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Research Article

Study on the Effect of Cu (II) and Zn (II) on the Accumulation of Pb (II) from Soil to the Biomass of Vegetable

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Among soil pollutants, lead (Pb) is one of the toxic metal pollutants widely used in many industrial processes and occurs as a contaminant in environment. In this study, a field experiment was carried out to investigate the accumulation of lead from soil contaminated by this metal ion on the biomass of some vegetables, including spinach, lettuce, carrots, and potatoes. The results showed that lead was cumulative metal. Besides, the level of lead accumulation in soil of the studied vegetables decreased in the order of tubers of carrots, tubers of potato, spinach root, lettuce root, stems and leaves of spinach, stem and leaves of carrot, stems and leaves of potato, and stem and leaves of lettuce, respectively. Our investigations demonstrate the effect of copper and zinc micronutrient elements which play an important role in the growth and development of plants, on the accumulation of lead from contaminated soil of the studied vegetables. The obtained results showed that high concentration of copper and zinc in soil cause competition with lead in the process of absorption and accumulation in the plant. Specifically, copper and zinc showed the inhibition effect on the uptake and accumulation of lead by these plants.

1. Introduction

Heavy metals are toxic because they tend to accumulate in crops and eventually enter the human body through the food chain, posing a threat to human health. Bioaccumulation results in the concentration of some chemical substances increasing through the food chain and over time. These compounds are absorbed and stored in crops or bodies, compared to the concentration of chemicals in the environment. Heavy metals accumulate in crops rather than being decomposed and metabolized or excreted from crops [1, 2]. The results of many works have proved that produced from plants cultivated in heavy metal-polluted areas, agricultural products can accumulate heavy metals at high levels and cause an impact directly on the health of consumers through a food chain [3–5].

Among the common pollutants that affect plants, lead is one of the most toxic and frequently encountered pollutants [6–8]. Industrialization, urbanization, mining, and many other anthropogenic activities have resulted in the redistribution of lead from the earth's crust to the soil and to the environment. Lead was reported as being the second most hazardous substance, after arsenic, based on the frequency of occurrence, toxicity, and potential for human exposure by the Agency for Toxic Substances and Disease Registry (ATSDR 2003) [9].

In soil, lead may occur as a free metal ion, complexes with inorganic constituents (e.g., HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^-), may exist as organic ligands (e.g., amino acids, fulvic acids, and humic acids), or may be adsorbed on to particle surfaces (e.g., Fe-oxides, biological material, organic matter, and clay particles) [10, 11]. The presence of lead in soil is one of the reasons of the absorption and accumulation of this metal in vegetables. Despite its lack of essential function in plants, lead is absorbed by plants mainly through the roots from soil solution and thereby may enter the food chain.

Therefore, to minimize the amount of metals in plants, it is necessary to handle them in the farming environment. However, most of the studies examined the accumulation of each metal from soil or water to plants and proposed solutions to handle such metals in soil and water. Meanwhile, in the polluted soil and water, metals are present and exist simultaneously [12]. This will lead to the possibility of competition among them, causing the state to increase or decrease the level of metal accumulation in the plant. Therefore, the study on competitive absorption among metals in plants is essential. Furthermore, the results of such work will allow predicting the level of metal accumulation in plants from the analysis report of metal content in the cultivated environments, without analyzing their content in the plants themselves.

On the other hand, the results of several studies showed that the use of fertilizers, complexion agents, or hyper accumulator plants was able to handle only one or a few metals with certain content. Therefore, to propose possible solutions to the problem of metal contamination in the soil, water, and their spread in plants, it is necessary to get results allowing the assessment of competitive absorption among the metals. The results of such a study combined with the results of the analysis of metal content in cultivated environments will allow predicting whether competitive absorption among metals happens or not, which metal is inhibited (i.e., inconsiderable metal accumulation), and which metal is absorbingly stimulated (i.e., a need for handling). This is the basis for the choice of soil treatment, irrigable water, or the choice of plants with the capacity of absorbing the desired metal to clean up arable land. Moreover, because it costs and requires time to handle soil water in current conditions, we envisage the results of this kind of research will initially provide the basis for the selection of plant varieties suitable for the soil conditions and current pollution.

Differing than other toxic heavy metals, zinc and copper play an important role in the growth and development of plants, as well as in human health. Shortage or excess of these elements is causing adverse effects. For plants, zinc and copper deficiency makes plants grow poorly, thereby reducing development and productivity. Thus, in farming, copper and zinc often are added in soil by using micronutrient fertilizers; since it is observed that micronutrients could have different influences on plants, the objective of this research was to estimate the effect of copper and zinc micronutrient elements on lead amount in soil and plants.

2. Experimental

2.1. Field Experiment. The study area is located in Ward 8, Dalat city, Lam Dong Province (11°57'39.7"N –108°26'28.3"E, 103°36' E–109°35' E) in Vietnam. Lam Dong Province presents area with suitable climatic and soil conditions for the cultivation of carrots, potatoes, lettuce, and spinach. The present study was conducted from March to September, during 2019 vegetation season. Empirical models within this investigation included three areas:

Model 1. To study on the accumulation of lead from soil contaminated by this metal on the biomass of spinach, lettuce, carrots, and potatoes. In this model, these plants were grown under the cultivation mode as in reality, but the soil was contaminated by lead at different levels of content, including 100, 200, 300, 400, 600, 800, 1000, 1200, and 1500 $mg{\cdot}kg^{-1}$. The soil was air-dried, passed through a 2 mm sieve, and spiked with different lead doses by spraying of $Pb(NO_3)_2$ solution. Twenty-five kilograms of the prepared soil were placed in each pot for growing vegetables.

Model 2. To study on the effect of copper and zinc on the accumulation of lead from soil on the biomass of studied vegetables. In this model, we fixed the lead concentration in soil at 100 ppm and changed the amount of copper or zinc at different levels (Table 1). The soil was prepared similar to the above model and spiked with different lead and copper, lead, and zinc doses by spraying of $Pb(NO_3)_2$, $Cu(NO_3)_2$, and $Zn(NO_3)_2$ solutions.

Control Area. Spinach, lettuce, carrots, and potatoes were grown under the same conditions as the models mentioned above in soil uncontaminated.

2.2. Soil Sample Measurements. The properties of the soil used in our work are given in Table 2.

2.3. Planting Plants. Spinach, lettuce, and potato seedlings were collected at the nursery and then planted in each treatment of the model with a density of 10 plants/carton for spinach and lettuce and 4 plants/carton for potatoes.

Carrot seeds were soaked in warm water (40°C) for 8 hours before standing for six days until the seeds germinate, and germinated seeds are sown in each treatment in the model with a density of 20 seeds/carton.

About 15 days after planting, weak or dead trees were removed, leaving only well-developed plants, with a density of 5 plants/carton for lettuce and spinach, 10 plants/carton for carrots, and 2 plants/carton for potatoes. Mature plants (after 45 days for lettuce and spinach and 100 days for carrots and potatoes) were harvested at the same time.

2.4. Elemental Analysis. At the end of the growth period, the plants were carefully removed from the soil. The stems, leaves, roots, and tubers were separated, cleaned, and washed properly; then, they were dried at 60°C in the drying oven to constant weight. The dried leaf samples were homogenized separately in a porcelain mortar. The homogenized leaf samples were also digested (HNO_3 and $HClO_4$, 25 : 10 mL) [13]. The clear digested liquid was filtered through filter paper, and the contents of lead in the filtrate were determined using the flame atomic absorption spectrophotometer (F-AAS).

2.5. Data Analysis. All data for evaluation were obtained in triplicate ($n = 3$) and presented in average ± standard deviation (SD). Excel 2013 software was applied to create the database and diagrams.

3. Results and Discussion

3.1. Accumulation of Lead in the Biomass of Spinach, Lettuce, Carrots, and Potatoes Grown in Lead-Contaminated Soil. The results obtained from the research model of accumulation of lead from soil to plants showed that lead was a cumulative metal. In increasing amount of lead in soil, the levels of hoarding in the examined vegetables were increased. The obtained lead contents in the biomass of these vegetables grown in lead contaminated soils are presented in Tables 3–6 and Figure 1.

The total amount of lead accumulated in the biomass of the studied vegetables is considered as the most important parameter to evaluate the potential of accumulation of this metal. The results shown in these tables and the figure demonstrated that all kinds of studied vegetables cultivated on contaminated soil by lead can accumulate this heavy metal. As the lead content in the soil increased, the amount of this metal accumulated in the biomass of the studied vegetables also increased. ANOVA analysis results for the analyzed data show that lead content in soil and lead content in the biomass of these plants have a statistically significant relationship ($p < 0.05$). The accumulated lead content in the biomass of the four studied vegetables ranged from 0.20 to 6.31 $mg \cdot kg^{-1}$ when cultivated on contaminated soil with the content of lead ranging from 100 to 1500 ppm.

The obtained data in experimental field showed that the content of lead in the biomass of the studied vegetables depends on the nature of each vegetable. This metal accumulation decreases in the order of tubers of carrots, tubers of potatoes, spinach roots, lettuce roots, stems and leaves of spinach leaves, stem and leaves of carrot, stems and leaves of potato, and stems and leaves of lettuce, respectively. On the other hand, these data showed that lead tends to accumulate in the lower parts (roots or tubers) higher than the upper parts (stems and leaves). For leafy vegetables, the average lead content in spinach roots is 2.2 times higher than the lead content in the stems and leaves. Meanwhile, the amount of lead in the roots of lettuce is 2.4 times higher than the amount of this metal in the stems and leaves. For carrots, the lead content in tubers is three times higher than it is in the stems and leaves. The results of this study are consistent with the results published by Adelene Basu et al. [14], and carrot is the vegetable with the highest ability to accumulate lead. According to these authors, the level of lead accumulation in the edible parts of the studied vegetables decreased in the order of carrots, radish, beet, cabbage, eggplant, cauliflower, spinach, tomato, and chili, respectively. This phenomenon can be explained by the fact that lead is not an element necessary for plant growth and plants do not contain the absorption lead channels as trace elements (copper and zinc). Meanwhile, this metal binds strongly to carboxylic groups of uronic mucilage and glucuronic acid on the root cell wall [15, 16]. Furthermore, most of the lead amount is absorbed in the roots because root is the first organ to expose this metal during transport to the biomass of plants. Lead has been existed in roots by the association of Pb with ion exchange sites on the cell wall and precipitate formation in the cells. Several studies showed that once present in the roots, most lead ions will replace the positions of easily exchangeable ions on the cell walls and precipitates in the form of phosphate or carbonates [17–19]. It transfers the unlinked lead through calcium transport channels and accumulates near the bark of the tree roots. Previous studies have shown that the vein in the root bark is the part that blocks the movement of lead from the roots to other parts of the plant. According to Brenan and Shelley [20], the high accumulation of lead in roots could be attributed to the formation of amorphous Pb-phosphate precipitates on the root surface. These data showed that the mechanism transporting lead from roots to stem and leaves differs from copper and zinc. According to J. Brunet et al. [21], most of the lead absorbed by plants accumulates in the root system, and a significant accumulation element in the leaves is found only in areas with high levels of lead pollution. Research by M. Wierzbicka [22] proved that the absorption of lead by plants depends on the stage of plant growth. In terms of vigorous plant growth, lead uptake increases because lead is strongly absorbed and part of the lead precipitates on the root cell walls. In contrast, the lead transported into young shoots of plants was very small, only about 3.5% of the total amount was absorbed after 7 days. According to Kabata-Pendias and Pendias [23], Pb is absorbed from soil by plants to a limited extent. The roots directly link to the soil, so the heavy metal content in the roots is often seen as an indicator of the amount of easily digested metal in the soil. The transport of heavy metals from the soil to the roots is a complex process influenced by many factors including soil characteristics, environmental conditions, vegetative, physiological, and biochemical characteristics of roots [19]. The transport of heavy metals from roots to stems, branches, and leaves is controlled by plant physiology and determines the most metals entering the food chain. The presence of xylem vessels in the tube's structure that allows the absorption of Pb on their surface can explain the high accumulation of Pb in carrots. Moreover, the formation of lead phytate compounds in xylem can store a certain amount of Pb in tubers.

3.2. The Effect of Copper on the Accumulation of Lead from Soil of Plants. The results obtained from model 2 showed that when both metals were present in the soil, they influenced to each other in the process of absorption and hoarding in these plants. The results of our work are given in Tables 7 and 8 and Figure 2.

The results from experimental fields showed that the presence of Cu (II) reduced the accumulation of lead in the biomass of spinach, lettuce, potato, and carrots, and this decrease increases with the increasing copper content in the soil. When soil was contaminated by copper and lead with the same amount (100 ppm), the cumulative lead content on stems and leaves and roots (tubers) was decreased by 9.8% and 11.8% in spinach, respectively; 12.0% and 14.1% in lettuce; 20.0% and 21.7% in carrots; and 17.9% and 19.6% in potato (entries 42 and 48, Tables 7 and 8). When copper

Table 1: Field experiments to investigate the effect of copper and zinc on the accumulation of lead from soil of plants.

Pb^{2+} (mg/kg)	Cu^{2+} (mg/kg)		Pb^{2+} (mg/kg)	Zn^{2+} (mg/kg)	
100	100		100	100	
100	200		100	200	
100	300	Control area	100	300	Control area
100	400		100	400	
100	500		100	500	

Table 2: The physical and chemical properties of soil studied.

Parameter	Unit	Value
pH		5.68
Organic matter	%	5.3
Amount of N (total)	%	0.21
Amount of N (available)	mg N_2/100g soil	8.15
Amount of P (total)	%	0.08
Amount of P (available)	mg P_2O_5/100g soil	17.2
Amount of K (total)	%	0.87
Amount of K (available)	mg K_2O/100g soil	17.9
Cu (total)	$mg.kg^{-1}$	17.8 ± 1.6
Pb (total)	$mg.kg^{-1}$	ND
Zn (total)	$mg.kg^{-1}$	15.0 ± 1.3

ND, detection.

Table 3: Concentration of lead in this metal-contaminated soil and in the biomass of spinach grown in this soil.

Entry	Lead content in soil[a]	Lead content the biomass of spinach[b]					
		Stems and leaves			Roots		
		Range	Average	SD	Range	Average	SD
1	Background	0.29 ÷ 0.34	0.03	0.03	0.53 ÷ 0.63	0.57	0.05
2	100	0.48 ÷ 0.55	0.51	0.04	0.94 ÷ 1.09	1.02	0.08
3	200	0.58 ÷ 0.67	0.63	0.05	1.06 ÷ 1.21	1.11	0.08
4	300	0.81 ÷ 0.94	0.89	0.07	1.67 ÷ 1.96	1.79	0.15
5	400	1.11 ÷ 1.26	1.19	0.08	2.63 ÷ 2.97	2.75	0.19
6	600	1.22 ÷ 1.42	1.31	0.10	2.65 ÷ 3.00	2.77	0.20
7	800	1.70 ÷ 1.93	1.79	0.12	3.72 ÷ 4.13	3.98	0.23
8	1000	1.80 ÷ 2.11	1.98	0.16	4.73 ÷ 5.46	4.97	0.42
9	1200	2.01 ÷ 2.33	2.16	0.16	4.87 ÷ 5.62	5.14	0.42
10	1500	2.12 ÷ 2.49	2.29	0.19	5.05 ÷ 5.79	5.52	0.41

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

Table 4: Concentration of lead in this metal-contaminated soil and in the biomass of lettuce grown in this soil.

Entry	Lead content in soil[a]	Lead content in the biomass of lettuce[b]					
		Stems and leaves			Roots		
		Range	Average	SD	Range	Average	SD
11	Background	0.15 ÷ 0.17	0.16	0.01	0.39 ÷ 0.47	0.42	0.04
12	100	0.23 ÷ 0.27	0.25	0.02	0.66 ÷ 0.75	0.71	0.05
13	200	0.31 ÷ 0.37	0.34	0.03	1.05 ÷ 1.21	1.13	0.08
14	300	0.63 ÷ 0.75	0.68	0.06	1.18 ÷ 1.37	1.26	0.10
15	400	0.70 ÷ 0.79	0.73	0.05	1.75 ÷ 2.09	1.97	0.19
16	600	1.06 ÷ 1.27	1.17	0.11	1.86 ÷ 2.18	2.05	0.17
17	800	1.54 ÷ 1.75	1.62	0.11	2.23 ÷ 2.58	2.41	0.18
18	1000	1.65 ÷ 1.95	1.79	0.15	3.67 ÷ 4.19	3.89	0.27
19	1200	1.76 ÷ 2.03	1.93	0.15	4.41 ÷ 5.13	4.72	0.37
20	1500	1.92 ÷ 2.17	2.07	0.13	4.61 ÷ 5.48	4.99	0.45

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

Table 5: Concentration of lead in this metal-contaminated soil and in the biomass of carrot grown in this soil.

Entry	Lead content in soil[a]	Lead content in the biomass of carrots[b]					
		Stems and leaves			Tubers		
		Range	Average	SD	Range	Average	SD
21	Background	0.17 ÷ 0.19	0.18	0.01	0.98 ÷ 1.09	1.03	0.06
22	100	0.18 ÷ 0.22	0.20	0.02	1.23 ÷ 1.40	1.29	0.09
23	200	0.90 ÷ 1.03	0.96	0.07	2.14 ÷ 2.45	2.33	0.16
24	300	1.29 ÷ 1.49	1.37	0.11	2.65 ÷ 3.17	2.95	0.27
25	400	1.72 ÷ 2.04	1.90	0.17	3.73 ÷ 4.38	4.13	0.35
26	600	1.98 ÷ 2.31	2.15	0.17	4.84 ÷ 5.64	5.20	0.41
27	800	2.32 ÷ 2.71	2.48	0.20	5.05 ÷ 5.85	5.44	0.40
28	1000	2.58 ÷ 2.93	2.72	0.18	5.46 ÷ 6.08	5.86	0.34
29	1200	2.80 ÷ 3.20	2.98	0.20	5.47 ÷ 6.46	6.02	0.50
30	1500	2.76 ÷ 3.25	3.04	0.25	5.58 ÷ 6.52	6.07	0.47

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

Table 6: Concentration of lead in this metal-contaminated soil and in the biomass of potato grown in this soil.

Entry	Lead content in soil[a]	Lead content in the biomass of potatoes[b]					
		Stems and leaves			Tubers		
		Range	Average	SD	Range	Average	SD
31	Background	0.14 ÷ 0.16	0.15	0.01	0.77 ÷ 0.92	0.84	0.08
32	100	0.26 ÷ 0.30	0.28	0.02	0.94 ÷ 1.12	1.02	0.09
33	200	0.44 ÷ 0.49	0.46	0.03	1.65 ÷ 1.94	1.79	0.15
34	300	1.47 ÷ 1.68	1.57	0.11	2.65 ÷ 2.99	2.75	0.22
35	400	1.51 ÷ 1.80	1.67	0.15	3.83 ÷ 4.18	3.85	0.32
36	600	1.84 ÷ 2.09	2.00	0.14	4.46 ÷ 5.12	4.79	0.33
37	800	2.59 ÷ 2.97	2.72	0.21	4.75 ÷ 5.47	5.17	0.37
38	1000	3.00 ÷ 3.51	3.22	0.26	5.21 ÷ 5.98	5.48	0.43
39	1200	3.14 ÷ 3.73	3.42	0.30	5.51 ÷ 6.36	5.81	0.48
40	1500	3.21 ÷ 3.60	3.35	0.22	5.78 ÷ 6.95	6.31	0.59

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

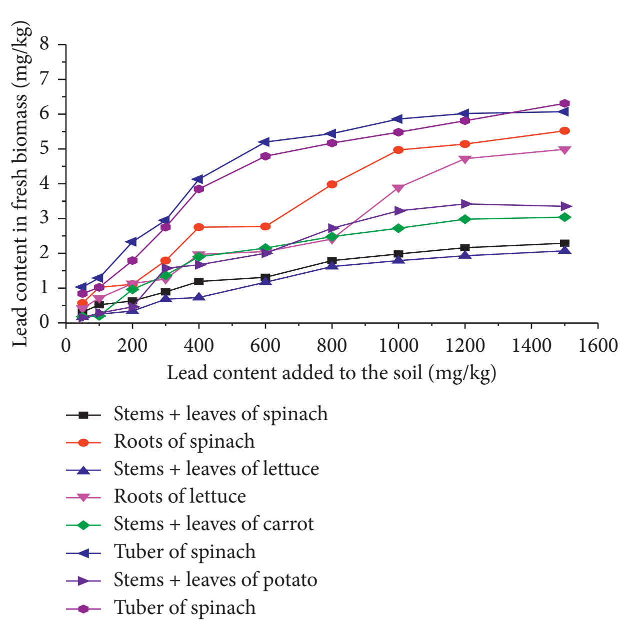

Figure 1: Lead concentrations in the soil and in the biomass of the studied vegetables grown in this soil.

Table 7: Effect of copper on the accumulation of lead from soil of leafy vegetables.

Entry	Copper content in soil[a]	Lead content in soil[a]	Lead content in the biomass of leafy vegetables[b]			
			Spinach		Lettuce	
			Stems and leaves	Roots	Stems and leaves	Roots
41	0	100	0.51 ± 0.04	1.02 ± 0.08	0.25 ± 0.02	0.71 ± 0.05
42	100	100	0.46 ± 0.04	0.90 ± 0.08	0.22 ± 0.02	0.61 ± 0.05
43	200	100	0.39 ± 0.03	0.91 ± 0.08	0.21 ± 0.02	0.58 ± 0.06
44	300	100	0.31 ± 0.03	0.78 ± 0.07	0.18 ± 0.02	0.45 ± 0.03
45	400	100	0.27 ± 0.03	0.64 ± 0.07	0.15 ± 0.01	0.42 ± 0.04
46	500	100	0.31 ± 0.02	0.60 ± 0.05	0.14 ± 0.01	0.37 ± 0.03

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

Table 8: Effect of copper on the accumulation of lead from soil to tuber vegetables.

Entry	Copper content in soil[a]	Lead content in soil[a]	Lead content in the biomass of tuber vegetables[b]			
			Carrots		Potatoes	
			Stems and leaves	Tuber	Stems and leaves	Tuber
47	0	100	0.20 ± 0.02	1.29 ± 0.09	0.28 ± 0.02	1.02 ± 0.09
48	100	100	0.16 ± 0.02	1.01 ± 0.08	0.23 ± 0.02	0.82 ± 0.07
49	200	100	0.12 ± 0.01	0.96 ± 0.08	0.21 ± 0.02	0.79 ± 0.08
50	300	100	0.14 ± 0.01	0.82 ± 0.07	0.22 ± 0.02	0.70 ± 0.08
51	400	100	0.12 ± 0.01	0.79 ± 0.08	0.20 ± 0.02	0.65 ± 0.06
52	500	100	0.11 ± 0.01	0.73 ± 0.06	0.18 ± 0.02	0.63 ± 0.06

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

content is 5 times higher than lead content in soil, the inhibition of copper on lead absorption is even more evident. Specifically, the content of lead in stems and leaves and roots of spinach decreased by 39.2% and 41.2%, respectively, while the reduction in the amounts in those parts corresponding to lettuce, carrots, and potatoes, respectively, is 44.0% and 47.9%; 45.0% and 43.4%; and 35.7% and 38.2%. This result proved that the presence of copper in soil had a dramatic effect on the lead accumulation from soil to plants. Although copper and lead have the same charge, both heavy metals exist mainly in the +2 oxidation state, and their identical crystal structures were similar (face-centered cubic). However, they play a different role in plant metabolism. While copper is a micronutrient, lead is a toxic heavy metal and plays no role in plants. Moreover, the ion radius of copper and lead are very different ($r_{Pb\,(II)} = 1.19\ A^0$, $r_{Cu(II)} = 0.73\ A^0$). These differences can play an important role in the selection of plants for the absorption process of lead in the presence of copper. In the process of transporting heavy metals from soil to the roots and from roots to other parts of the tree because the ion radius of Pb (II) is greater than the ion radius of Cu (II), the absorption affinity of Pb (II) is greater than that of Cu (II). Consequently, Pb (II) will be preferentially absorbed by centers of cation absorption on the cell wall. As a result, the amount of Cu (II) stored by the cation uptake center decreases, leading to a decrease in the concentration of Cu (II) moving inside the plant cell. This allows predicting the absorbing ability of copper from soil to plants will be reduced when coexisting with lead in soil. In addition, the competition between two heavy metals at exchanging sites on the soil surface during adsorption and competition for transport through cell membranes has reduced lead accumulation in the biomass of the studied vegetables. Because of these reasons, when copper presented in the soil, the uptake and accumulation of lead from soil to the biomass of spinach, lettuce, carrots, and potatoes was reduced.

3.3. The Effect of Zinc on the Accumulation of Lead from Soil of Plants. The results of the competitive absorption between zinc and lead from soil to the biomass of these vegetables when they coexist in soil are illustrated in Tables 9–10 and Figure 3.

The study on the competition absorption between zinc and lead in lettuce, spinach, carrots, and potatoes showed that when both metals were present in the soil, they influenced to each other in the process of absorption and hoarding in these plants. Similar to copper, experimental results indicated that the presence of zinc reduces the accumulation of lead in the biomass of spinach, lettuce, potatoes, and carrots, and this decline increases with increasing zinc content in the soil.

When the zinc content in the soil was equal to the lead content (100 ppm), the accumulate content of lead in stems and leaves and roots (tubers) decreased by 5.9% and 10.8%, respectively, in spinach; 8.0% and 8.5% in lettuce; 15.0% and 17.1% in carrots; and 10.7% and 11.8% in potato.

When zinc content is 5 times higher than lead content in soil, the inhibition of zinc on lead absorption is even more

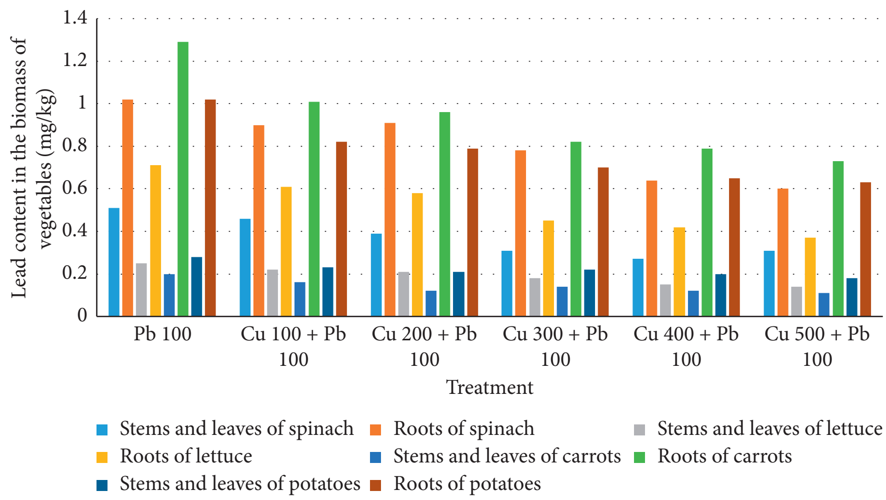

Figure 2: Effect of copper on the accumulation of lead from soil on the biomass of the studied vegetables.

Table 9: Effect of zinc on the accumulation of lead from soil of leafy vegetables.

Entry	Zinc content in soil[a]	Lead content in soil[a]	Concentration of lead in the biomass of leafy vegetables[b]			
			Spinach		Lettuce	
			Stems and leaves	Roots	Stems and leaves	Roots
53	0	100	0.51 ± 0.04	1.02 ± 0.08	0.25 ± 0.02	0.71 ± 0.05
54	100	100	0.48 ± 0.05	0.91 ± 0.07	0.23 ± 0.01	0.65 ± 0.05
55	200	100	0.45 ± 0.04	0.83 ± 0.06	0.21 ± 0.02	0.61 ± 0.05
56	300	100	0.40 ± 0.03	0.79 ± 0.07	0.22 ± 0.02	0.56 ± 0.06
57	400	100	0.38 ± 0.04	0.71 ± 0.08	0.19 ± 0.01	0.48 ± 0.04
58	500	100	0.35 ± 0.03	0.67 ± 0.07	0.16 ± 0.01	0.40 ± 0.03

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

Table 10: Effect of zinc on the accumulation of lead from soil to tuber vegetables.

Entry	Zinc content in soil[a]	Lead content in soil[a]	Concentration of lead in the biomass of tuber vegetables[b]			
			Carrots		Potatoes	
			Stems and leaves	Tuber	Stems and leaves	Tuber
59	0	100	0.20 ± 0.02	1.29 ± 0.09	0.28 ± 0.02	1.02 ± 0.09
60	100	100	0.17 ± 0.01	1.07 ± 0.08	0.25 ± 0.02	0.90 ± 0.01
61	200	100	0.16 ± 0.01	0.96 ± 0.07	0.26 ± 0.03	0.82 ± 0.01
62	300	100	0.18 ± 0.02	0.90 ± 0.08	0.24 ± 0.02	0.79 ± 0.01
63	400	100	0.15 ± 0.01	0.83 ± 0.07	0.22 ± 0.02	0.71 ± 0.01
64	500	100	0.13 ± 0.01	0.78 ± 0.07	0.21 ± 0.01	0.65 ± 0.01

a, mg/kg of dried soil; b, mg/kg of fresh vegetable.

evident. Specifically, the content of lead in stems and leaves and roots of spinach decreased by 31.4% and 34.3%, respectively, while the reduction in the amounts of those parts corresponding to lettuce, carrots, and potatoes, respectively, is 36.0% and 43.7%; 35.0% and 39.5%; and 25.0% and 36.3%.

The presence of zinc in the soil may increase the amount of free lead in the soil fluid due to competition for adsorption sites on soil particles, consequently, releasing an amount of lead in the form of adsorbent on the soil colloid. While this may increase the uptake of lead by plants, the competition between lead and zinc during uptake and transport from soil to plants can reduce lead accumulation in the biomass of plants. Thus, with different mechanisms in which competition between heavy metals occurs, the addition of trace

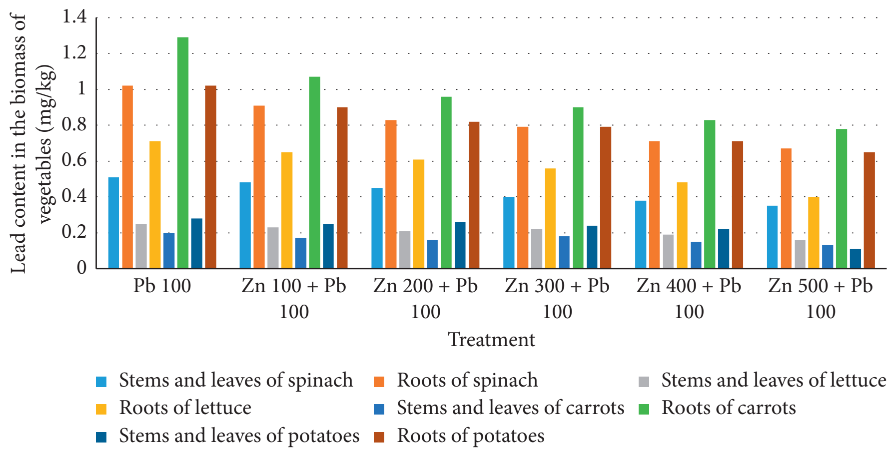

FIGURE 3: Effect of zinc on the accumulation of lead from soil to the biomass of the studied vegetables.

elements during cultivation can reduce the absorption and accumulation of heavy metals from polluted soil of crops.

4. Conclusion

The results of this study proved that the concentration of heavy metals in soil effected significantly on the heavy metal pollution in agricultural products. The absorption and accumulation of heavy metals from soil to plants depended on the biological features of each plant. Furthermore, in soils with heavy metals was observed that they effected on each other in the process of absorption and accumulation in the plant. The results of this study proved that copper and zinc inhibited the uptake of lead from soil to the biomass of lettuce, spinach, carrots, and potatoes when they coexisted in soil. Thus, using micronutrients in farming can reduce the accumulation of heavy metals from soil to plants which could provide valuable information in safe food production.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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