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HEAVY METAL UPTAKE AND TRANSLOCATION BY SEMULOH (*FAGOPYRUM DIBOTRYS*) FROM SAWDUST SLUDGE CONTAMINATED SOIL

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Abstract

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Heavy metal pollution to the soil environment has become a major source of concern and has posed serious health problems in many developed countries. A glass house experiment was conducted to evaluate the potential of *Fagopyrum dibotrys* to absorb heavy metals from sawdust-contaminated soil. *Fagopyrum dibotrys* seedlings were planted on six different growth media (soil+sawdust) comprising: 100% soil, 20% sawdust + 80% soil, 40% sawdust +60% soil, 60% sawdust +40% soil, 80% sawdust +20% soil and 100% sawdust. The maximum height, basal diameter and number of leaves were found in 80% sawdust +20% soils. Copper, iron and zinc were highly concentrated in the roots, lead in the stems and roots, while aluminum was concentrated in both stems and leaves. *Fagopyrum dibotrys* seems to have potential to absorb sufficient amounts of Fe, Al, Pb and Zn in the stems, leaves and roots. This species showed high translocation factor (TF) in the contaminated soil and was able to tolerate and accumulate heavy metals. This species therefore, can be considered as a potential phytoremediator.

Key words: Heavy metal accumulation, *Fagopyrum dibotrys*, phytoremediation, sawdust sludge, translocation

*Abbreviation*s: ANOVA- Analysis of variance, As-Arsenic , Cd- Cadmium, CEC- Cation exchange capacity, C- Celsius, Cr- Chromium, Cu - Copper, DMRT-Duncan's Multiple Range Test, HCl - Hydrochloric acid, Hg-Mercury, HNO_3 - Nitric acid, Ni-Nickel, Pb- Lead, Zn- Zinc, Pb - Lead, USDA- United State Depatment of Agriculture and Zn - Zinc

Introduction

Heavy metal pollution in soil is one of the major environmental problems throughout the world. Heavy metals have a significant toxic effect on humans, animals, microorganisms and plants. The heavy metals are being released into the environment by various anthropogenic activities, such as manufacturing processes of industries, domestic refuse and waste materials particularly sawdust sludge, sewage sludge, textile industry sludge and slaughter house sludge (Duffus, 2002).Sawdust is composed of the fine particles of wood and also waste from wood factory. It can be reprocessed into particle board or used to produce heat for other milling operations, Sawdust also collects in piles and gives harmful leachates into local water systems, creating environmental hazard. However, it is one of the most efficient removals of Cu, Zn, Pb, Fe, Cd, Cr, As, Hg and Ni (Shukla et al., 2002). Among low-cost adsorbent, sawdust has been considered as the most important due to its abundance and availability mostly from wood-based industries. It is usually used

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as a cheaper alternative to absorb oil or chemical spill and other contaminants from factories (Mohamed et al., 1998). Many factories in Malaysia dispose the contaminated sawdust into landfill to minimize the cost and this causes environmental pollution (DOE, 2011).

Excess concentration of metalloids and heavy metals in soils such as As, Cd, Cr, Cu, Hg, Pb and Zn has caused the disruption of natural terrestrial ecosystems (Wei et al*.,* 2007). Lead and cadmium are non-essential elements, but zinc at lower concentration is an essential plant micronutrient. Higher doses of these metals may cause metabolic disorders and growth inhibition for most plants and often cause mortality (Wong et al., 2003 and Tripathi et al., 2007). Heavy metals also pose threats to soil quality and human health and high concentrations of heavy metals are harmful to plants and animals. The common environmental problems are related with plant productivity, food quality and human health (Alloway, 1990). Their potential accumulation in human tissues and bio-magnification through the food chain can cause DNA damage and carcinogenic effects (Ghafoori, 2011).

These soil contaminants need to be cleaned up for a safer environment, but some existing methods such as microbial bioremediation, physical and chemical treatments, excavation and burial at a waste site is not sufficient, costly and time consuming. Plants can be used to remediate waste land and to restore soil health. For effective phytoremediation process, the plant species should be non-edible and can be grown abundantly on large scale. Plants should be able to tolerate harsh condition such as heavy metal contamination, low nutrient content and drought (Kumar, 2008). Considering all the options available, *Fagopyrum dibotrys* has been selected for this experiment. It is perennial Buckwheat belonging to the family Polygonaceae. A very tolerant and easily grown plant, it prefers dry sandy soils but succeeds in most conditions including poor, heavy or acidic soils and it prefers a good soil in partial shade. It also grows very well in woodland conditions. Some works of phytoremediation on polluted soils have been done but phytoremediation in sawdust sludge contaminated soil with *Fagopyrum dibotrys* has not been reported. Therefore, the present study was initiated to: (i) study the growth performance of *Fagopyrum dibotrys* in sawdust contaminated soil, (i) determine heavy metal concentrations in *F. dibotrys* plant parts and (ii) quantify the heavy metal concentrations in the growth medium before planting and after harvest.

Materials and Methods

Site description and growth media

The experiment was conducted at the bioremediation research glasshouse, Universiti Putra Malaysia, 4°06′ N latitude and 101° 16′ E longitude from April to July 2009. The temperature of the glass house ranged from 26 to 36^0C. The growth media prepared using soil mixing with different levels of contaminated sawdust sludge was T0 (Control, 100% soil), T1 (20% sawdust + 80% soil), T2 (40% sawdust + 60% soil), T3 (60% sawdust + 40% soil), T4 (80% sawdust + 20% soil), and T5 (100% sawdust). A Completely Randomized Design (CRD) was used with four replications. *Fagopyrum dibotrys* was used as the test plant.

Nature of plant materials

Commonly known as perennial Buckwheat, the species is found in forested and cultivated areas from Pakistan to S.W. China at elevation of 1500 - 3400 meters (Polunin and Stainton, 1984). It is also common alongside ditches and fertile soils in China. A very tolerant and easily grown plant, it prefers dry sandy soils but succeeds in most conditions including poor, heavy or acidic soils and it prefers a fertile soil and grows very well under partial shade. It easily regrows vegetative from the base (Don, 2011).

Seedling preparation, planting and growth measurement

The seedlings were prepared from cuttings of matured plants to provide uniform size and age. The cuttings were placed in gelatin media for two months for root initiation. About 80 seedlings were then transplanted into polyethylene bags before being planted. Healthy saplings of three months old and similar in form were selected for this study. After filling the pots with the growth media, the seedlings of uniform age and size were transplanted into the pots. Intercultural operations (weeding and watering) were done when necessary to ensure normal growth of the seedlings. Twenty four plants were used to measure growth parameters including basal diameter, number of leaves, and height at certain interval of time. Height was taken using a ruler and basal diameter was measured with a caliper. The growth parameters were measured twice a month.

Soil and plant sampling and chemical analysis

Growth media samples were collected, dried and ground for chemical analysis. Particle size distribution was analyzed by pipette gravimetric method. Soil pH and total carbon were determined by using glass electrode pH meter (Jackson, 1973) and loss on ignition method, respectively. Plant samples (whole plant) at harvest were collected for heavy metal analysis. 1.0 g dried plant sample and 20 ml aqua regia solution (mixture of concentrated HNO_3 and HCl in a ratio of 3:1) was acid digested at 80 to 120°C for 3 hours. After digestion, the solution was filled into 100 ml beaker and ready for analysis using ICP-MS (Inductively Couple Plasma Mass Spectrometry) method (Sahoo et al., 2009).

Plant biomass measurement

Plant biomass was measured separately for leaves, stems, and roots and calculated accordingly. The loss in weight upon drying is the weight originally present. The moisture content of the sample was calculated using the following equation

$$\%Moisture = \frac{\text{Wt. wet sample} - \text{Wt. dry sample}}{\text{Wt. dry sample}} \times 100 \quad (1)$$

Determination of translocation factor (TF)

The plant's ability to translocate metals from roots to shoots was estimated using the translocation factor (TF) and calculated as follows:

$$\text{TF} = \frac{\textbf{Metal concentration in aerial parts}}{\textbf{Metal concentration in root}} \quad \ldots (2)$$

Statistical analysis

Analysis of variance for growth and heavy metal concentrations (in soil and plant parts) were done following the ANOVA test and the mean values were adjudged by DMRT (P=0.05) method (Steel et al., 1996). Comparison using t-test was also done to detect any significant differences between before planting and at harvest.

Results and Discussion

Properties of the growth media

The soil texture of the growth media was different between the control and the sawdust sludge. The texture of the control (100% soil) was clay having 22.45% sand, 10.29% silt and 67.25% clay and that of sawdust-contaminated media was sandy clay loam. Texture is an important soil characteristic that plays important role in soil management and crop production. Sandy clay texture is suitable for seedling growth and development because it contains high nutrients, high CEC and water holding capacity is also high. Clay soils crack excessively while drying, if they are very low in organic matter, it may lose its structure, become cloddy, and compacted (Aljibury, 2011). Before planting, soil pH ranged from 5.94 to 7.34. Treatments T4 (80% sawdust sludge) and T5 (100% sawdust sludge) showed highest pH value (7.34) followed by T3 (7.21) and T1 (7.07). The minimum pH (5.94) was found in the control (Table 1). After harvest, pH decreased in all the treatments except the control. The highest pH reduction (-0.68) was found in T5 followed by T4 (-0.35) and T1 (-0.35). The lowest reduction was in T2 (-0.06), while pH increased in the control (+0.14) (Table 1). The decrease of soil pH might be due to release of heavy metals from sawdust sludge during decomposition, which may create acidity in soil through hydrolysis of water. Ghafoori (2011) also reported similar results during cultivation of *Acacia mangium* in sewage sludge contaminated soil.

Before planting, Total organic carbon varied from 16.43 to 34.67%, highest (34.67%) in T5 followed by T4 (34.00%) and the lowest (16.43%) was in the control (Table 1). Total carbon content was highest in T5 (100% sawdust) because sawdust is rich in carbon. After harvest, total carbon content decreased (Table 1). The maximum reduction was found in T5 (-2.63%) followed by T4 (-2.34%). The control showed the minimum reduction (-0.73%). Treatments T2 and T3 showed similar reduction at -1.4% and -1.5%, respectively. Treatments T4 and T5 contained high levels of total carbon, which improves, water holding capacity and soil fertility. This resulted in better growth and development including height, basal diameter and higher biomass production (Ghafoori, 2011). Total carbon is also responsible for the availability of heavy metals in the soil and hence T5 showed high concentrations of Cu, Pb, Fe and Zn because of higher total carbon content in the growth medium. Clemente et al. (1991) also reported higher concentrations of heavy metals in sewage sludge contaminated soils, which are in agreement with findings of our study.

Growth performance

The growth parameters monitored were height, basal diameter and number of leaves. There was a significant difference in height among the treatments ($p \leq 0.05$). At harvest, the highest height (14.25 cm) was in T4 (80% sawdust + 20% soil) followed by T3 (60% sawdust + 40% soil) and T2 (40% sawdust + 60% soil). The lowest height (10.37 cm) was in T5 and this might be due to the toxic effect of heavy metals. The weekly height growth also showed an increase for each treatment except T5 (Figure 1a). From week, 2, 6, 10 and 14 the average height was 8.55, 9.84, 10.82 and 12.16 cm, respectively. *Fagopyrum dibotrys* showed normal growth in terms of plant height, as it is known to be a fast-growing species (Don, 2011). There was no significant difference among the treatments for basal diameter. The highest basal diameter (2.54 mm) was in T4 (80% sawdust) and followed by T3 (2.36 mm) and T2 (2.10 mm). The minimum basal diameter (1.72 mm) was in the control (Figure 1b). The average basal was 1.58, 1.71, 1.91 and 2.07 for week 2, 6, 10 and 14, respectively. Basal diameter increment was slow in T5 and this might be due to heavy metal toxicity. Moreover, the basal diameter increase in T0 and T1 slowed down after week 10 and this might be due to low nutrient content in the growth medium (Figure 1b). The number of leaves was significantly influenced ($p \leq 0.05$) by the different treatments. Treatment T3 (60% sawdust + 40% soil) showed highest number of leaves (12) followed by T4 (11). The lowest number of leaves (5) was found in T5 (Figure 1c). The increase in leaf number was 6, 6, 7 and 9 for week 2, 6, 10 and 14, respectively. In week six, the number of leaves decreased and this was due to metal toxicity. However, after week 8, the number of leaves again increased and this might be because the soil condition becomes more stable for plant growth after a certain period. The number of leaves increase every week indicating that the plant is able to survive in sawdust contaminated soil except for T5 (100% sawdust). pH did not seem to affect growth performance. Moderate increase in the number of leaves was found in T0 (control) probably due to low nutrient content in the growth medium.

Biomass production

Different levels of sawdust sludge ($p \leq 0.05$) significantly influenced dry biomass of Fagopyrum dibotrys. T4 gave the highest biomass of plant parts such as roots (0.85 g), stems (0.88 g) and leaves (0.22 g) compared to the other treatments (Figure 2). Total biomass ranged from 0.69 to 1.95 g per plant, highest in T4 followed by T3 and lowest was in T5. Among the plant parts, roots showed the highest biomass (0.62 g) followed by stem (0.34 g). The lowest biomass (0.16 g) was the leaves. T4 is the most suitable medium for *Fagopyrum dibotrys* in terms of biomass production. Though the biomass

Table 1
pH and total organic carbon change in the growth media

Treatment	pH in the growth media		Total C (%) in the growth media	
	Before planting	After harvest	Before planting	After harvest
T0	5.94	6.08	16.43	15.70
T1	7.07	6.72	16.63	15.47
T2	6.85	6.79	16.53	15.13
T3	7.21	6.96	27.27	25.77
T4	7.34	6.99	34.00	31.37
T5	7.34	6.66	34.67	32.33
SE (±)	0.22	0.13	3.61	3.35

T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge.

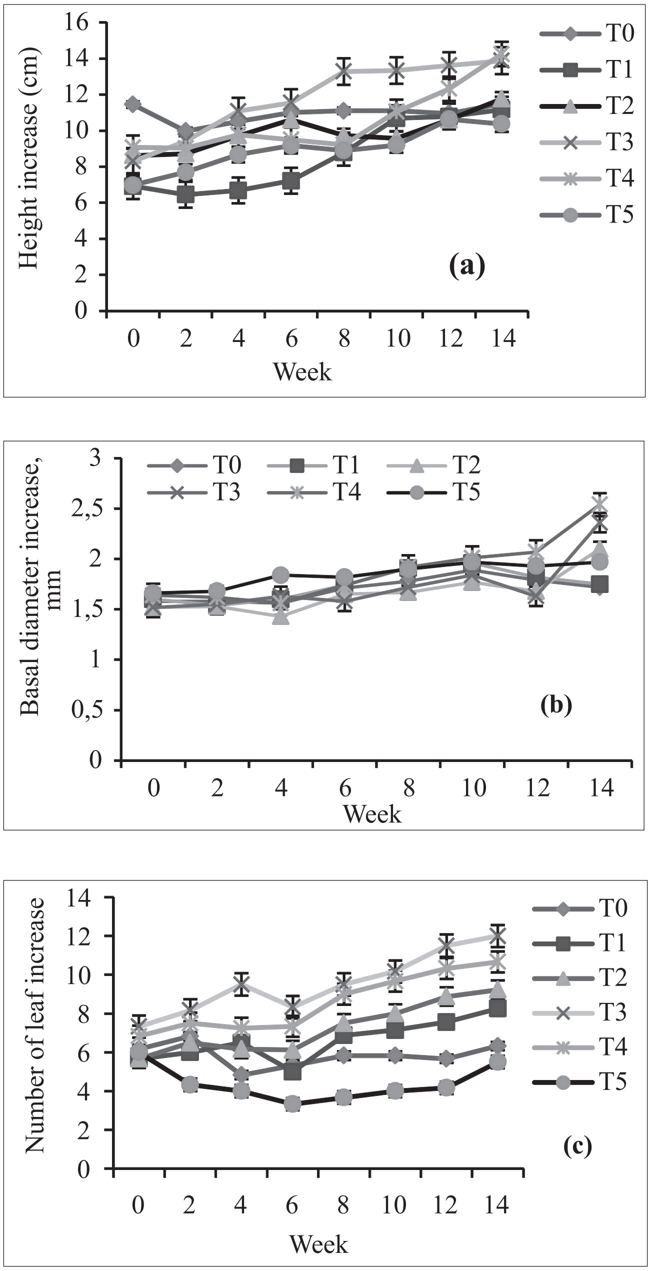

Fig. 1. Plant height (a), basal diameter (b) and number of leaves (c) of *Fagopyrum dibotrys* at different weeks after planting as influenced by different treatments (increase per two weeks). Growth media indicates different proportion of sawdust sludge and soil, i.e. T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge. Means ± SE are shown in error bars ($p = 0.05$).

production of this species was low, it showed continuous increase in the number of leaves and stem growth. A greenhouse experiment showed that the biomass of *M. jalapa* grown in petroleum (5000 mg kg^{-1}) contaminated soil did not decrease significantly compared with that in the control (Peng, 2009).

Heavy metal concentration in the growth media

Heavy metal concentration in the growth media was significantly variable ($p \leq 0.05$). Before planting, copper concentration ranged from 12.06 to 37482.46, the highest in T5 (100% sawdust sludge) followed by T4 (21681.39 ppm) and T3 (17623.68 ppm). The lowest (12.06 ppm) was in the control (Figure 3a). It was observed that Cu concentration in the growth media increased with increase in sawdust percentage. At harvest Cu concentration decreased in the growth media. Treatment T3 showed highest reduction (8892.83 ppm) followed by T5 (8610.72 ppm) and T2 (8505.33 ppm). The lowest reduction (8.97 ppm) was in the control (Figure 3a). The reduction of Cu concentration in the growth media might be due absorption by the plants. Majid et al. (2011) observed similar results in Cu contaminated soil planted with *Acacia mangium*. Copper is an essential micronutrient and constituent of many enzymes but in higher concentrations it creates toxicity to plants, humans and microorganisms (Perk, 2006).

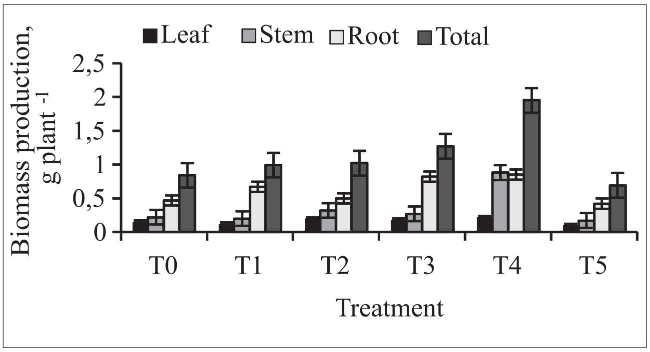

Fig. 2. Dry biomass of leaves, stems and roots of *Fagopyrum dibotrys* at harvest as influenced by different treatments. Growth media indicates different proportion of sawdust sludge and soil, i.e. T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge. Means ± SE are shown in error bars ($p = 0.05$).

Initially in the growth media, iron concentration ranged from 1255 to 5489 ppm. The control showed highest concentration (5489 ppm) followed by T1 (4408 ppm) and T2 (4243 ppm). The lowest concentration (1255 ppm) was in the 100% sawdust contaminated media. It was found that Fe concentration decreased with increase in sawdust content in the growth media. After harvest, Fe concentration increased in T3, T4 and T5 treatments (Figure 3b). The maximum increase (1350 ppm) was in T3 followed by T4 (470 ppm). T5 showed the lowest increment (38.7 ppm). The increase of Fe concentration in treatments T3, T4 and T5 might be due to release of Fe after decomposition of sawdust sludge as well as decrease in soil pH. However, Fe concentration decreased in the control, T1 and T2 having the highest reduction (902.87 ppm) in T1 followed by the control (834.97ppm) and the lowest was in T2 (273.83 ppm) (Figure 3b).

Lead concentration also increased with increase in sawdust in the growth media and significantly different among the treatments ($p \leq 0.05$). It ranged from 0.81 to 6632.65 ppm before planting, the highest in T5 (6632.65 ppm) followed by T4 (3789.85 ppm) and the lowest (0.81 ppm) was in the control (Figure 3c). Lead is potentially toxic even at low concentrations and is one of the most common inorganic pollutants in the soil (Alkorta et al., 2004).The normal levels of Pb in Malaysian soils are the range of 0.85 to 65.8 % (Zarcinas, 2003). The Pb concentration of the sawdust-contaminated media was much higher than the stated concentration. After harvest, Pb concentration decreased in the growth media. Treatment T2 showed maximum reduction (1430.77 ppm) followed by T3 (1345.76 ppm) and the lowest (0.46 ppm) was in the control. Among treatments, minimum Pb reduction (412.41 ppm) in the growth media was in T5 except for control, this might be due to toxicity, and plant was not able to absorb sufficient amount of Pb from the growth media. Before planting, aluminum concentration ranged from 28.81 to 3239.37 ppm in the growth media the highest was in the control (3239.37 ppm) followed by T1 (2996.84 ppm) and lowest in T5 (28.81 ppm). After harvest, Al concentration increased in all treatments (Figure 3d). The highest increment (2358.43 ppm) was in T2 followed by T3 (2190.69 ppm). The lowest increment (19.58 ppm) was in T5. It was also observed that Al concentration decreased with increase of sawdust in the growth media. Al is abundant in the acid soils. The increase in Al concentration after planting might be due to decomposition of sawdust and release of Al as well as decrease of soil pH, which influenced the solubility of Al. Zinc concentration in the growth media ranged from 14.72 to 26875.61 ppm with the highest in T5 and lowest, was in the control. It was also found that Zn concentration increased with increase of sawdust sludge percentage. After harvest, zinc concentration significantly decreased in the growth media ($p \leq 0.05$). T3 showed the highest reduction (6319.74 ppm) which and similar with T2 (6300.93 ppm) but significantly different from the other treatments (Figure 3e). The lowest reduction (11.69 ppm) was in the control. The decreased of Zn concentration in the growth media might be due to plant absorption. Zn is an essential element in access will create toxicity (Kabata-Pendias and Pendias, 1992). Among the elements, Zn showed the highest concentration in the sawdust contaminated media (Figure 3e).

Heavy metal concentration in plant parts

The heavy metal concentration in the plant parts was significantly variable among treatments ($p \leq 0.05$). The roots showed highest Cu accumulation (3.34 ppm) followed by the leaves (2.82 ppm). The lowest accumulation (1.87 ppm) was in the leaves. Qihang et al. (2011) also reported highest Cu absorption by the roots for *J. curcas* grown on metal contaminated acid soils. Among all treatments, the control showed the highest accumulation (4.70 ppm) in the roots followed by T2 (3.98 ppm) and the lowest (2.52 ppm) was in T4 (2.52 ppm) (Figure 4a). In the stems, Cu accumulation ranged from 0.301 to 3.36 ppm, the highest in T3 followed by T5 (2.86 ppm) and the lowest was in the control. In treatment T5, leaves had the highest absorption (10.14 ppm) and the lowest was in the stems (2.86 ppm) and roots (2.60 ppm). This might be due to translocation of Cu from roots to the aerial parts. Average lead concentration in the plant parts ranged from 0.09 to 5.06 ppm. The highest Pb accumulation was in the stems (mean 5.06 ppm) followed by the roots (mean 3.03 ppm) and the lowest (0.09 ppm) was in the leaves. Qihang et al. (2011) reported highest Pb accumulation by the *Jatropha curcas* root, which disagrees with the findings of our results. In the stems, T2 (6.39 ppm) showed maximum Pb accumulation followed by the control (5.90 ppm) and the minimum (3.12 ppm) was in T1 (Figure 4c). The highest Pb accumulation (4.13 ppm) in the roots was also found in T2 followed by T3 (3.56 ppm). The lowest accumulation (0.52 ppm) was in the control. The total Pb absorption by the plant varied from 3.67 to 10.6 ppm having the highest in T2 followed by T3 (9.463 ppm) and the minimum (3.67) was in the control (Figure

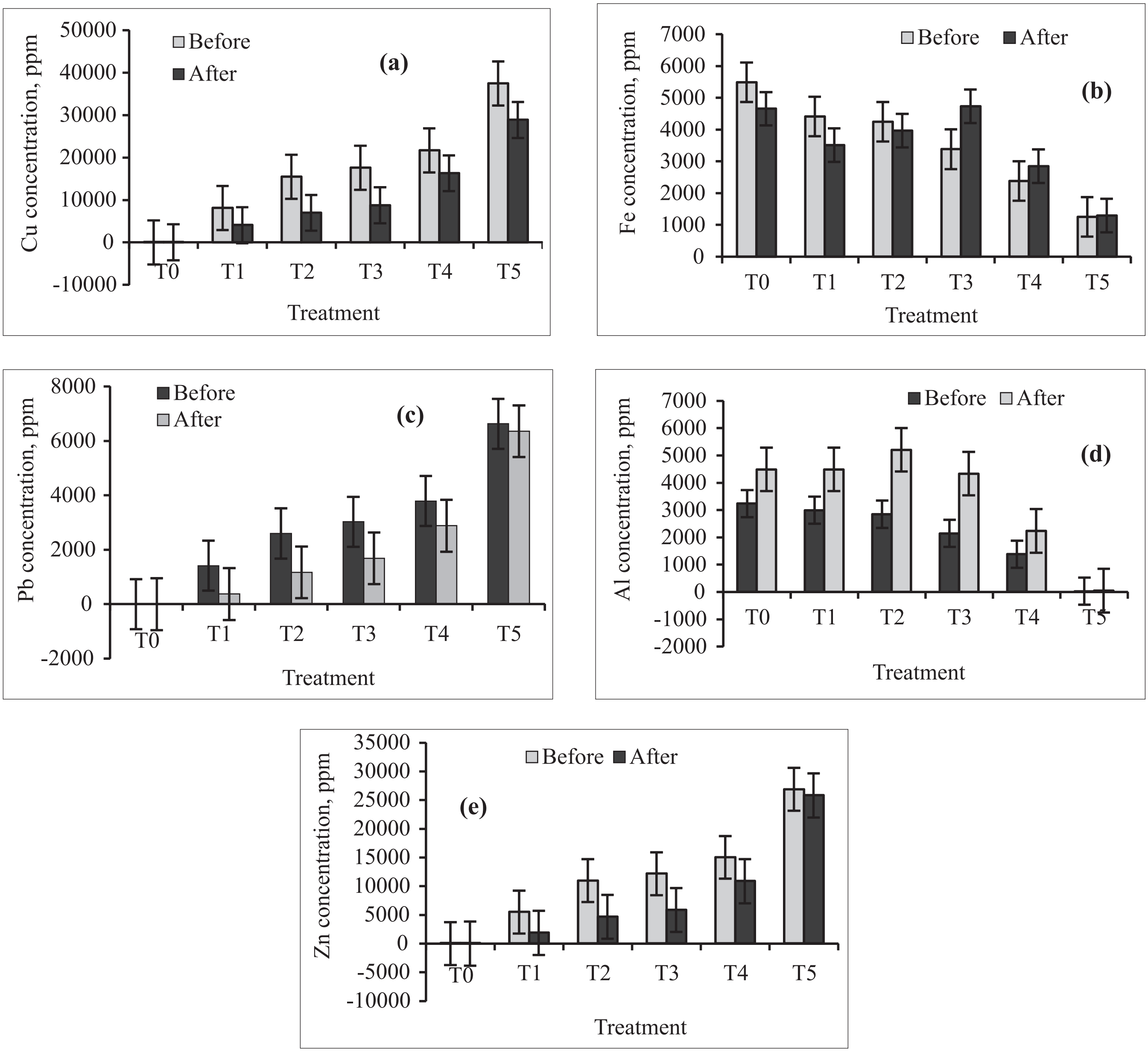

Fig. 3. Change in copper (a), iron (b), lead (c) aluminium (d) and zinc (e) concentrations in the growth media after cultivation of *Fagopyrum dibotrys* as influenced by different treatments. Growth media indicates different proportion of sawdust sludge and soil, i.e. T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge. Means ± SE are shown in error bars (*p* = 0.05)

4c). 100% sawdust failed to show maximum accumulation and this might be due to restriction in soil-root and root-shoot transfer at higher metal concentrations in the soil. Lead is a non-essential element and toxic to mammals including humans as well as plants. The normal concentration of Pb in the plant ranged from 0.1 to 5.0 ppm (Reeves and Baker, 2000). All the treatments except the control showed higher Pb concentration than normal or at phytotoxic levels. It is therefore, not wise to use sawdust for food crop cultivation. The iron con-

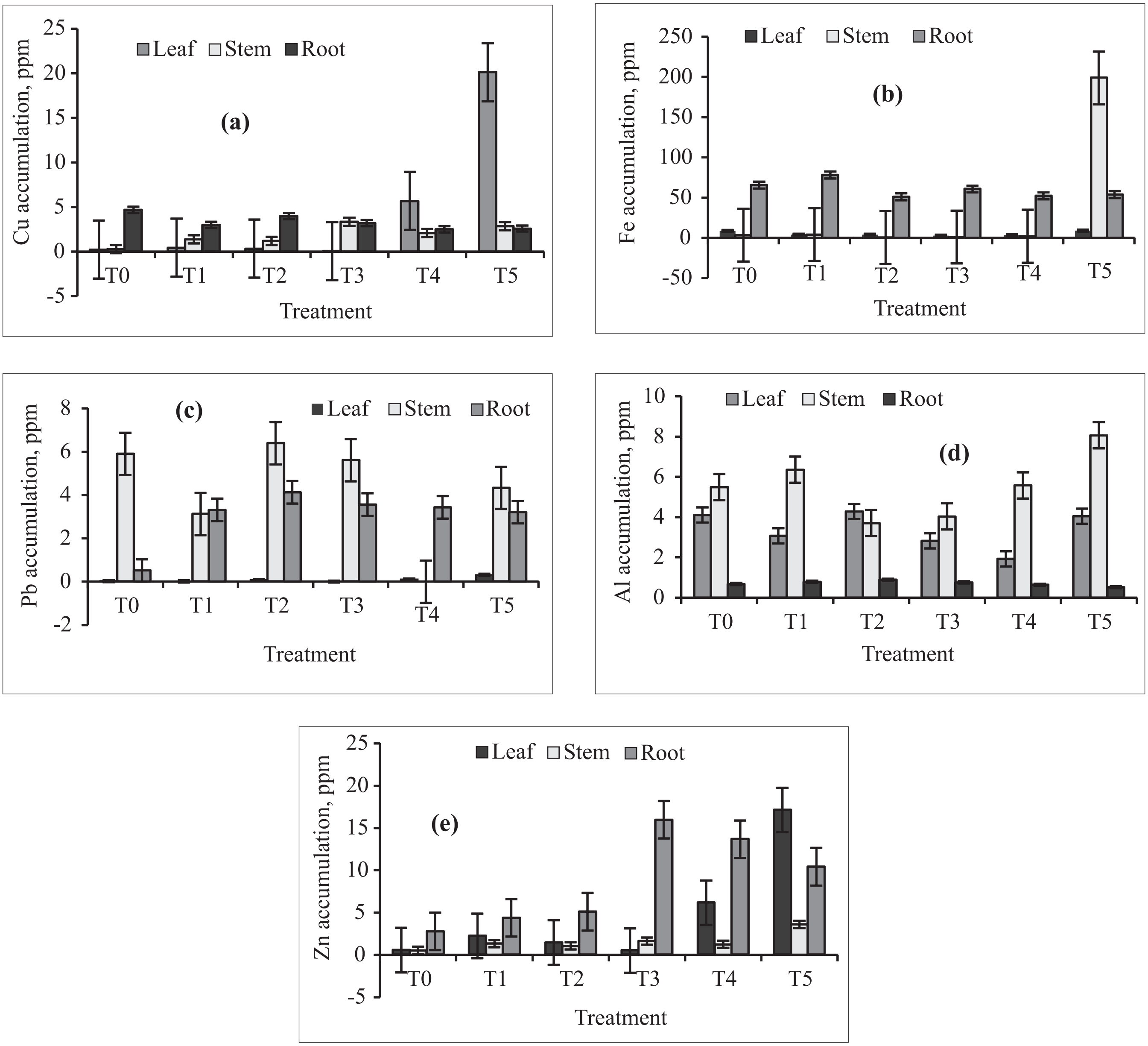

Fig. 4. Copper (a), iron (b), lead (c) aluminium (d) and zinc (e) accumulation in different parts of Fagopyrum dibotrys as influenced by different treatments Growth media indicates different proportion of sawdust sludge and soil, i.e. T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge. Means ± SE are shown in error bars (p = 0.05).

centration in the plant was significantly influenced by the treatments ($p \leq 0.05$). In the leaves, Fe concentration ranged from 2.75 to 8.96 ppm, the highest in T5, which was identical to the control but higher than the other treatments. The lowest concentration (2.75 ppm) was in T3 (Figure 4b). T1 showed highest accumulation (78.02 ppm) by the roots followed by the control (65.46 ppm). Among the plant parts, the highest Fe accumulation (mean 60.19 ppm) was found in the roots followed by the leaves (5.39 ppm) and the lowest was in the stems (2.87 ppm) (Figure 4b). Similar result was observed by Ghavri and Singh (2010) where *Jatropha curcas* grown on iron rich wasteland soil. Wong (2005) also reported lowest iron concentration in the stems than other plant parts, which are in agreement with the findings of our results. The total Fe concentration ranged from 55.52 to 86.12 ppm. It was observed that T4 and T5 failed to absorb highest amount of Fe by the plant and this might be due to toxic effect of heavy metal. Iron is an essential element for men and plants as well as part of nitrogenase enzyme and helps in photosynthesis and chlorophyll formation but in excess will cause toxicity to plants and human. Among the plant parts, the stems showed the highest aluminum accumulation (5.53 ppm) followed by the leaves (3.37 ppm) and the lowest (0.70 ppm) was in the roots (Figure 4d). Majid et al. (2011a) also reported similar results with *Justicia gendarussa* grown in textile sludge contaminated soil. In the stems, Al concentration varied from 3.70 to 8.06 ppm. The maximum accumulation (8.06 ppm) was in T4 followed by T1 (6.35 ppm) and the minimum (3.70 ppm) was in T2 (Figure 4d). The control and T4 showed similar Al absorption by the stems. T2 showed highest Al accumulation (4.27 ppm) by the leaves followed by the control (4.10 ppm) and T5 (4.04 ppm). The total Al concentration in the plant ranged from 7.59 to 12.61ppm, the highest was in T5. The control showed the second highest absorption (10.26 ppm) followed by T1 (10.20 ppm) and the lowest was in T3 (7.59 ppm). The different levels of sawdust ($p \leq 0.05$) significantly influenced the total zinc concentration in the plant. Total Zn content ranged from 3.86 to 31.18 ppm. The maximum Zn concentration (31.18 ppm) was in T5, which was significantly higher than the other treatments. T4 showed the second highest concentration (21.11 ppm) followed by T3 (19.12 ppm) and the lowest (3.86 ppm) was in the control (Figure 4e). Among the plant parts, roots had the highest concentration (average 8.72 ppm) followed by the leaves (4.85 ppm) and the lowest was in the stems (1.57 ppm). 100% sawdust exhibited maximum Zn concentration (17.14 ppm) in the leaves followed by the roots (10.43) that means Zn is easily translocated from roots to the shoots. Zn is an essential trace element, is a component of many enzymes, and needed for growth and DNA synthesis (Perk, 2006). In the roots, Zn accumulation varied from 2.77 to 15.98 ppm, the highest concentration in T3 (15.98 ppm) followed by T4 (13.69 ppm) and the lowest (2.77 ppm) was in the control (Figure 4e). Increasing soil zinc is known to reduce cadmium availability to plants because Zn inhibits cadmium uptake and cadmium translocation from roots to shoots of plants (Chaney, 1983). Zn and Cu are both essential for man, plants and animals but in high concentration can be toxic. In addition, zinc plays an important role in many biochemical functions in the plants (Fox and Guerimot, 1998).

Translocation factor of heavy metal

Different sawdust sludge levels ($p \leq 0.05$) significantly influenced translocation factor of copper and aluminum. The translocation factor for Cu ranged from 0.11 to 5.00, the highest (5.00) in T5 followed by T4 (3.09). The lowest translocation factor (0.11) was in the control (Figure 5a). The low translocation factor in the control might be due to low Cu concentration in the control media. Translocation factor of Al was also significantly variable among the treatments ($p \leq 0.05$). T5 also showed maximum translocation factor (23.73) of Al, which was significantly higher than the other treatments. The second highest translocation factor (14.31) was found in the control followed by T1 (12.08) and the minimum was in T2 (9.06) (Figure 5a). Naturally, the soil was rich in Al and concentration decreased with increase in sawdust content. This is apparent in 100% sawdust sludge, which has the highest translocation factor. Treatment T5 also showed the maximum translocation factor (1.99) for Zn and the minimum was in T3 (0.13) (Figure 5d). Translocation factor (TF) of lead varied from 1.45 to 6.06(Figure 5b). The highest TF value was found in the control, which was significantly higher than the other treatments. T1 showed

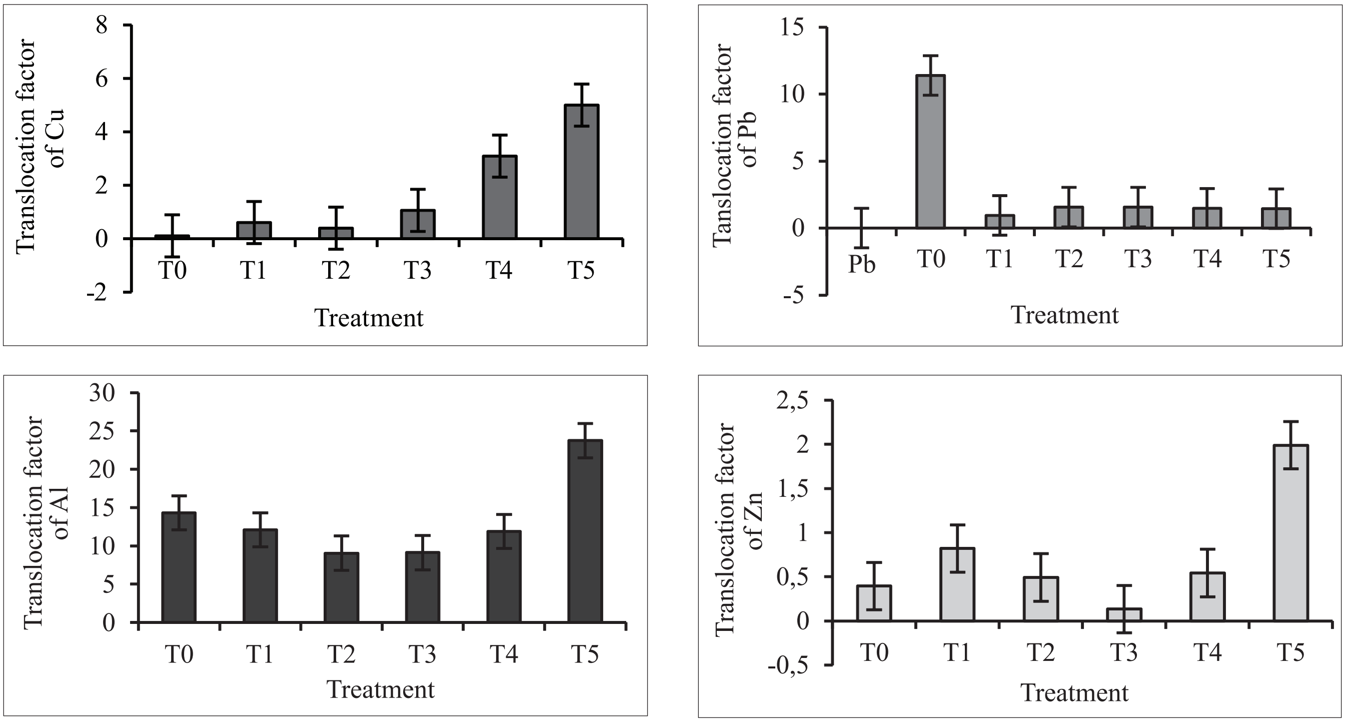

Fig. 5. Translocation factor of heavy metal in *Fagopyrum dibotrys* as influenced by different treatments. Growth media indicates different proportion of sawdust sludge and soil, i.e. T0 = 100% soil, T1 = 20% sawdust sludge + 80% soil, T2 = 40% sawdust sludge + 60% soil, T3 = 60% sawdust sludge + 40% soil, T4 = 80% sawdust sludge + 20% soil, and T5 = 100% sawdust sludge. Means ± SE are shown in error bars (p = 0.05). Translocation factor = Ratio of shoot and root metal concentrations.

the second highest TF value followed by T3 and the minimum was in T5 (Figure 5b). The lowest TF value was in the T5 (Figure 5b), which may indicate restriction in root-shoot transfer at higher metal concentrations in the soil. Yoon et al (2006) found similar results. Majid et al (2011a) also observed lowest TF at higher metal concentration for *Justicia gendarussa* grown in textitle sludge contaminated soil. TF of metal excluder species is <1 whereas, metal accumulator species has TF>1(Baker, 1981). It was observed that 60 to 100% sawdust contaminated soil exhibited higher TF values (>1) except for Pb. *Fagopyrum dibotrys* species showed high translocation factor in sawdust sludge contaminated soil. Heavy metal tolerance with high TF value was suggested for phytoaccumulator of contaminated soils (Yoon et al., 2006) and therefore, *Fagopyrum dibotrys* can be used as a potential phtyoremediator for sawdust sludge contaminated soils.

Conclusion

The 80% sawdust in combination with 20% soil showed highest growth performance in terms of height, basal diameter and number of leaves. The plant was able to remove copper, iron, lead, aluminum and zinc from the growth media. Copper, iron and zinc were concentrated in the roots, lead in the stems and roots, while aluminum was concentrated in both stems and leaves. *Fagopyrum dibotrys* seems to have high potential to absorb sufficient amounts of Fe, Al, Pb and Zn in the stems, leaves and roots. This species showed high translocation factor (TF) and was able to tolerate and accumulate heavy metals. Therefore, *Fagopyrum dibotrys* can be considered as a potential phytoremediator. It is also suggested that a field study need to be conducted to verity the findings obtained from this glasshouse study.

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