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RESEARCH ARTICLE

PHYTOREMEDIATION POTENTIAL OF COMMON TROPICAL HYPERACCUMULATOR PLANTS ON TIN POLLUTED SOILS

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ABSTRACT

This study assessed the phytoremediation potentials of common tropical hyperaccumulator plants for their germination, survival, and phytoextraction abilities of Tin from polluted soils. Familiar Nigerian crop specieswhich include Sorghum (*Sorghum bicolor* (L.) Moench), Wheat (*Triticum aestivum* L.), Maize (*Zea mays* L.) of White grain and Yellow grain varieties, as well as three varieties of Tomato (*Solanum lycopersicum* L.) i.e. Hausa, Ogbomoso and Ijebu, were planted in a greenhouse pot experiment. The soils were contaminated with Tin (II) chloride dihydrate ($SnCl_2.2H_2O$) at concentrations of 0.6g, 1.2g, 1.8g and 2.4g per 3kg of soil in each pot. The percentages of germination and survival were measured for each plant, and the plants were later assayed using atomic absorption spectroscopy to determine the Tin phytoextraction prospects by the plants. Sorghum presented the most promising Tin hyperaccumulating potential (11.415 ppm) among the sampled plants. Analysis of variance and Least Square means revealed that the Tin phytoextracting potential were significantly different among the sampled plants. Alternatively, the White grained maize recorded the lowest germination (80%) and survival (52.4%) rates, and Tin phytoextracting potential (8.44 ppm). Furthermore, the Pearson correlation coefficient showed that the percentage survival of the phytoremediator plants had a significantly positive correlation with the amount of Tin phytoextracted (r=0.560*). Sorghum is well adapted and widely cultivated across Nigerian agricultural ecologies, hence, it is necessary to be mindful of the Tin content in sorghum which are grown in zones with high soil Tin amounts to check possible Tin poisoning in humans and animals.

INTRODUCTION

The rapid industrialization and increased exploration of mineral resources in developed and developing countries have brought about environmental pollution in the ecosystem via anthropogenic activities such as the indiscriminate use of agricultural chemicals, energy and fuel production, electroplating, sewage sludge treat ment and mining (Garbisu *et al.,* 2002). Metal mining is the second largest source of heavy metal contamination in the soil after sewage sludge (Dudka and Adriano, 1997; Nouri *et al.,* 2009; Singh, 2009). In Plateau state Nigeria, Tin mining has gradually destroyed much of the environment as reported by the Nigerian Environmental Study Action Team (Abiodun, 1999).Also, in Malaysia mining activities have resulted in the deposition of about 113,700 hectares of Tin tailings throughout its peninsula (Balamurugan, 1991).

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Tailings bring about unfavourable conditions to natural vegetations by damaging the soil physico-chemical properties, especially by lowering the pH, promoting low water retention capacity and low levels of plant nutrients bioavailability, as well as causing phytotoxic effects when present above certain amounts (Henriques and Fernandes, 1991; Norland and Veith, 1995; Wong, 2003). In nature, Tin occur as "Cassiterite" or "Tin stone" (Ossei, 2001). Tin concentration in the earth crust averages 2.5mgkg^{-1} and its compounds are found in various environmental media in both inorganic and organic forms (Ossei, 2001). Despite the consequences of Tin poisoning, their applications in industries, such as the paint industry and the plastic industry, and in agriculture through pesticides such as Triphenyltin is still increasing (Zuckerman *et al.,* 1978; Lee *et al.,* 2006). Notwithstanding the global ban on the application of organotin compounds as biocides as it was scheduled by the International Maritime Organization (IMO) to begin in January 2003, the convention has however not yet been enforced and the use of Tin compounds persists in several countries especially in Africa where increase in usage of organotin products still occurs till date (Okoro *et al.,* 2011). Since the first reports on the environmental contamination of organotin compounds in the early 1970s, considerable amount of research has been performed worldwide on organotin compounds in the environment. However, the study assessing the phytoremediation potentials of common tropical hyperaccumulator plants for their germination, survival, and phytoextraction abilities of Tin from polluted soils is yet to be carried out. It is widely known that organotin compounds are present in placesof maritime activities such as harbours, shipyards and marinas (Furdek *et al*., 2012). Relative high concentrations of organotin compounds have been detected in sediments and organisms in the two most important areas of maritime activity in Brazil (Camilla *et al.,* 2004; Magi*et al.,* 2008; Fernandez *et al.,* 2005; Godoi *et al.,* 2003). Organic Tin bonds are the most dangerous forms of Tin for humans, whereby Triethyltin is the most dangerous (Dubey and Roy, 2003). Humans can absorb Tin bonds through food, breathing and skin contact. Tin poisoning cause both acute effects such as eye and skin irritations, headaches, stomach aches, dizziness, excessive sweating, breathlessnessandurinary disorders, including long-term effects such as depression,liver damage, immune systems damage, chromosomal damage, red blood cells shortage, brain damage leading to anger, sleeping disorders, and memory loss (Krigman and Silverman, 1984; Blunden and Chapman, 1986; WHO, 2010; Ayari *et al.,* 2010). Wax and Dockstader (1995) reported that nausea and vomiting occurred among all the members of a family of five who were exposed at home to tributyltin oxide contained in paint for mildew control. Also, Tri organic tin compounds can bind to mitochondria to disturb oxidative phosphorylation (Reuhl *et al.,* 1985). Furthermore, Tributyltin is extremely toxic Tin compound that promote the mortality of marine organisms and even cause major environmental problems through the food web (Laughlin and Linden, 1985; Cima *et al.,* 1997; Vos *et al.,* 2000). The most extreme Tributyltin concentrations were found in coastal areas all over Europe and the open North Sea (Maguire *et al.,* 1986). Tributyltin is extremely toxic to aquatic organisms.

It may cause imposex and calafication abnormalities in mollusc (Alzieu *et al.,* 1989). Toxic lesions among laboratory and process workers handling di- and tributyltin compounds were typical acute skin burns, caused by the colourless di- or tributyltin dichloride (Lyle, 1958). Ingestion of fruit juices containing high concentrations of Tin brings about major symptoms and signs like nausea, vomiting, diarrhoea fatigue and headache (Horio *et al.,* 1967).Tributyltinat low Nano-molar aqueous concentrations (1-2 ng L^{-1}) can threaten aquatic life. Acute poisoning by Tributyltinhave been reported in algae, Zooplankton, molluscs and the larval stage of some fishes (Gibb's and Bryan, 1996). Lethal concentrations are in the range of 0.04-16 μg L^{-1} for short term exposure, depending on the aquatic species (W.H.O, 1990). Tin concentrations of vegetables, fruits and fruit juices, nuts, dairy products, meat, fish, poultry, eggs, beverages, and other foods not packaged in metal cans are generally less than 2 parts per million (ppm) (Tsuda *et al.,* 1995). Tin concentrations in pastas and breads have been reported to range from less than 0.003 to 0.03 ppm. Greater than 90% of tin-lined cans used for food today are lacquered. Only light-coloured fruit and fruit juices are packed in unlacquered tin-lined cans, since tin helps maintain the colour of the fruit (CMI, 1988). Generally, Tin concentrations have been reported to be high in Tin-canned foods (WHO, 1980, 2003; Biégo *et al.,* 1999). Most soil contain about 1 ppm Tin, some soils may contain as much as 200 ppm tin (Gerritse *et al.,* 1982; WHO, 1980). Organic Tin poisoning mainly results from eating seafood from coastal waters or from contact with household products that contain organotin compounds, (polyurethane, plastic polymers, and silicon-coated baking parchment paper) (Kannan *et al.,* 1999). Acute exposure of rats to high concentrations (generally >2 mg/kg/day) of tributyltins and other organotins have caused immune alterations. The effect is characterized by reduced thymus weight and size and lymphocyte depletion (Tennekes *et al.,* 1989a, 1989b; Dacasto *et al.,* 1994a, 2001a, 2001b).

Many families of vascular plants have been identified as metal hyperaccumulators (Reeves and Baker, 2000; Prasad and Freitas, 2003), and many of them belongs to Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Euphorbiaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Scrophulariaceae and Violaceae. Ashraf *et al.*(2010) reported that *Cyperus rotundus*, *Imperata cylinderica, Melastomamalabathricum* and *Pteris vittata*can grow and significantly remediate Tin from polluted environments.There is a limited availability of fertile agricultural lands, and the increasing demand for uncontaminated agricultural lands, have prioritized the need to remediate contaminated soils. The use of metal-tolerant native flora represents an inexpensive long-term solution (Garbisu *et al.,* 2002). Other techniques for remediating contaminated soils such as physical, chemical, photo degradation have the drawbacks of being too expensive and leaving behind break down compounds which are more toxic to the environment than the parent compounds (Frick *et al.,* 1999). Phytoremediation is one of the most viable options that offers a green technology solution for remediating contaminated soils (Merkl *et al.,* 2005). Phytoremediation, is an ecologically friendly approach which utilizes plants to extract, sequester, remove, contain or detoxify environmental contaminants. The mechanisms include biophysical and biochemical processes like adsorption, transport and translocation, as well as transformation and mineralization by plant enzymes (Meagher, 2000). Phytoremediation have been reported to be an effective, non-intrusive, inexpensive, aesthetically pleasing and socially accepted technology in remedying polluted soils (Pradhan *et al.,* 1998, Anderson *et al.,* 1993; Cunningham & Lee 1995; Schwab *et al.,* 1995).

The ideal characteristics of Plants used for heavy metal phytoextraction include; tolerance of heavy metal contaminants beyond lethal limits, ability to accumulate reasonably high levels of the metal contaminants in its biomass, produce reasonably high biomass in the field with profuse root system and rapid growth rate (Ralinda and Miller, 1996). In Nigeria, Tin is a major environmental pollutant in the Plateau environs such as Bukuru, Rayfield, Shere Hills and Anglo-Jos. Candidate tropical hyperaccumulator plants which have successfully demonstrated heavy metal remediationability such as maize, sorghum, tomatoes, Amaranthus, wheat etc.,(Lin *et al.,* 2006; Palmroth *et al.,* 2006; Lee *et al.,* 2007; Batty and Anslow, 2008; Wu *et al.,* 2012; Lu and Zhang, 2014) are largelygrown in Nigeria. Hence, this research work was aimed at assessing the phytoremediation potentials of some common tropical hyperaccumulator plants available in Nigeria, in the context of their ability to grow, tolerate and remove Tin contaminant from polluted soils.

MATERIALS AND METHODS

Experimental Site and Sample Collection

The research was conducted in a greenhouse study at the Department of Plant Science and Applied Zoology, Olabisi Onabanjo University, Ago-Iwoye, Nigeria. Seven common hyperaccumulator plants were employed for the experiment, these involved three major Nigerian tomatoevarieties (*Solanum lycopersicum* L.) i.e Hausa (HT), Ogbomoso (OT) and Ijebu (IT),two cultivars of Maize (*Zea mays* L.) i.e White grained (WM) and Yellow grained (YM), Guinea corn *Sorghum bicolor* (L.) Moench) (S), and Wheat (*Triticum aestivum* L.) (W).

Experimental Design and Plant Treatments

5L garden plastic pots were filled with 3kg of soil collected from Olabisi Onabanjo University. The pots were arranged in a Randomized Complete Block Design (RCBD) of four blocks, whereby each block represented a particular Tin concentration. The soil in the pots were then contaminated with different concentrations of Tin (II) chloride dihydrate($SnCl_2.2H_2O$) at concentrations of 0.6g, 1.2g, 1.8g and 2.4g and in two replications. Homogeneity was ensured by stirring the sand and the pollutant thoroughly within each pot. Hence, the seven different hyperaccumulator plants employed in this research represented the treatments.Ten seeds of each hyperaccumulator plant were planted per pot, and these were watered periodically. Two weeks following germination, the seedlings were thinned down to five seedlings to prevent competition.

Data collection

After planting, data were measured from the plants, during the research period, these include the percentages of germination and survival, as well as observing the morphological traits such as the Plant height (cm), Girth (cm), Number of leaves, Leaf length (cm) and Leaf breadth (cm) using meter rule and calliper. The percentage germination and percentage survival were calculated as thus;

$$\text{Percentage of germination} = \frac{\text{Number of seed that germinated}}{\text{Number of seeds planted}} \times 100$$

$$\text{Percentage of Survival} = \frac{\text{Number of seedling that survived the research period}}{\text{Number of seed that germinated}} \times 100$$

Statistical Analysis

At the end of the research, the sampled plants were analysed using atomic absorption spectroscopy at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan Nigeria, to estimate the amount of Tin present in the plants biomass. Then the results from the spectroscopic analysis and also the morphological measurements were subjected to Analysis of Variance (ANOVA) and Least Square Means for significance testing, including Pearson Product Moment Correlation Coefficient analysis to show the relationship in phytoextraction abilities between the plants. The SAS (version 9.3) software was used for this purpose.

RESULTS

The Analysis of Variance (Table 1) showed that there was a significant difference among the hyperaccumulator plants for their ability to tolerate the phytotoxic effects of the Tin contaminant (survival rate) during the period of the phytoextraction study. Also, the amount of Tin phytoextracted were significantly different among the various hyperaccumulator plants.

Table 1. Analysis of variance for the sampled hyperaccumulator plants (treatments)

Source of Variable	Degree of freedom	% Germination	% Survival	Tin Contamination in Plant
Treatment	6	178.571	648.040*	2.569**
Error	7	64.286	103.632	0.000
Total	13			

* =Significant at P<0.05; ** = Significant at P<0.01

The Least Square Means (Table 2) revealed that among the seven hyperaccumulator plant varieties sampled in this study, the White grained Maize significantly exhibited the least ability to withstand Tin phytotoxicity. Also, the White grained Maize phytoextracted the lowest amount of Tin from the polluted soil, and this amount was significantly different from the other sampled plants. Alternatively, Sorghum was observed to have taken up the largest amount of Tin from the contaminated soil, and this was significantly higher compared to the Tin taken up by the rest sampled hyperaccumulators plants.

Table 2. Least Square Means of the sampled hyperaccumulator plant varieties

Treatments	% Germination	% Survival	Tin contamination in plant (ppm)
Hausa Tomato (HT)	100.000a	100.000a	9.873e
Ogbomoso Tomato (OT)	100.000a	100.000a	10.643c
Ijebu Tomato (IT)	100.000a	100.000a	9.877d
White grained Maize (WM)	80.000b	52.380b	8.439g
Yellow grained Maize (YM)	100.000a	100.000a	8.562f
Sorghum (S)	80.000b	100.000a	11.415a
Wheat (W)	95.000ab	100.000a	10.879b
Mean	93.571	93.196	9.995
Std. Error	2.891	5.035	0.005

Mean with the same letter(s) in the same column are not significantly different at P<0.05

The Pearson Product Moment Correlation Coefficient (Table 3) revealed that the survival ability of the hyperaccumulator plants has a weak positive and insignificant relationship to the germination rate. Also, the amount of Tin phytoextractedis weak negative and also insignificantly related to the germination rate of the plants. Alternatively, the percentage survival of the plants is significantly positively correlated with the amount of Tin contaminant taken up.

Table 3. Pearson product moment correlation coefficient for the hyperaccumulator plant characters

	% Survival	Tin uptake in plant (ppm)
% Germination	0.344	-0.419
% Survival	-	0.560*

* =Significant at P<0.05

DISCUSSION

It was observed in this study that the sampled plants exhibited delayed germination in comparison to the control set-up (data not included). Also, allTomato varieties and the Yellow grained maizeshowed 100% germination. The germination rate of the restplants may have been reduced by the Tin contaminant, since a preliminary pilot study revealed a 100% germination rate for all seed lots of the sampled plants (data not included). Kranner and Colville, (2011) had documented that the negative impact of heavy metal on seed germination can be due togeneral physiological toxicity or by physical inhibition of water uptake. This implies that germination of hyperaccumulator species in heavy metal contaminated soils depends on both the species itself and the specific contaminant. Except for the White grained Maize (which had the least Tin phytoremediation ability), all the sampled plants have100% survival rate. This also suggests that if these plants are exposed to the same Tin pollution stress, they could survive in a similar pattern. This is in agreement with Chirakkara and Reddy (2015), where their sampled hyperaccumulator plant species survived mixed contaminated conditionssimilarly. Furthermore, the percentagesurvival showed a significant positive correlation with Tin uptake. This is reasonable because as the hyperaccumulator plants survived longer on the contaminated soil, so does it accumulate more Tin in its biomass overtime.Sorghum had the highest potential to phytoextract Tin amongst the tested plant species. In fact, at a concentration of 1.8g/kg, the Sorghumplants were growing better in terms of height andleaf with stem morphology when compared to the other hyperaccumulator plants. The reason for this attribute was not clear and thus will require further research.

Conclusion and Recommendations

Tin contaminated fields which requireremediation to restore its agricultural suitability are presentin Nigeria. Phytoremediation has a remarkable potential to remediate these fields in a way that is economical and environmentally friendly, however, it has itslimitations. The ability for plants togerminate, survive and take up Tin are essential factors to consider for Tin phytoremediation using tropical hyperaccumulator plants. Our study has shown that Sorghum (among the sampledplants) is primarily recommended for Tin phytoremediation due toitshigh significant Tin uptake potential. However, further research is required to ascertain the level at which Tin is phytotoxic to Sorghum itself and other hyperaccumulator plants. The result from this research can be adopted when soil remediation is desired especially in Sorghum growing agroecologies where the soilis consequentlyhighly contaminated withTin.

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