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Efficacy of biochar on the phytoremediation potential of *Tithonia diversifolia* on spent oil-contaminated soil

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Abstract

Background The application of biochar has gained attention as a simple, affordable and sustainable strategy for the remediation of contaminated soils. However, the phytoremediation potential of certain plants and interactions with biochar are necessary to achieve effective environmental clean-up. This study evaluated the influence of biochar on the remediation potential of *Tithonia diversifolia* grown in spent oil-contaminated soil.

Methods *T. diversifolia* was grown for six weeks in spent oil-contaminated soil amended with rice biochar (RB), sorghum biochar (SB) and standard biochar (StB). Four different application rates (0, 1, 2 and 3% w/w) were used. The heavy metals studied included copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd) and chromium (Cr). Biochar treatments was assessed using one-way analysis of variance (ANOVA) and significant differences in soil properties, plant growth, and heavy metal content were further investigated with Duncan's multiple range test (DMRT). All statistical analyses were conducted using SPSS 21.0 statistical package.

Results The results of this study showed that biochar enhanced the biomass of *T. diversifolia* particularly by RB treatment. Also, biochar influence the bioavailability of heavy metals in polluted soil. The specific biochar relation with *T. diversifolia* affect its status from a phytoextractor to a phytostabilizer for specific heavy metal. On the other hand, SB changed Cu-phytostabilizing *T. diversifolia* to a Cu-phytoextracting plant.

Conclusions Generally, the phytoextraction and phytostabilization capacities of *T. diversifolia* is dependent on the biochar features. These features are influenced by the feedstock, the pollutant and soil type. Hence, the need for further studies on the interaction of *T. diversifolia* and biochar for soil remediation. Feasible long term field studies and monitoring strategies can be conducted on varied biochar types in relation to plants remediating potential for specific heavy metal. This will provide a valuable insight on sustainable biochar application for remediation of heavy metal contaminated soil.

Keywords Biochar, Heavy metals, Phytoextraction, Phytostabilization, *Tithonia diversifolia*

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Background

Tithonia diversifolia is a shrub in the Asteraceae family that is widely spread throughout the world but is presently distributed in 64 countries [1]. It has been reported to be a native plant of Mexico. This plant was introduced as ornamental/green manure in the humid and subhumid tropics of Africa [2, 3]. It is regarded as a dicot weed found on farms, waste areas and roads in Nigeria [4]. *T. diversifolia* is widely valued in several cultures for its medicinal properties [5] due to the presence of bioactive compounds with significant therapeutic values and favorable safety indices [2]. Comprehensive research on the phytochemical composition, therapeutic efficiency, soil fertility capacity, antioxidant capability, toxicity and allergenic potential of these plants has been published [6–11]. However, there are few studies on the phytoremediation potential of *T. diversifolia* in heavy metal-polluted soils [12, 13] because soil is one of the natural resources threatened by pollutants, that result from anthropogenic activities and natural environmental occurrences [14].

Reports on the responses of *T. diversifolia* at polluted sites can serve as indicators for soil recovery, which is a cheap, sustainable strategy for cleaning the environment [15]. Ayesa et al. [16] and Al.-Jobori and Kadhim [17] identified *T. diversifolia* as a promising species for the phytoextraction of heavy metals from contaminated sites. The invasive nature of *T. diversifolia* and its capacity to produce massive biomass and a well-developed expanded root system [2], particularly in soils with low nutrient levels, suggest the need to investigate this plant for its metal accumulation potentials. In addition, plants found growing naturally in polluted environments are suggestive of their potential for remediation purposes in such areas [18]. Additionally, the focus on non-crops plant species such as *T. diversifolia* is advantageous, since they are not consumed, thereby avoiding threats to human wellbeing. Studies have shown that plants that produce specific secondary metabolites (medicinal plants) can create an adaptive mechanism of tolerance by forming complexes with heavy metals against divalent metals [19, 20]. This mechanism is interrelated with the chelation of metal ions by specific secondary metabolites in medicinal plants [21, 22]. *T. diversifolia*, as a medicinal plant and it possesses specific secondary metabolites known as targitinins [2] that could be responsible for its capacity to tolerate heavy metals.

Few studies have been conducted on the synergistic effects of biochar and plants on the remediation of heavy metal-polluted soils [23, 24]. However, there are no studies on the phytoremediation potential of *T. diversifolia* grown on spent oil-contaminated soil amended with biochar. A previous report by Ogunremi et al. [25] revealed high pH, porosity, fixed carbon and O/C and abundant surface functional groups of biochar derived from rice and sorghum straws. The study further demonstrated the potentials of rice and sorghum biochars to amend spent oil-contaminated soil, improving the physicochemical properties and reducing the bioavailability of heavy metals. The objective of this study was to evaluate the influence of biochar on the growth and phytoremediation potential of *T. diversifolia* on spent oil-contaminated soil. It is hypothesized that application of biochar derived from sorghum and rice straws will effectively adsorb heavy metals from spent oil contaminated soil, minimize the heavy metal uptake by *T. diversifolia* and enhance the growth of the plant.

Methods

Study area

The study was carried out at the Green House of Botanical Garden, University of Ilorin, Ilorin, Kwara State, Nigeria. The University of Ilorin Botanical Garden lies between latitude 8.500° N and longitude 4.550° E, with an annual rainfall of approximately 1200 mm and a temperature varying between 33 °C and 34 °C [25].

Collection of materials

Seeds of *T. diversifolia* were collected from the Botanical Garden, University of Ilorin, Ilorin, Kwara State. The soil samples were collected from the surroundings of the Botanical Garden, University of Ilorin, Ilorin, Kwara State. The spent engine oil was collected from the Toyota Automobile Company, Ilorin, Kwara State. Commercial grade biochar (wheat straw, 700 °C) was obtained from the UK Biochar Research Centre (UKBRC). Rice straw and sorghum straw were collected from Rice Farm, Patigi, Kwara State, and Sorghum Farm, Ilorin, Kwara State, respectively. Biochars were respectively derived from the straws as previously reported by Ogunremi et al. [25].

Preparation of substrate

Sandy loam soil was bulked and homogenized to give one representative sample of approximately 300 kg. The soil was sieved through a 2 mm mesh to ensure that the soil was free of unwanted materials, which could disturb the proper functioning of the soil microorganisms, proper stretching of the roots and organization of the soil. The soil was spiked with 50 ml/kg (5% v/w) spent engine oil, thoroughly mixed manually with hand-protected gloves and left for two weeks in a moist, cool garden environment [26] to ensure the uniformity of the oil, moisture content, air content, temperature, and effective activities of the soil microorganisms. Biochar was introduced to the spiked soil at different rates of 0%, 1%, 2% and 3% w/w with thorough mixing at 60% moisture content, and allowed to incubate for one month. The physicochemical properties of the soil samples were previously reported by Ogunremi et al. [25].

Pot experiment

The experiment was conducted in 30 pots for six weeks [27]. Polythene pots (19 cm surface diameter and 23 cm depth) were filled with 3 kg of topsoil, and ten *T. diversifolia* seeds were planted in each polythene pot. The germinated plants were thinned to two plants per pot. Watering was made daily with 180 ml of tap water, and regular weeding was performed by hand picking. The treatments were replicated three times with a complete randomized design (CRD) [28].

Plant growth measurement

Plant height was measured using a meter ruler from the soil level to the collar of the uppermost leaf [29]. Stem girth was measured with thread, which was later extrapolated on a ruler. Leaves were counted and leaf area was measured using the method of Watts [30]. The plants were harvested and the shoot biomass was separated from the root biomass. Soil and biochar particles were carefully removed from the root biomass and the root lengths were measured. Fresh biomass of shoots and roots were weighed separately, while their dry biomasses were weighed after oven drying to constant weights [28].

Heavy metal determination in plant and soil samples

The method of Thompson and Wood [31] was adopted. One gram of each plant or soil sample was digested in a 4:1 ratio of concentrated 69% HNO_3 (analytical grade) and concentrated 60% $HClO_4$ (Merck, Germany). The mixture was heated to dryness. The residue was then leached with 5 M 36% HCl (analytical grade) and filtered through Whatman No. 41 filter paper. The filtrate was finally diluted with distilled water to 1 M HCl. The samples were analyzed for multiple elements, including Cd, Cu, Pb, Ni and Zn, with an atomic absorption spectrophotometer (AAS model 210VGP, Buck Scientific Incorporated USA) with an air-acetylene flame. Procedural blanks were carried out, and samples were tested in triplicate to validate the accuracy of the procedure.

Plant–soil relationship

The movement of heavy metals from polluted soil into the roots of plants and their ability to translocate metals from roots to aerial parts were assessed by means of bioconcentration factor (BCF) and translocation factor (TF) models [32]. Equation 1 represent the bioconcentration factor (BCF) calculated as the ratio of the concentration of heavy metals in plant roots to that in soil:

$$\mathrm{BCF} = \frac{\mathrm{Cmr}}{\mathrm{Cms}} \tag{1}$$

where C_{mr} is the concentration of heavy metals in roots, C_{ms} is the concentration of heavy metals in soil. BCF value > 1 implies that the plant is a hyperaccumulator of the heavy metal [33].

Equation 2 represent the translocation factor (TF) calculated as the ratio of the heavy metal concentration in the plant shoot to that in the plant root:

$$\mathrm{TF} = \frac{\mathrm{Cmsh}}{\mathrm{Cmr}} \tag{2}$$

where C_{msh} is the metal concentration in the shoot, and C_{mr} is the concentration of heavy metals in the root. TF value < 1 indicates that the plant is an excluder, TF > 1 indicates that the plant is an accumulator, while TF = 1 indicates that the plant is an indicator [34].

Statistical analyses

One-way analysis of variance (ANOVA) was used to assess the significant differences among the biochar treatments. Duncan's multiple range test (DMRT) was used to determine the significance of the differences among the biochar treatments based on the soil properties, growth parameters and heavy metal contents ($p < 0.05$). SPSS 21.0 Statistical Package was used for the statistical analyses.

Results

Table 1 shows the growth parameters of *T. diversifolia*. The height of *T. diversifolia* decreased with increasing StB and increased with increasing SB and RB. In response to RB 3%, highest height (13.36 cm) of *T. diversifolia* was recorded. The number of leaves of *T. diversifolia* in the 1% (8.00) and 3% (7.00) RB treatment groups was significantly greater than that in the untreated group. Only the leaf area of *T. diversifolia* plants treated with RB was significantly greater than that of the control plants. In addition, the 1% RB treatment had the greatest number of leaves and greatest leaf area. Highest stem girth was observed in *T. diversifolia* upon RB3% application. Stem girth decreased with increasing StB concentration, while the stem girth increased with increasing RB concentration. In general, RB treatment relatively improved the growth of *T. diversifolia*.

Table 2 shows the biomass of *T. diversifolia* under the different biochar treatments. SB2%, RB1% and RB2% had a positive effect on the root length of *T. diversifolia*. SB2% treatment resulted to *T. diverisfolia* with the longest root length (9.73 ± 2.46 cm). Furthermore, *T. diversifolia* plants treated with RB had significantly greater shoot and root fresh weights and shoot dry weight, ($p < 0.05$) than the control plants. However, SB3% significantly ($p < 0.05$) increased the shoot dry weight of *T. diversifolia*, while the root dry weight of untreated *T. diversifolia* was significantly greater than that of the treated plants, except for SB2%.

Table 1 Effect of different concentrations of StB, SB and RB on the growth of *T. diversifolia*

Biochar	Rate (%)	Height (cm)	No of leaves	Leaf area (cm^2)	Stem girth (cm)
Control	0	9.60 ± 0.95^{c}	6.00 ± 0.00^{b}	2.45 ± 1.75^{bc}	1.46 ± 0.09^{d}
StB	1	9.40 ± 1.61^{c}	4.00 ± 0.00^{c}	1.70 ± 0.32^{c}	1.66 ± 0.08^{c}
	2	8.27 ± 0.72^{d}	6.00 ± 0.00^{b}	1.58 ± 0.29^{c}	1.62 ± 0.08^{c}
	3	5.50 ± 0.20^{e}	4.00 ± 0.00^{c}	0.40 ± 0.26^{d}	1.25 ± 0.00^{e}
SB	1	N	N	N	N
	2	8.93 ± 0.85^{d}	4.00 ± 0.00^{c}	1.06 ± 0.26^{c}	1.52 ± 0.09^{cd}
	3	10.33 ± 0.25^{b}	5.00 ± 0.00^{c}	1.74 ± 0.48^{c}	1.33 ± 0.09^{d}
RB	1	10.70 ± 0.46^{b}	8.00 ± 0.00^{a}	5.08 ± 3.95^{a}	1.57 ± 0.00^{cd}
	2	12.90 ± 0.72^{a}	6.00 ± 0.00^{b}	3.42 ± 2.59^{bc}	1.98 ± 0.18^{b}
	3	13.37 ± 1.08^{a}	7.00 ± 0.00^{a}	4.40 ± 4.25^{a}	2.30 ± 0.48^{a}

Values are presented as means ± S.D of triplicate values. Values with different superscripts in the same column differ significantly at $p \leq 0.05$. StB – Standard Biochar; SB – Sorghum Biochar; RB - Rice Biochar, N- Necrosis

Table 2 Effect of different concentrations of StB, SB and RB on biomass of *T. diversifolia*

Biochar	rate (%)	RL (cm)	SFW (g/kg)	RFW (g/kg)	SDW (g/kg)	RDW (g/kg)
Control	0	8.20 ± 1.90^{a}	0.32 ± 0.05^{abc}	0.06 ± 0.02^{ab}	0.02 ± 0.01^{bc}	0.02 ± 0.03^{a}
StB	1	6.97 ± 1.21^{a}	0.20 ± 0.07^{bc}	0.10 ± 0.02^{a}	0.02 ± 0.01^{bc}	0.001 ± 0.00^{a}
	2	5.50 ± 0.40^{a}	0.20 ± 0.01^{bc}	0.06 ± 0.04^{ab}	0.01 ± 0.001^{c}	0.002 ± 0.001^{a}
	3	8.17 ± 0.55^{a}	0.09 ± 0.01^{bc}	0.05 ± 0.02^{ab}	0.002 ± 0.001^{c}	0.001 ± 0.001^{a}
SB	1	N	N	N	N	N
	2	9.73 ± 2.46^{a}	0.17 ± 0.04^{bc}	0.07 ± 0.05^{a}	0.05 ± 0.01^{bc}	0.02 ± 0.03^{a}
	3	6.23 ± 0.45^{a}	0.25 ± 0.07^{bc}	0.05 ± 0.03^{ab}	0.12 ± 0.08^{a}	0.001 ± 0.001^{a}
RB	1	8.40 ± 6.02^{a}	0.47 ± 0.31^{ab}	0.08 ± 0.04^{a}	0.08 ± 0.07^{ab}	0.01 ± 0.01^{a}
	2	8.83 ± 1.17^{a}	0.47 ± 0.15^{ab}	0.08 ± 0.01^{a}	0.08 ± 0.03^{ab}	0.001 ± 0.001^{a}
	3	8.00 ± 2.54^{a}	0.65 ± 0.55^{a}	0.07 ± 0.06^{a}	0.09 ± 0.08^{ab}	0.01 ± 0.01^{a}

Table 3 Bioconcentration factors and translocation factors of heavy metals in *T. diversifolia*

Biochar rate (%)		Cu		Zn		Pb		Cd		Cr	
		BCF	TF	BCF	TF	BCF	TF	BCF	TF	BCF	TF
Control	0	1.00	0.00	0.00	0.00	1.00	7.60	0.00	2.17	1.33^{**}	1.50^{**}
StB	1	0.66	1.09	1.23^{*}	0.00^{*}	0.60	1.67	0.62	1.30	0.00	0.00
	2	0.00	0.06	1.30^{*}	0.00^{*}	2.30^{*}	0.00^{*}	1.76^{*}	0.00^{*}	1.57^{*}	0.64^{*}
	3	0.00	0.00	0.00	0.00	0.46	2.67	0.00	0.00	1.25^{**}	1.60^{**}
SB	1	0.24	1.25	0.00	0.00	0.38	2.17	0.00	0.00	1.10^{*}	0.36^{*}
	2	0.00	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.75
	3	1.00	5.51	0.46	1.00	1.66^{**}	1.30^{**}	0.00	2.00	1.00	1.25
RB	1	0.00	0.00	1.00	0.63	1.00	0.50	1.00	1.54	0.64	0.86
	2	0.63	2.03	1.00	1.00	0.77	1.30	1.00	2.00	0.86	0.67
	3	2.00^{*}	0.78^{*}	0.50	0.00	1.00	0.77	0.00	0.00	0.71	1.00

StB – Standard Biochar, SB – Sorghum Biochar, RB –Rice Biochar, BCF- Bioconcentration factor, TF- Translocation factor, Phytoextractor** means BCF &TF > 1, Phytostabilizer * means BCF > 1 and TF < 1, Indicator means TF = 1

Values are presented as means ± S.D of triplicate values. Values with different superscripts on the same column differ significantly at $p \leq 0.05$. StB – Standard Biochar; SB – Sorghum Biochar; RB - Rice Biochar; RL – root length, SFW – shoot fresh weight; RFW – Root fresh weight; SDW – shoot dry weight; RDW – root dry weight, N- Necrosis.

Table 3 shows that *T. diversifolia* grown in control soil had BCF and TF < 1 which indicate the potential of the plant as a phytostabilizer for Cu. However, all the concentrations of SB enhanced the phytoextraction capacity of *T. diversifolia* for Cu with TF values greater than one (TF > 1). With respect to Zn bioaccumulation, it was observed that StB1% and 2% with BCF values of 1.23 and 1.30 respectively and TF value of 0.00 indicated restriction of Zn translocation in *T. diversifolia*. The TF value for Pb was greater than 1 (TF > 1) in *T. diversifolia* grown in control soil indicating its high phytoextracting capacity for Pb. while the phytoextracting capacity of *T. diversifolia* for Pb was reduced by StB2% as observed in

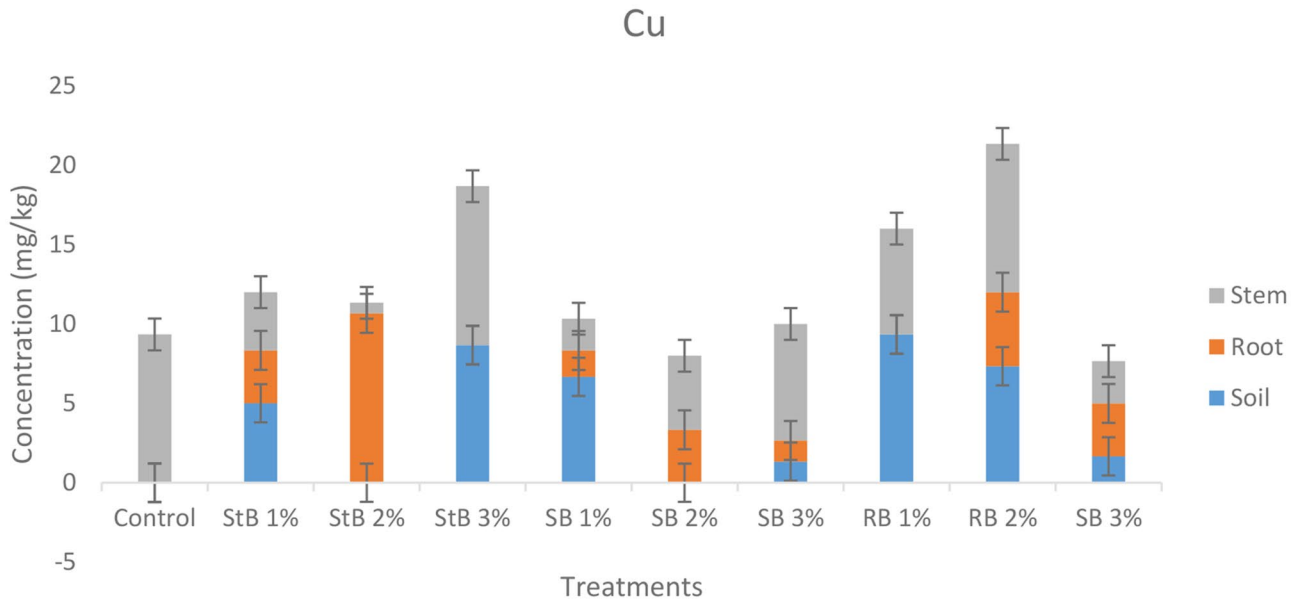


Fig. 1 The effect of different concentrations of StB, SB and RB on Cu content in soil, root and shoot of *T. diversifolia*

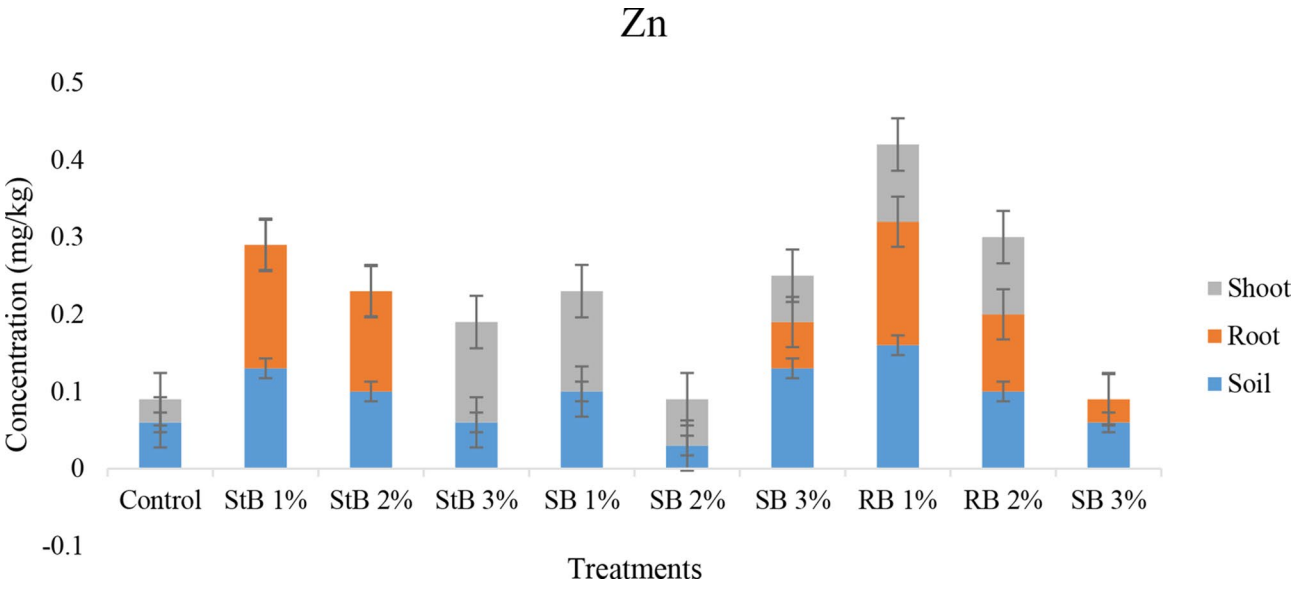


Fig. 2 The effect of different concentrations of StB, SB and RB on Zn content in soil, root and shoot of *T. diversifolia*

the BCF and TF values (Table 3). In the case of Cd, *T. diversifolia* accumulated high Cd from the control soil to its shoot as indicated in the TF value (2.17) but STB2% reduced the phytoextracting capacity of *T. diversifolia* for Cd. It was observed that Cr concentration was high in the control of *T. diversifolia* as indicated in the BCF (1.33) and TF (1.50) values which are greater than one suggesting the plant as a suitable phytoextractor but the its accumulation capacity was reduced by StB2% and SB1%.

Figures 1–5 show the effect of biochar application on the distribution of heavy metals within the contaminated soil and root and shoot of *T. diversifolia*. This revealed variation of the heavy metal concentration in *Tithonia* plant and this denotes the different interaction of biochar with heavy metal. In addition, shoot of *T. diversifolia* recorded higher concentrations of Cu than in the roots.

Discussion

This study revealed that biochar amendment enhanced the growth of *T. diversifolia* in spent oil contaminated soil. Ayesa et al. [16] revealed that pollutants decrease the growth biomass of *T. diversifolia* in the soil, due to heavy metal toxicity. The incorporation of biochar in the soil is widely known to improve plant growth [35] due

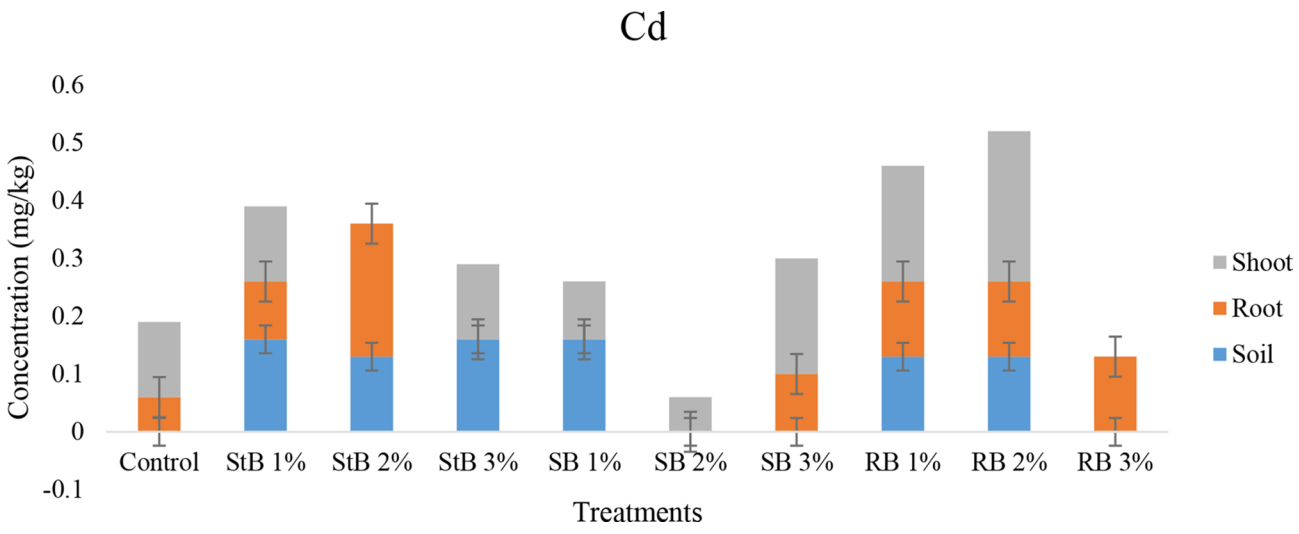


Fig. 3 The effect of different concentrations of StB, SB and RB on Cd content in soil, root and shoot of *T. diversifolia*

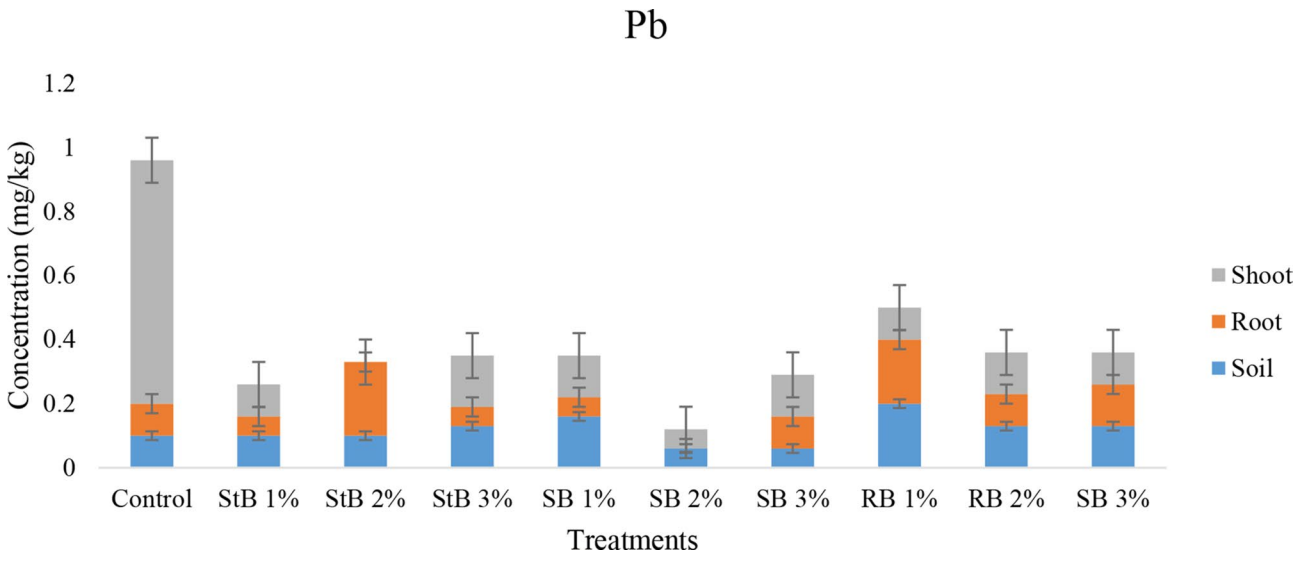


Fig. 4 The effect of different concentrations of StB, SB and RB on Pb content in soil, root and shoot of *T. diversifolia*

to its unique properties. The rice straw biochar and sorghum straw biochar used in this study were characterized by Ogunremi et al. [25], to have high pH, porosity, carbon content and active surface functional groups. When the biochars are applied, these properties contribute to increased porosity and water holding capacity in the soil [36], thereby improving the growth of *T. diversifolia*.

With respect to the root and shoot biomass, RB was observed to improve the plant biomass. As opined by Genesio et al. [37], the dark coloration of biochar could contribute to the physical properties of soil by altering the thermal dynamics thereby supporting the plant germination. Furthermore, the biochar pore structure is a contributory effect on soil porosity which creates conducive environments for microbial activities [28], hence improving the soil organic matter, nutrient and water retention [38]. In this context, the higher nutrients uptake by *T. diversifolia* through the root could attribute to its shoot growth. Furthermore, conducive environment for microorganisms enhances their interactions (direct or indirect) with heavy metals through their various metabolic activities. During the process of microbial activities, the microorganisms secreted organic acids which dissolves the heavy metals in the soil [35]. Additionally, the ability of these biochars to restrict the availability of heavy metals to *T. diversifolia* could be responsible for its improved growth and biomass.

The different effect of biochar on heavy metal bioavailability is dependent on the type of biochar and specific heavy metal [28]. Biochar possesses some key attributes such as high pH, porosity, cation exchange capacity, water holding capacity and active functional groups [39]

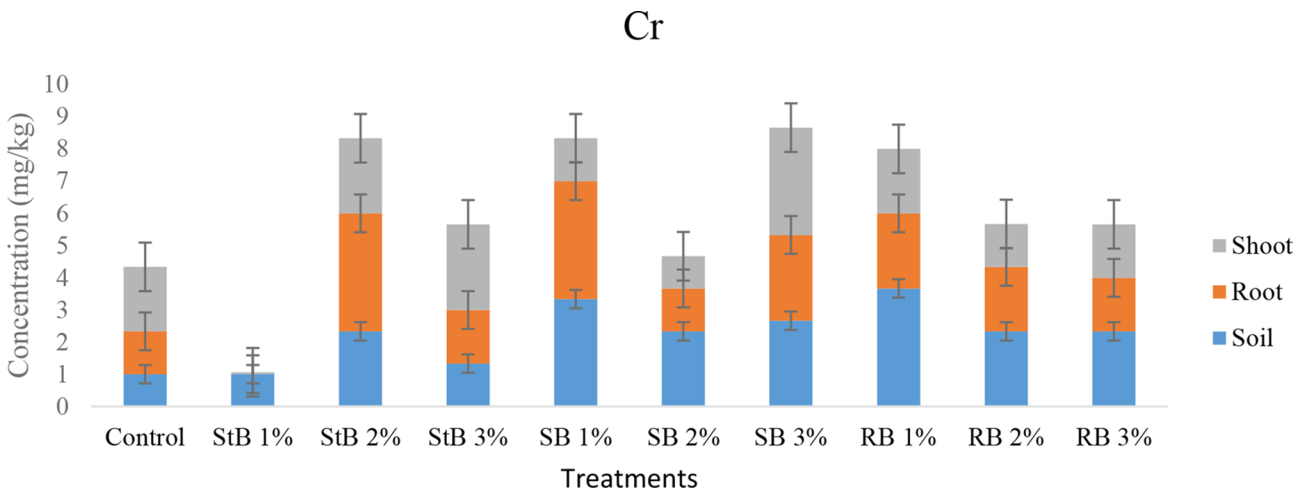


Fig. 5 The effect of different concentrations of StB, SB and RB on Cr content in soil, root and shoot of *T. diversifolia*

for heavy metal adsorption in contaminated soils, thereby resulting to low uptake by plants [14]. Gu et al. [40] revealed the capacity of cornstalk biochar to reduce the Cd concentration and enhanced the root growth of *Beta vulgaris*. In the present study, the application of different types of biochar reduced heavy metal bioaccumulation and/or translocation in *T. diversifolia*. In another study by Jing et al. [41], there was reduction in Cd bioaccumulation and translocation in *Oryza sativa*, as a result of the application of wheat straw-derived biochar.

This current study reported exceptional cases where bioaccumulation and/or translocation were enhanced in the plant. Phytoextraction is a type of phytoremediation in which heavy metals are removed from polluted soils and then translocated to above ground tissues [42]. Plants that are recognized as hyperaccumulators must be able to accumulate high levels of heavy metals and still retain their health status, such as high biomass and tolerance to metal toxicity [43]. For plants to be efficient tools for the phytoextraction of heavy metals in polluted soils, the bioconcentration factor and translocation factor must be greater than one [44, 45]. In this study, phytoextraction capacity of *T. diversifoli*a for Cu was enhanced when sorghum straw biochar was applied. In a similar manner, rice straw biochar enhanced phytoextracting capacity of *Gynura cusimbua* for Cu, Zn and Pb in mine water contaminated soil [46].

Phytostabilization is another phytoremediation that involves immobilization of heavy metals and accumulation of these metals in underground biomass, which primarily focuses on heavy metal sequestration in roots [47, 48]. Plants with BCF values greater than 1 and TF values less than 1 are appropriate for phytostabilization [49, 50]. This implies that such plants are unable to translocate heavy metals to aerial parts [51]. The current study showed that selected biochar application at different concentrations restricted the movement of heavy metals to the root of *T. diversifolia*. It was observed that STB at 1% and 2% application rates had BCF values greater than one (1.20 and 1.30 respectively) and TF values less than one (0.00) for Zn which implies that the biochar treatment restricted the translocation of Zn to the root of *T. diversifolia*. The mechanisms that could result in the restriction of heavy metal mobility include water erosion and leaching prevented by plant roots, precipitation [52, 53], root adsorption or absorption and a reduction in metal valency [54]. Report by Geleto et al. [55] revealed that the reaction rate among the heavy metals on the adsorption site of biochar was high especially for Zn. It was also revealed in the work of Antonangelo et al. [28] that Zn was more restricted.

Moreover, it was observed that only StB2% enhanced the restriction of Cd and Pb translocation to the root of *T. diversifolia*. The negative charged on the outer surface of biochar and its alkalinity helps in adsorption and tolerance of heavy metal through different mechanisms [56]. Therefore, the alkalinity of the studied biochars may be a contributory factor to Cd and Pb restriction to the shoot of *T. diversifolia* as the biochar used in this report increased the soil pH according to Ogunremi et al. [25].

In a study reported by Houssou et al. [57], the Cd and Pb uptake by *Brassica chinensis* was reduced at 3% rate of biochars derived from green waste. Similarly, another study by Zhu et al. [58] showed that Pb was immobilized through precipitation when treated with wheat straw biochar at 700 °C. Biochar has the potential to immobilize heavy metals differently through various mechanisms such as complexation, electrostatic attraction, precipitation and ion exchange [59]. In the case of Pb, biochar explored the mechanism of precipitation in two ways such as increasing the soil pH causing the metal ion to precipitate or the inorganic compounds (PO_4^{-3}

and CO_3^{-2}) in biochar react with the metal ion. In this regards, alkalinity nature of biochar is the key factor responsible for these mechanisms to take place.

The present study showed that StB2% and SB1% reduced the translocation capacity of *T. diversifolia* for Cr as compared to the control. This could attribute to the abundant functional groups present in the biochar as reported by Ogunremi et al. [25]. Since Cr can be reduced by oxygenated functional groups on the biochar surface and the reduced metal bind to the biochar surface through complexation. Also, biochar immobilizes Cr by adsorbing the metal on its surface through electrostatic attraction between the negatively charge chromium and its positively charged surface [28].

Moreover, it is generally known that biochar enhanced soil porosity as a result of its porous nature providing suitable habitats for microorganisms to carry out their degradation activities in order to sequester pollutants. A study revealed reduction in the bioavailability of Cd and Cu in soil when a charcoal engineered with Cd-Cu tolerant bacterial strain (*Pseudomonas* sp) was applied [59]. Also, Tu et al. [60] reported a massive reduction of Pb content in soil treated with rice biochar carrying phosphate-solubilizing bacteria. These microorganisms release their negatively charged surface functional groups which react with metal ions for sequestration to occur [61]. The current work showed that the biochars immobilized and restricted most of the heavy metals in the soil and to the root of *T. diversifolia* respectively.

Conclusions

The biochars evaluated in this study increased the biomass of *T. diversifolia*. This study also revealed that biochars influence the bioavailability of heavy metals in polluted soil. The interaction of specific biochar with *T. diversifolia* influenced change in the plant's status from a phytoextractor to a phytostabilizer for specific heavy metal. In another vein, sorghum biochar changed Cu-phytostabilizing *T. diversifolia* to a Cu-phytoextracting plant.

Feedstock used for biochar production and surface functional groups on biochar may account for the unique interactions of biochar with plants and heavy metals. Hence, the need for further studies on long term field trials focusing on the parameters associated with biochar-heavy metal interactions in soil with respect to plant for phytoremediation. Producing standard based biochar must be prioritized for effective remediation. This will account for sustainable environmental factors and ensure practical application for agricultural purpose and environmental remediation.

Abbreviations

RB	Rice Biochar
SB	Sorghum Biochar
StB	Standard Biochar
Cu	Copper
Zn	Zinc
Pb	Lead
Cd	Cadmium
Cr	Chromium
ANOVA	One Way Analysis of Variance
DMRT	Duncan's Multiple Range Test
UKBRC	UK Biochar Research Centre
CRD	Complete Randomized Design
AAS	Atomic Absorption Spectrophotometer
BCF	Bioconcentration Factor
TF	Translocation Factor
RL	Root Length
SFW	Shoot Fresh Weight
RFW	Root Fresh Weight
SDW	Shoot Dry Weight
RDW	Root Dry Weight
N	Necrosis

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Author contributions

O.O. contributed substantially to the conception, methodology, investigation, formal analysis, writing- original draft, O.A. contributed to the methodology and formal analysis; C.O. contributed to the supervision, reviewing and editing, P.F. made a contribution to the conception, supervision, writing- reviewing and editing. All authors reviewed the manuscript.

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Data availability

The authors declare that all data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Seed collection for this research was conducted under the ethical guidelines provided by University of Ilorin and approved by its University Ethical Review Committee (UERC) with approval no: UERC/ASN/2017/899. This permit covered access to University of Ilorin Botanical Garden. All collection activities were in compliance with relevant institutional, national, and international guidelines and legislation.

Consent for publication

Not applicable.

Competing interests

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