wavelength indicates a variable stretch of alkene presence in the respective isolates whilst that of 1640 measure the presence of amide, aromatic and alkene functional groups. Faghihzadeh et al. [42] reported the presence of these surface molecules to be indicative of proteins structures. It should be noted that an observable shift in the wavelength occurred after heavy metal experiment at between 3200-3400 for all the isolates. This shift in wavelength might be as result of bonding and complexation due to metal interaction in the isolates. Studies that are similar to this research reported by [9-43] reported similar findings at which peak transmittance actually reduced as a result of metal interaction occurring on the surface. This finding agreed with that of [44-47] who all reported similar observations on heavy metal uptake and surface structure property of different bacterial isolates.

5. CONCLUSION

From the findings of this research, it can be concluded that *Aeromonas* spp. BDL2 identified in this study exhibited higher tolerance to Pb with attendant higher uptake of both metals assayed, even though biosorption technique was shown to be efficient process in metal uptake. Surface

molecules and their positional properties revealed the presence of hydroxyl, carboxyl, amine and amide group ligands with significant shifts after accumulation and biosorption experiment suggesting interaction between these surface molecules and heavy metal ions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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