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Phytoremediation Potential of Tomato *(Lycopersicon Esculentum Mill)* in Artificially Contaminated Soils

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Abstract: This study investigated the uptake and distribution of heavy metals in tomato (Lycopersicon esculentum Mill) in artificially contaminated soil. The seeds were germinated in trays filled with typical farm soil and at its third truly leaf, transplanted in soil pots contaminated with low and high levels of copper, iron, cadmium and nickel. The elemental distributions of the heavy metals in the plant organs were determined after harvesting stage. The uptake and distribution of the three heavy metals Fe, Cd and Ni were accumulated in the different organs of tomato in decreasing pattern of root>stem>leaf>fruit, while Cu has root>fruit>stem>leaf order were observed. This pattern of distribution in the plant organ exhibit the typical pattern of an excluder plant with higher concentration of metals accumulated in the roots than in the shoots. The decreasing pattern of the bioconcentration factor (BCF) showed that the ability of tomato to accumulate heavy metals was reduced as the level of contamination is increased.

Key words: tomato, heavy metals, elemental distributions, bioconcentration factors (BCF)

INTRODUCTION

Heavy metals are toxic to most organisms and a variety of mechanisms have evolved for coping with the toxic effects of these elements (Scheller et al. 1987). The fast growing industrial, agricultural and urban activities increased heavy metal concentrations in some soil ecosystem.

Metal pollutants can easily enter the food chain if heavy metal-contaminated soils were used for the production of food crops (Wang et al. 2003). Investigating the fate and effects of metals in components of ecosystems is of great significance (Swaileh et al. 2001).

Numerous tests were carried including leaching, replacing contaminated soil, applying soil amendments (Wang et al. 2003) and remediation (Ximenez-Embum et al. 2001). Unfortunately, they were expensive procedures and produced irreversible damage to the environment (Ximenez-Embum et al. 2001). However, a novel approach, phytoremediation, has emerged and aroused high interest (Wang et al. 2003) and gaining more significance since it is a cost effective and an environmentally friendly technology (Ximenez-Embum et al. 2001).

Phytoremediation also known as green technology consist of the use of plants, including trees, grasses, herbs and aquatic plants to remove innocuous range of toxic pollutants present in the soil, in water or even in air. It uses the natural capacity of plants to extract elements from soil and distribute them between roots, stems, leaves, flowers and fruits depending on the biological process in which the elements are involved (Ximenez – Embum et al. 2001). It intends to screen the potential plant species that have the capacity of accumulating and tolerating high amounts of metals in their harvestable parts (Ximenez-Embum et al. 2001).

The present study investigated the heavy metals uptake and distribution by tomato

(Lycopersicon esculentum mill) in artificially contaminated soils. The elemental distribution of heavy metals in the vegetative organs and fruit of tomato as well as the ratio of heavy metal concentration in tomato to the available heavy metal in the soil were also evaluated.

MATERIALS AND METHODS

Experimental Treatments

Soil used was sampled from an agricultural farm in Calimbahin Farm Bayan Luma III, Imus, Cavite, Philippines. Using a spade, approximately up to 15 cm deep was taken from the surface (A horizon) and was prepared by carefully removing the overlying layers. Fifty-four plastic pots (28 x 28 x 46 cm) were prepared, six contained "clean" soil, six each contained material with low-level metal contaminations (25 ppm Cu as $CuSO_4$; 50 ppm Fe as $FeCl_3$; 25 ppm Cd as $CdSO_4$; 500 ppm Ni as $Ni(NO_3)_2$) and another six each contained high-level metal contamination (50 ppm Cu; 100 ppm Fe; 50 ppm Cd; 1000 ppm Ni) (Chunilall et al. 2004).

Plant Cultivation and Harvest

Tomato seeds were germinated in trays filled with farm soil. The trays were kept under greenhouse conditions with all agricultural managements required for the production of tomato seedlings (Gad et al. 2007). At three-leaf stage (45 days from sowing), seedlings with uniform stem thickness were transplanted into the potted soil contaminated with low and high levels of metals. After 105 days, tomato plants were already in harvesting stage. The final height was measured and the amount of heavy metal was analyzed and determined in leaves, stem, roots and fruits of the plant.

Drying of Plant Samples

Plant samples were dried in the oven (Memmert®) at 100ºC for 40-60 min and ashed in the furnace (Thermolyne 1400®) at 450ºC for another 60-90 minutes (Angelova et al. 2004; Ching et al. 2008). Soil samples were also oven dried for 60-90 min at 100-105ºC. A representative sample was taken by quartering technique and ground to pass a 60-mesh sieve. About 0.5 g of the sample was weighed into the porcelain crucible and ignited at 450ºC in a furnace to destroy the organic matter (Mitra 2003; Ching et al. 2008).

Data Gathering and Statistical Analysis

After 105 days from transplanting (harvesting stage) of growing tomato in contaminated soils, plant's aliquots and soil solution were taken for the concentration analysis of the heavy metal copper, iron, cadmium, and nickel using graphite furnace atomic absorption spectrophotometry (Shimadzu® AA-6300) at the Chemistry Research Center of De La Salle University, Taft Avenue, Manila. Each degree of heavy metal concentrations of plant saamples in different treatments were measured using bioconcentration factors (BCF). The BCF for the four metals in the test plants were calculated by dividing their concentrations in the different parts of the harvest plant by the total available amounts in the soils (Wang et al. 2002).

Randomized complete block design (RCBD) was employed in this experimental research which is set up in triplicate. Two-way analysis of variance (ANOVA) was used to assess the significant difference in the heavy metal concentrations among different treatments and different organs of tomato. If there was significant difference, Tukey test method (the pair-wise comparison test) was used as a post statistical treatment of data to identify pair-wise differences at 0.5 significance levels.

RESULTS AND DISCUSSION

The elemental distribution of heavy metals in the different organs of tomato is presented in Table 1.

The concentration of copper in the different parts of the plants both in high and low level of contamination was found to decrease in the order of roots>fruits>stem>leaf. It showed a large variability among different organs of the plants. Roots exhibit the highest Cu concentration with 1.22450 ppm and 1.05510 ppm both at low and high

level of contamination as compared to the control with 0.66543 ppm. The leaves obtained the lowest Cu concentration among the plant organs with 0.17217 ppm and 0.17627 ppm both in low and high level of contamination as compared to the control with 0.23073 ppm.

In case of the three heavy metals Fe, Cd, and Ni, similar patterns were observed. The elemental distribution appeared in the decreasing order from roots>leaf>stem>fruits reflecting the heavy metal assembly in the plants. Parallel to the Cu, root is the organ that accumulated the highest level of metal contamination. Iron (Fe) recorded the highest concentration ranged from 21.02753 ppm and 19.23827 ppm as compared to the control with 9.99717 ppm. In contrast with the Cu, fruits accumulated the least concentration of heavy metals. Cadmium recorded the lowest concentration with 0.17893 ppm and 0.27817 ppm both in low and high level of contamination, but this value was greater than the control with 0.15193 ppm.

The presence of the four heavy metals Cu, Fe, Cd and Ni in the different vegetative organs (root, stem and leaf) as well as in fruits of the tested plant exhibit a significant difference ($p<0.05$) both in control, low and high levels of contamination (Appendix B4 *a-c*), except for nickel concentration in the roots that shows no significant difference ($p>0.05$) as compared to the fruits, and the fruits as compared to the leaf (Appendix B4 *d*).

Significant differences ($p<0.05$) were also observed between the levels of metal contamination in the different organs of the tested plants (Appendix B5). On the other hand, no significant difference was reflected between low and high level of Cu concentration in leaf and between the control and high level of iron contamination in fruits (Appendix B5 *a and b*).

Table 1. Uptake and distribution of heavy metals after harvesting stage.

Heavy Metals	Cont. Level	Average Concentration (ppm) Roots	Stems	Leaves	Fruit	total
Cu	control	0.66543^{AX}	0.15990^{BX}	0.23073^{CX}	0.57037^{DX}	1.62643
	low	1.22450^{AY}	0.14573^{BY}	0.17217^{CY}	0.45770^{DY}	2.0001
	high	1.05510^{AZ}	0.28897^{BZ}	0.17627^{CY}	0.51403^{DZ}	2.03437
Fe	Control	9.99717^{AX}	0.48243^{BX}	3.81890^{CX}	0.42980^{DX}	14.7283
	low	21.02753^{AY}	1.91383^{BY}	5.53453^{CY}	0.20877^{DY}	28.68466
	High	19.23827^{AZ}	2.82427^{BZ}	3.29790^{CZ}	0.22983^{DX}	25.59027
Cd	Control	0.26923^{AX}	0.18843^{BX}	0.22093^{CX}	0.15193^{DX}	0.83052
	low	2.01147^{AY}	0.49643^{BY}	0.72337^{CY}	0.17893^{DX}	3.4102
	High	4.30213^{AZ}	0.46940^{BZ}	1.47427^{CZ}	0.27817^{DZ}	6.52397
Ni	Control	0.29783^{AX}	0.22667^{BX}	0.26223^{CDX}	0.26330^{ADX}	1.05003
	low	7.70370^{AY}	0.41507^{BY}	0.57840^{CY}	0.49047^{DY}	9.18764
	High	2.98120^{AZ}	1.21063^{BZ}	3.48947^{CZ}	0.62023^{DZ}	8.30153

Letters ABCD show the significant differences between columns (root, stem, leaf and fruits. Different letters indicate significant statistical value ($p<0.05$).

Letters XYZ show the significant differences between rows (control, low and high contamination levels in each heavy metal). Different letters indicate significant statistical value ($p<0.05$).

Plants can take up elements selectively. They can uptake heavy metals by their roots or even via their stem and leaf and accumulate them in their organs (Cheng 2003). Among the four heavy metals studied, iron (Fe) accumulated the highest level of contaminations in most part of the plant particularly in roots. The distribution of iron in different organs and in the roots was described for plants grown at different levels of iron concentrations (Pich and Scholz 1995; Pich et al 1994).

In general, the uptake and distribution of the four heavy metals, essential and non – essential elements was significantly accumulated in the root part of the tested plant. This result concord with the observations of Ching (2008) in peanut, Herrero et al (2003) in oil rape and sunflower, Ximenez – Embum et al (2002) in lupin plants, Wang et al (2002) in corn and wheat, and Peng et al (2006) in several plant species. The decreasing pattern observed in plant parts from roots to the aerial parts indicated the poor translocation (Ximenez – Embum et al 2002; Kramer et al 1996; Ching 2008) and different ion capacities to cross the physiological barriers, primarily the plasmalemma at the cell level and the endodermis in the tissue level (Seregin et al 2003). Other mechanisms include compartmentalization within the vacuoles of the cell (Herrero et al 2003; Vasquez et al 1992; Ching 2008). Plants characterized by high biomass production (Sekara et al 2004) and intensive heavy metal accumulation with no sign of toxicity (Olosuga and Osibanjo 2007; Sekara et al 2004; Ching 2008) can be used as a phytoremediants.

The concept of the bioconcentration factor (BCF) was used to specify the quantity to which plants accumulate metals from their substrates. In some circumstances, BCF is an even better criterion for identifying hyperaccumulators than plant metal concentration because the concentration of the element in the substrate is not taken into account by the latter (Wang et al 2002; Ching 2008). Figure 1 shows the BCF of the four heavy metals in tomato at both levels of metal contamination.

The BCF values of the tomato plants treated with the elements Cd and Ni recorded the highest in the control followed by those plants treated with low level of metal contamination and then decreased with those treated with high levels of contamination. The BCF values of copper was also highest in the control but it was followed by those treated with high metal contamination and decreased with those treated with low level of contamination. Iron on the other hand showed the highest BCF values with those treated with low level of contamination and lowest value was those in the control.

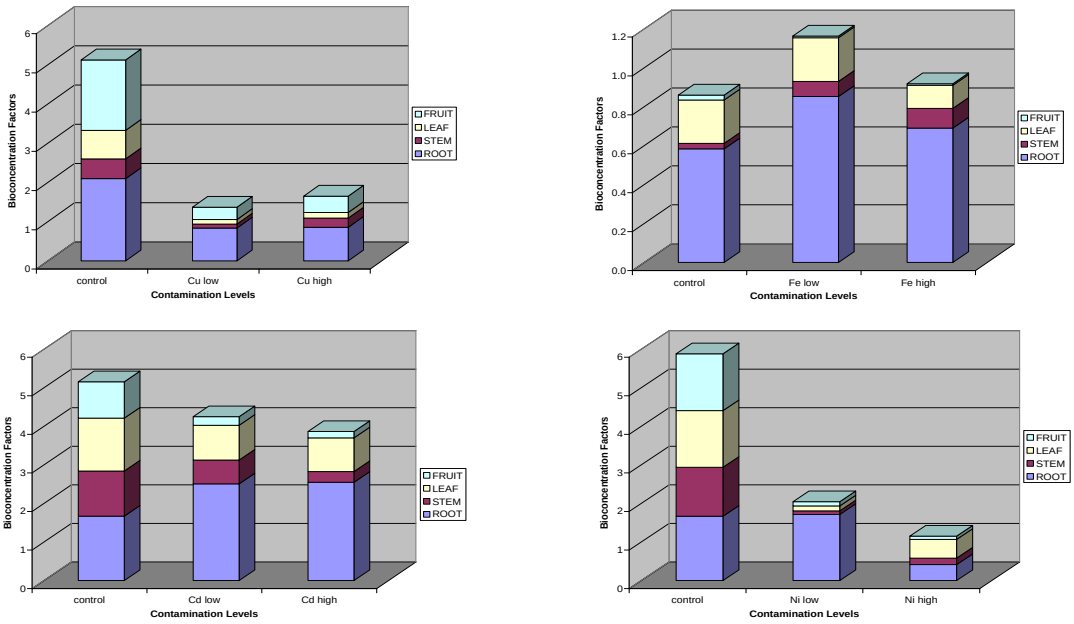

Figure 1 Bioconcentration factors of tomato after the harvesting stage

The changes in the BCF with metal supply rates indicated that the BCF is a concentration – parameter dependent (Wang et al 2002; Ching 2008). The BCF values of the plants treated with Cd and Ni shows a decreasing order of BCF values from control to the high level of contamination confirms that the ability of tomato to accumulate heavy metals is reduced as the level of metal contamination is increased. This signify that tomato can accumulate more metal in soil only with low levels of Cd and Ni contamination. Though the BCF of copper and Fe recorded control and low level of contamination as the highest it also show that tomato has the potential to accrue Cu and Fe even at high concentration in the soil.

CONCLUSION

The elemental distribution of the three heavy metals Fe, Cd and Ni were accumulated in the different organs of tomato in decreasing pattern of root>stem>leaf>fruit, while Cu has root>fruit>stem>leaf order were observed. It is very significant to note that the heavy metals were accumulated in the vegetative part particularly in the root and not in the fruit of the plant making it safe for public consumption. This pattern of distribution in the plant organ exhibit the typical pattern of an excluder plant with higher concentration of metals accumulated in the roots than in the shoots. This suggests that there is a degree of selectivity in the metal uptake and partitioning within the plant compartments. The total amount of metal removed in the soil is a result of the metal content in the harvestable tissue of the plant biomass per unit area. Considering the high biomass production of tomato, it can be used as phytoremediants.

The decreasing pattern of the bioconcentration factor (BCF) from the control to those treated with high level of Fe, Cd and Ni contaminations showed that the ability of the tomato to accumulate these metals were reduced as the level of contamination is increased. This means that tomato can accumulate metal in soil only with low levels of Fe, Cd and Ni contaminations. In Cu, although the BCF values were recorded high in the control, it showed that the tomato has the potential to accumulate Cu even in higher concentration in the soil.

RECOMMENDATION

Further research must be done in order to study the uptake of metals from the roots to the shoots along with establishing the possible transformation mechanisms for metal tolerance of the tomato and evaluate the effects of the individual heavy metals as well as the combined effects of different levels on soil quality and relative uptake to the edible plant species.

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