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Remediation of Heavy Metal Contaminated Soil using Fermented Breadfruit Extract

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Abstract
The feasibility of remediating a soil contaminated with heavy metals using fermented breadfruit extract was studied. The soil used was collected from a site which has been used for dumping of condemned vehicular parts located in Aluu community, Obio-Akpor Local Government Area, Rivers state. The breadfruit was obtained from a rural market in Enugu State and kept in a polythene bag for 30 days to ferment. Thereafter, the breadfruit seeds were removed, and the fermented breadfruit extract was obtained. The soil sample and fermented breadfruit extract were digested using standard procedure and analysed independently for the baseline concentration of heavy metals, including Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As), and Copper (Cu), using Flame Atomic Absorption Spectrophotometer. Four different concentrations of the fermented breadfruit extract (0.0, 0.1, 0.3 and 0.5 g/ml) were mixed with 0.5 kg of the soil sample. The soil mixture with 0.0 g/ml breadfruit extract served as the Control. Each mixture was setup in quadruplicate. Results obtained showed that the concentration of the heavy metals in soil decreased with increasing time for both Control and fermented breadfruit extract treated soils. However, higher reductions of the heavy metals were observed in the fermented breadfruit extract treated soils. Among the treated soils, the optimum remediation occurred at a fermented breadfruit extract concentration of 0.5g/ml and at a period of 8 weeks. This condition reduced the concentration of Pb, Cr, As, Cd and Cu by approximately 76, 83, 87, 92 and 96%, respectively. Therefore, it is concluded that fermented breadfruit extract is an effective remediating material for a soil contaminated with heavy metals.

Keywords: *Remediation; Contamination; Soil; Heavy metals; Breadfruit extract*

1. Introduction

Pollution of the soil by heavy metals released into the environment through various activities such as mining, smelting, etc. is one of the world's major environmental problems (Mahar et al., 2016). The production of heavy metals from current worldwide mine is considerably huge (Shahid et al., 2014). Soil contaminated with heavy metals poses a serious threat to both man and animals (Bhargava et al., 2012), as the contaminants can pollute the groundwater as well as the surface water. Heavy metals in the soil subsequently enter the human food web through plants and they constitute risk to the ecosystem as they tend to bioaccumulate (Ali et al., 2013).

Heavy metals constitute an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites include Lead (Pb), Chromium (Cr), Copper (Cu), Arsenic (As), Cadmium (Cd), Mercury (Hg) and Zinc (Zn) (Wuana and Okieimen, 2011). Among these heavy metals, As, Pb, Cd and Hg are included in the top 20 hazardous substances of the Agency for Toxic Substances and Disease Registry (ATSDR, 2012) and the United States Environmental Protection Agency (USEPA). These heavy metals can cause several disorders in humans including cardiovascular disease, cancer, cognitive impairment, chronic anaemia, and damage to essential body parts (Jarup, 2003; Ali et al., 2013). Contamination of the soil by these heavy metals can be as a result of disposal of high metal wastes, coal combustion residues, sewage sludge, spillage of petrochemicals and atmospheric deposition. Therefore, remediation of soil contaminated by heavy metals is necessary in order to reduce the associated risks, make the land resource available for agricultural production, enhance food security, and scale down land tenure problems (Wuana and Okieimen, 2011). However, a detailed site characterization (risk assessment) must be performed to access the type and level of metals present and allow evaluation of remedial alternatives.

Many techniques of remediating a soil contaminated with heavy metals have been developed, such as immobilization, soil washing, phytoremediation, soil replacement, soil isolation, biological and physical remediation. However, the major drawback of some of these methods is cost due to high labour work, production of dangerous waste and negative effect on soil (Ali et al., 2013; Khalid et al., 2017; Liu et al., 2018). Biological remediation, which has to do with use of plant and animal wastes or microorganisms to detoxify or remove organic and inorganic compounds from the environment offers the best environmentally friendly method for remediating soils contaminated with heavy metals. It offers a cost-effective remediating technique compared to other remediation methods, because it is a natural process and does not usually produce toxic by-products (Khalid et al., 2017; Liu et al., 2018). Other advantages of biological remediation compared to other treatment methods include long-time protection of public health, minimal exposure of workers to the contaminant, destruction rather than transfer of the contaminants to another medium, etc. (Liu et al., 2018).

There have been many biological methods used for remediation such as the use of sewage sludge, fungi and bacteria. However, fermented breadfruit extract is suggested in this research due to its availability, cost-effectiveness and characteristics. It can be easily seen and gotten with little or no cost. The breadfruit tree is native to many parts of west and tropical Africa. Based on the phytochemical screening, the seeds of the breadfruit are rich in bases such as flavonoids, polyphenols, cardiac glycoside, saponins and anthraquinones, which are known to be antimicrobial (Sofowora, 1980; Osabor et al., 2009). Since there is accumulating evidence that acid rain can enhance heavy metal mobilization in soil ecosystems, its combination with the seed can lead to neutralization. However, the breadfruit extracts contain numerous beneficial biologically active compounds used in various biological activities including antibacterial, antiviral, antifungal, antitubercular, antiplatelet, antiarthritic, tyrosinase inhibitory and cytotoxicity (Jagtap and Bapat, 2004). Thus, this study aimed to assess the effectiveness of fermented breadfruit extract in remediating a soil contaminated with heavy metals.

2. Materials and methods

2.1. Soil

The soil used in this study was obtained from a site used for dumping condemned vehicular parts in Aluu Community, Obio/Akpor Local Government Area, Rivers State. The site has been used for over a decade and is surrounded by residential buildings. The soil sample was randomly collected from ten spots within 0 - 40cm depth and mixed together. The collected soil was sun-dried for 48 hours and sieved using a 5mm sieve to remove debris and large stones.

2.2. Remediating substance

The remediating substance (breadfruit) was obtained from a rural market in Enugu State. The breadfruit was kept in a polythene bag for 30 days to ferment. Thereafter the seeds were removed, and the fermented waste was taken to the laboratory for analysis.

2.3. Experimental setup

Three different concentrations of fermented breadfruit extracts (0.1, 0.3 and 0.5 g/ml) were prepared by dissolving 150 g of fermented breadfruit waste in 1500, 500 and 300 ml of water, respectively. Exactly 0.5 kg of the heavy metal contaminated soil was measured into sixteen (16) plastic containers of 3000 ml. The plastic containers were divided into four (4) sets. Exactly 100 ml of 0.1, 0.3 and 0.5 g/ml fermented breadfruit extracts were individually mixed with the 0.5 kg soil in sets 1, 2 and 3, respectively. The remaining set had no fermented breadfruit extracts mixed with the soil (Control). The four (4) sets of experiments were sampled at two (2) weeks interval for two (2) months.

2.4 Laboratory analysis

The soil samples collected at two (2) weeks intervals were dried at 65^{o}C for 48 hours. A total volume of 100 ml of sulphuric acid (H_2SO_4), nitric acid (HNO_3), perchloric acid ($HClO_4$) was mixed in a ratio of 40%: 40%: 20%, respectively. Exactly 2 ml of the mixed acid was mixed with 1g of the soil sample in a conical flask. The mixture was heated in a fume cupboard at 40^{o}C in a hot plate until white fumes appear, indicating that all the organic compounds have been burnt off and digestion has taken place i.e. the acid has reacted with the inorganic matters. Thereafter, the conical flask was removed from the hot plate and allowed to cool. The digested soil sample was poured through a funnel containing a filter paper into a 100 ml flask and was topped up with a distilled water to 50 ml.

Each sample solution was analysed by atomizing it in a burner. Atoms in this condition absorb characteristic resonance radiation of precisely the same wavelength that they would emit. The instrument was put on for 10-20 minutes so as to warm it up until energy source stabilizes and each lamp was set at its specific wavelength and current. The fuel (acetylene) and air were turned on and set to maintain a constant pressure in the nebulizer to prevent decrease in the aspiration rate and give maximum sensitivity for the metal being measured. The concentration of the element was determined from a calibration curve, obtained using standards of known concentration.

Similarly, the fermented breadfruit extract was analysed to ascertain the concentration of the specified heavy metals in it.

3. Results

3.1. Heavy metals in fermented breadfruit extract

The concentration of heavy metals in fermented breadfruit extract is presented in Figure 1. Cadmium (Cd) and Arsenic (As) were below detention limit while Lead (Pb), Chromium (Cr) and Copper (Cu) had negligible concentrations.

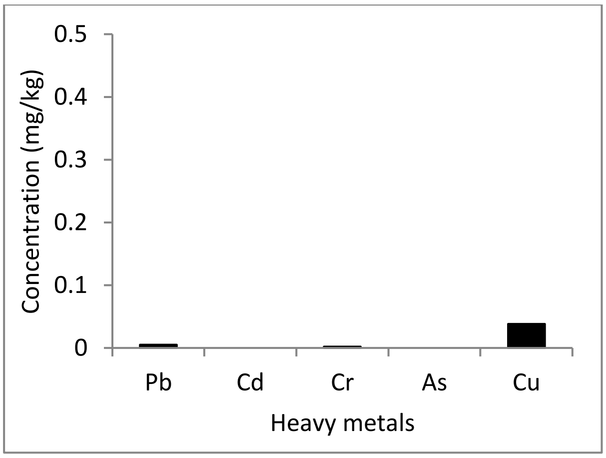

Fig. 1: Concentration of heavy metals in fermented breadfruit extract

3.2. Concentration of Pb in soil

The concentrations of Pb in soil with time for different concentrations of fermented breadfruit extract are shown in Figure 2. The concentration of Pb in soil decreased with increasing time and concentration of the fermented breadfruit extract. The control with the least reduction of Pb decreased by 2.5, 14.6, 23.8 and 33.2% while the 0.5 g/ml fermented breadfruit extract treatment with the highest reduction of Pb decreased by 30.6, 58.2, 69.1 and 76.1% for 2, 4, 6 and 8 weeks, respectively.

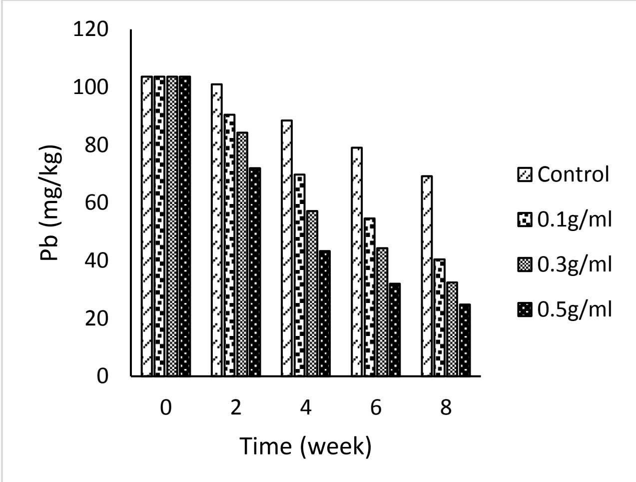

Fig. 2: Pb concentration in soil with time for different concentrations of remediating substance

3.3. Concentration of Cd in soil

The concentrations of Cd in soil with time for different concentrations of fermented breadfruit extract are shown in Figure 3. The concentration of Cd in soil also decreased with increasing time and concentration of the fermented breadfruit extract. The control with the least reduction of Cd decreased by 5.0, 10.6, 21.6 and 30.2% while the 0.5 g/ml fermented breadfruit extract treatment with the highest reduction of Cd decreased by 40.4, 66.2, 83.2 and 94.0% for 2, 4, 6 and 8 weeks, respectively.

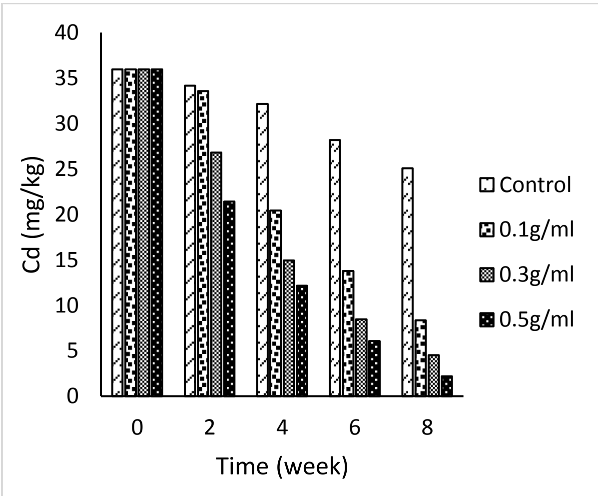

Fig. 3: Cd concentration in soil with time for different concentrations of remediating substance

3.4. Concentration of Cr in soil

The concentrations of Cr in soil with time for different concentrations of fermented breadfruit extract are shown in Figure 4. The reduction in the concentration of Cr in soil similarly decreased with increasing time and concentration of the fermented breadfruit extract. The control with the least reduction of Cr decreased by 4.8, 17.2, 26.5 and 34.9% while the 0.5 g/ml fermented breadfruit extract treatment with the highest reduction of Cr decreased by 33.9, 54.0, 74.2 and 83.2% for 2, 4, 6 and 8 weeks, respectively.

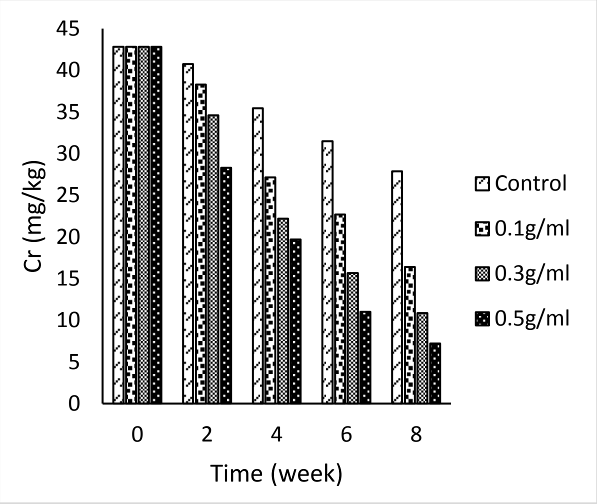

Fig. 4: Cr concentration in soil with time for different concentrations of remediating substance

3.5 Concentration of As in soil

The concentrations of As in soil with time for different concentrations of fermented breadfruit extract are shown in Figure 5. The reduction in the concentration of As in soil similarly decreased with increasing time and concentration of the fermented breadfruit extract. The control with the least reduction of As decreased by 6.6, 17.1, 32.2 and 40.8% while the 0.5 g/ml fermented breadfruit extract treatment with the highest reduction of As decreased by 40.0, 65.9, 80.8 and 87.4% for 2, 4, 6 and 8 weeks, respectively.

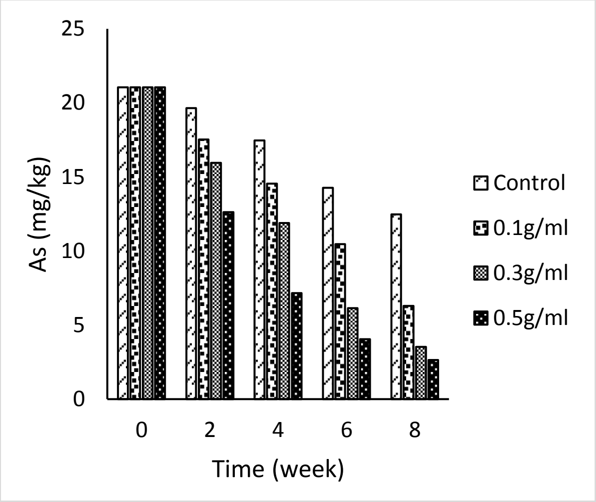

Fig. 5: As concentration in soil with time for different concentrations of remediating substance

3.6. Concentration of Cu in soil

The concentrations of Cu in soil with time for different concentrations of fermented breadfruit extract are shown in Figure 6. The reduction in the concentration of Cu in soil similarly decreased with increasing time and concentration of the fermented breadfruit extract. The control with the least reduction of Cu decreased by 14.5, 25.1, 39.1 and 59.1% while the 0.5 g/ml fermented breadfruit extract treatment with the highest reduction of Cu decreased by 61.4, 74.3, 87.2 and 95.7% for 2, 4, 6 and 8 weeks, respectively.

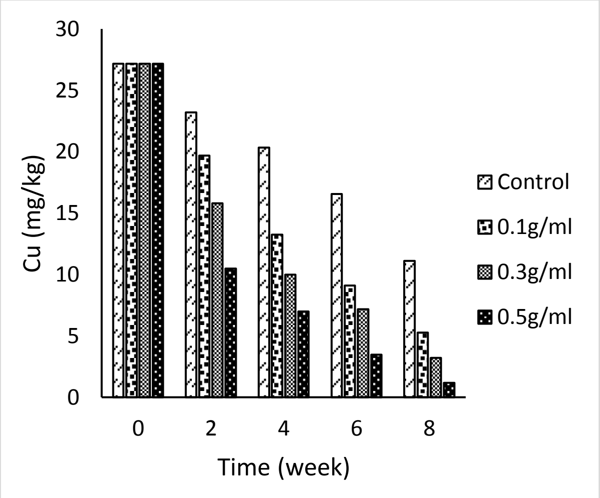

Fig. 6: Cu concentration in soil with time for different concentrations of remediating substance

4. Discussion

The fermented breadfruit extract has negligible concentration of the selected heavy metals in it (Fig. 1), indicating its suitability as a remediating substance for soils contaminated with heavy metals. It also indicates that breadfruit extract has no potential to destroy the soil fertility because of its extremely low contents of heavy metals. According to De Souza (2016), breadfruit contains minerals like potassium, phosphorus, magnesium, calcium, manganese, copper and iron which improve soil fertility. The concentration of all five (5) heavy metals in soil decreased with increasing time for both control and treated soils (Fig. 2 – Fig. 6). However, higher reductions were observed in the treated soils than in the control. This suggests that the fermented breadfruit extract is an effective remediating material for heavy metals in the soil. Among the treated soils, the reduction of the heavy metals was found to be in the order of 0.5 g/ml > 0.3 g/ml > 0.1 g/ml (Fig. 2 – Fig. 6), implying that the higher the concentration of the fermented breadfruit extract in soil, the more effective would be the remediation of the heavy metals. The percentage of reduction of the heavy metals at 8 weeks in the control experiment was generally equivalent to the percentage reduction at 2 weeks in the highest (0.5 g/ml) fermented breadfruit extract treatment. The reduction of the heavy metals as a result of treatment by fermented breadfruit extract was found to be in the order of Cu > Cd > As > Cr > Pb, indicating that fermented breadfruit extract treatment would be most effective in copper contaminated soil. Further study is recommended to fully explain the reasons for the difference in reduction among the heavy metals. Overall, the result of this study shows that fermented breadfruit extract is an effective remediating material for a soil contaminated with heavy metals, and the effectiveness depends on the concentration of the fermented breadfruit extract and the time allowed for remediation. The main advantage of this method is that it requires less time to remediate a soil contaminated with heavy metals compared to the widely advertised phytoremediation (Wuana and Okieimen, 2011; Bhargava et al., 2012; Ali et al., 2013).

5. Conclusions

The effectiveness of fermented breadfruit extract in remediating a soil contaminated with heavy metals was studied. The analysis of the fermented breadfruit extract shows that it has no potential to destroy the soil fertility because of its extremely low contents of heavy metals but contains minerals which improve soil fertility. Results obtained showed that the concentration of the heavy metals in soil decreased with increasing time for both control and treated soils, signifying that heavy metals in soil could be reduced via natural attenuation as well as fermented breadfruit extract. However, higher reductions of the heavy metals were observed in soils with fermented breadfruit extract than in the control, suggesting that the fermented breadfruit extract is more effective than natural attenuation. In the soils mixed with fermented breadfruit extract, the reduction of the heavy metals in the mixture was in the order of 0.5 g/ml > 0.3 g/ml > 0.1 g/ml, implying that the higher the concentration of the fermented breadfruit extract in soil, the more effective would be the remediation of the heavy metal contaminated soil. The reduction of the heavy metals as a result of treatment by fermented breadfruit extract was found to be in the order of Cu > Cd > As > Cr > Pb, indicating that fermented breadfruit extract treatment would be most effective in copper contaminated soil. Conclusively, the result of this study showed that fermented breadfruit extract is an effective remediating material for a soil contaminated with heavy metals, and the effectiveness depends on the concentration of the fermented breadfruit extract and the time allowed for remediation.

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