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RESEARCH ARTICLE

Differences on Pb accumulation among plant tissues of 25 varieties of maize (*Zea mays*)

DAI Quanlin[1], YUAN Jiangang[1], FANG Wei[2], YANG Zhongyi (✉)[1]

1 School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China
2 Biology Department, Long Island University-Brooklyn, NY 11201, USA

Abstract Pollution of agricultural land by heavy metals has imposed an increasingly serious risk to environmental and human health in recent years. Heavy metal pollutants may enter the human food chain through agricultural products and groundwater from the polluted soils. Progress has been made in the past decade on phytoremediation, a safe and inexpensive approach to remove contaminants from soil and water using plants. However, in most cases, agricultural land in China cannot afford to grow phytoremediator plants instead of growing crops due to food supply for the great population. Therefore, new and effective methods to decrease the risk of heavy metal pollution in crops and to clean the contaminated soils are urgently needed. If we can find crop germplasms (including species and varieties) that accumulate heavy metals in their edible parts, such as the leaves of vegetables or grains of cereals, at a level low enough for safe consumption, then we can grow these selected species or varieties in the lands contaminated or potentially contaminated by heavy metals. If we can find crop germplasms that take in low concentrations of heavy metals in their edible parts and high content of the metals in their inedible parts, then we can use these selected species or varieties for soil remediation. In this study, the feasibility of the method is assessed by analyzing Pb concentrations in edible and inedible parts of 25 varieties of maize (*Zea mays*) grown in Pb-contaminated soils. The soil concentrations of Pb were 595.55 mg/kg in the high Pb exposed treatment and 195.55 mg/kg in the control.

The results showed that the Pb concentrations in different tissues were in the order of root > shoot ≌ leaf > grain. Compared with the control, the Pb concentrations in root, shoot and leaf were greatly increased under the high Pb exposed condition, while the increments of Pb concentration in grain were relatively lower. Under the high Pb exposure, the grain Pb concentrations of 12 varieties exceeded the maximal Pb limitation of the National Food Hygiene Standard of China (NFHSC) and were inedible. This indicates that there is a high Pb pollution risk for maize grown on Pb polluted sites. Although 22 of the 25 tested varieties had harvest loss under the highly Pb stressed condition, ranging from 0.86%–38.7% of the grain biomass acquired at the control, the average harvest loss of all the tested varieties was only 12.6%, which is usually imperceptible in normal farming practices. Therefore the risk of Pb pollution in maize products cannot be promptly noticed and prevented based only on the outcome of the harvest. However, we did find that 13 of the 25 tested varieties had grain Pb concentrations lower than the limitation of the NFHSC. It is, therefore, possible to reduce the pollution risk if these favorable varieties are used for maize production in Pb-contaminated or potentially contaminated agricultural lands.

Pb concentrations in vegetative tissues (root, stem and leaf) were significantly correlated with each other, while Pb concentrations of each vegetative tissue were not significantly correlated with that of grain. Among the 25 tested varieties, some varieties had Pb concentrations in grain lower than (No.1–3 and No.6) or slightly above (No.4) the limitation of the NFHSC, while their Pb concentrations in the vegetative tissues were among the highest. When excluding these varieties, correlations between the Pb concentrations of grain and those of vegetative tissues of the rest of the tested varieties became highly significant. In addition, variety No.1 had the lowest harvest loss under high Pb exposed, and the highest Pb accumulation in vegetative tissues (51.69 mg/plant, 12 times as much as in the control). Similar features were also observed in varieties No.2, No.3 and No.6, which absorbed Pb for 36–42 mg/plant under high Pb exposed. We recommend these varieties of maize to be used for bioremediation of Pb contaminated soil and crop production at the same time.

Keywords maize, Pb concentration, variation among varieties, phytoremediation, heavy metal contamination in agricultural soil

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E-mail: adsyzy@mail.sysu.edu.cn

1 Introduction

With the development of industries and modernization of agriculture, soil pollution has become more increasingly serious. The heavy metal concentrations are so high in soils of many areas of China that they can poison the soil-plant system, degenerate the soil, and reduce the quality and products of crops. Moreover, they can threaten the health of animals and human beings upon entering the food chain. Although remediation of heavy metal contaminated sites has become a major issue in the international community, most of the traditional physical and chemical methods for the remediation are extreme in either cost or time spending. So it is difficult to remediate large areas of the contaminated agricultural soils. Scientists are finding new ways to remediate the heavy metal contaminated sites to solve the problems, but there should be no more time to wait.

Pb is a major contaminant that can influence the function of procreation and the immunity of genitalia tumour of organisms, including humans. As Pb enters the soil, it can bring a biological response making roots poisoned and causing plant death. In China, there are over 2×10^7 hm^2 soils that are evidently contaminated and a loss up to tens of billion Yuan is caused due to heavy metal contamination (Zhong et al., 2001). The arithmetic average Pb content in soils of China is 26.0 mg/kg, and the range is 0.68–1143 mg/kg (Wei et al., 1991). In the area around the Yangtze River and the Pearl River Delta, wastewater irrigated areas and mining areas, Pb contamination is especially severe. According to research in many areas of China, average Pb concentrations in the blood of children were 120–150 μg/L (Feng et al., 2002), which are higher than the maximum limitation set by the World Health Organization (WHO). Recent studies have led to significant advances in phytoremediation, using mainly hyperaccumulative plants to remediate heavy metals contaminated soils, which has been received great attention because of its low costs, better effectiveness, stable efficiencies and lesser ecology hazards. A concentration of Pb as high as 8200 mg/kg was found in tissues aboveground of *Thlaspi rotundifolium*, a typical Pb hyperaccumulator (Cunningham and Ow, 1996). Blaylock (1997) found that Pb concentration in shoots of *Brassica juncea* was as high as 1.5% when grown in a nutrition solution containing high Pb level and EDTA added for 1 week. However, it is also noticed that most of the hyperaccumulators are usually with lower biomass and slower growing rate which leads to a long time taking for the soil remediation. Thus, the phytoremediation is difficult to bring into use right away, especially for the vast lightly contaminated agricultural soils in China.

Because the abilities to absorb and accumulate heavy metals is different for different plant species, varieties and tissues, the feasibility using crop species or varieties with lower heavy metals accumulation capability is valuable to study for decreasing the risk of heavy metals entering the food chain from the contaminated soil. Furthermore, if a species or variety produce large inedible biomass, in which volume of heavy metals accumulated are large enough to remove the heavy metals from soil effectively, and simultaneously the heavy metal concentration in its edible parts is low enough to ensure food safety, the species or variety shall be useful for both food production and soil remediation.

Maize (*Zea mays* L.) has large vegetative biomass and is one of the most important crops in China and in the world. In 1998, the cropping area of maize was 2×10^7 hm^2 and the total yield was 1.254×10^4 t (22.13% of the gross grain production) in China (Feng, 2001). The aim of this study was to find maize varieties with lower Pb concentrations in their grains that do not exceeded the maximal Pb limitation of the National Food Hygiene Standard of China (NFHSC), but with higher Pb concentrations in their non-edible parts to evaluate the feasibility of the method above-mentioned.

2 Materials and methods

The experimental site was located in Qingyuan City in Guangdong Province, which belongs to subtropical monsoon climate zone. The average annual temperature is 22.0°C (39°C for the highest and −3°C for the lowest) and the annual rainfall is 2215 mm.

2.1 The tested soil and maize varieties

The soil used in this experiment is composed of organic fertilizer, pond mud taken from the local pond and sand at the proportion 3:6:1. The organic fertilizer was made of wood bits, cotton shuck and pig dung, and composted for two months. The soil was air-dried at room temperature followed by sifting with a 2 mm sieve, and its water content is about 8%. Contents of organic matter, NH_4^+-N, available P, available K, and total Pb were 7.30%, 0.48%, 0.17%, 0.91% and 195.55 mg/kg, respectively, and pH value was 6.7.

Twenty-five maize varieties were tested, including Yuetian-3, Yuetian-2, Luoyou-2, Chaotian-38, Chaotianjingyinli-1, Jiamei-1, Chaotian-711, Fengtian-1, Chaotian-28, Yueziluo-1, Zhengtian-8, Mingtian-8, Mingtian-5, Chaotian-613 and Yuebailuo-1 (purchased from Guangdong Academy of Agricultural Sciences), Shuitian-2, Guangluo-1, Shuitian-1 (purchased from Guangzhou Institute of Agricultural Sciences), Huatian-1 and Huatian-3 (purchased from Huanan Agricultural University), Tianduan-21 (obtained from the Chinese Agricultural University), Lubachaotian maize, Lubachaotian-76, Dingtian-1 (purchased from Guangzhou Luba Seed and Seedling Co., Ltd.), Nongtian-3 (purchased from Guangzhou Yongxin Vegetable Research Center), and Chaotian-113 (purchased from Guangzhou Zhuoyi Seed Company).To avoid commercial issues, serial numbers from high to low according to the Pb concentrations in the roots were used instead of names of the varieties.

2.2 Methods

2.2.1 Pot experiment

Plastic pots with 20.5 cm inner diameter and 18 cm height were filled with the air dried soil at 5 kg/pot. Pb added (treatment) and no Pb added (control) were conducted, and three pots were cropped as replication for each variety under both the control and the treatment. As to the Pb treatment, soils of each pot were mixed with the Pb solution containing Pb $(NO_3)_2$ 3.20 g, and the final Pb concentration was 595.55 mg/kg. The soils were allowed to stabilize for 10 days in a green house. To prevent Pb loss, three pots of the same treatment were put in a big box and all the water in the box was averagely re-watered into the three pots. In the end of the experiment, the average Pb concentrations were 400.15 mg/kg and 160.67 mg/kg under the treatment and the control, respectively.

On April 8th, 2003, healthy even seeds were sown into the pots at eight seeds per pot. In the 12th day and the 20th day, 2–3 seedlings and 1 seedling per pot were remained, respectively. The pots were watered to keep soil moisture, and the seedlings were fertilized with compound fertilizer (N:P:K = 15:15:15) at 8 g and 18 g per pot in the seedling and flowering period, respectively. Plant tissue samples were harvested on July 15th, 2003.

2.2.2 Sample preparation and Pb analysis

All maize roots samples were soaked in EDTA-Na_2 solution (0.01 mol/L) for 15 min to remove the heavy metals adhered in root surface and then rinsed with deionized water. After drying to constant weight at 105°C for 48 h, all roots, shoots (including core), leaves and grains (only the edible parts) samples were milled with mortar and pestle and sieved through a 100 meshes plastic sift, then airproofed and kept in refrigerator at 4°C.

Pb concentrations of all of the samples were determined with a flame atomic absorption spectrophotometer (FAAS, Buck 200AA) following HNO_3-$HClO_4$ (4:1, v/v) digestion procedures with a microwave decomposition device (MK-III, Shanghai, China). All reagents used were of analytical grade.

3 Results and analysis

3.1 Pb concentrations in different tissues of the tested varieties

Under both the Pb treatment and the control, the Pb concentrations in different tissues were roots > shoots ≌ leaves > grains (Table 1). The average Pb concentrations in the tested tissues were 210.11, 66.49, 62.08 and 0.24 mg/kg for root, shoot, leave and grain, respectively, under the Pb treatment, and were respectively 5.7, 5.9, 6.0 and 1.0 folds higher than those under the control (31.50, 9.60, 8.88 and 0.12 mg/kg).

Ranges of Pb concentrations of the tested varieties were 84.17–427.68 mg/kg in root, 25.19–109.27 mg/kg in shoot, 29.35–125.22 mg/kg in leave and 0.15–0.60 mg/kg in grain, under the Pb treatment, and they were 10.29–56.25, 2.31–19.68, 2.59–16.20 and 0.06–0.21 mg/kg, respectively, under the control. The variations of Pb accumulation in all the tested tissues among the tested varieties were greater under the Pb treatment than under the control. The coefficients of variation (C.V.) for vegetative tissues ranged from 35% to 37%, lower than that in grain (47%).

Under the Pb treatment, there were 12 varieties with Pb concentrations in grain exceeded the maximal Pb limitation (0.2 mg/kg) of the National Food Hygiene Standard of China (NFHSC). Under the control, only 1 variety exceeded the limitation. Under the Pb treatment, the variety with the highest Pb concentrations in roots (var. No.1) had Pb concentrations in shoots and leaves for 109.27 and 93.57 mg/kg, respectively, but its Pb concentration in grains was only 0.19 mg/kg, which did not exceeded the limitation of the NFHSC. Variety No. 5 was also a noticeable variety, which had higher Pb concentrations in root, the second high Pb concentration in shoot and the highest Pb concentrations in leave and grain, indicating a high efficiency in translocation of Pb.

3.2 Correlations between Pb concentrations in different tissues each other

Correlation coefficients between the Pb concentrations in different tissues each other are shown in Table 2. Under both the control and the treatment, there was significant positive correlation between Pb concentrations in between all the vegetative tissues each other ($p < 0.01$), while those between the grain and the vegetative tissues each other were not significant ($p > 0.05$). The correlative coefficients between the vegetative tissues each other were higher under the Pb treatment than under the control.

However, Figure 2 revealed that the tested varieties might be able to be divided into two groups under the Pb treatment. One was included the varieties with Pb concentration higher in root and lower in grain (No.1–4 and No.6), i.e. the group possess of especially lower Pb translocation ability from root to grain. Another was constituted of the other 20 varieties whose Pb concentrations in the grain were still correlative to those in the root.

3.3 Grain biomasses of the tested varieties

Grain biomasses of the tested varieties are shown in Table 3. Under the control, average biomass of the grains was 111 g/plant, and the highest one was variety No.4 (176 g/plant), while under the Pb treatment, the average was only 98 g/plant, 12.6% lower than that under the control. There were 22 varieties whose grains biomass decreased under the stress of Pb, and the range was 0.9% to 38.1%.

Table 1 Pb concentrations in root, stem, leaf and grain of the tested maize varieties (mg/kg)

Varieties	Root		Stem		Leaf		Grain	
	Pb treat.	Control	Pb treat.	Control	Pb treat.	Control	Pb treat.	Control
No.1	427.68^{a}	34.57^{ef}	109.27^{a}	8.09^{ghi}	93.57^{b}	9.50^{cdefgh}	0.19^{efghi}	0.10^{def}
No.2	325.77^{b}	38.79^{de}	86.35^{c}	13.50^{b}	88.37^{c}	12.79^{abc}	0.19^{efghi}	0.11^{cdef}
No.3	306.81^{c}	41.16^{cd}	85.37^{c}	11.52^{bcde}	80.65^{d}	8.62^{defghi}	0.17^{ghi}	0.11^{cdef}
No.4	302.82^{c}	32.24^{fghi}	100.24^{b}	10.95^{bcdef}	92.52^{bc}	13.58^{ab}	0.21^{defghi}*	0.12^{cdef}
No.5	300.25^{c}	47.12^{b}	108.48^{a}	12.68^{bc}	125.22^{a}	12.61^{abcd}	0.60^{a}*	0.11^{cdef}
No.6	289.92^{d}	28.64^{ghij}	99.65^{b}	10.23^{cdefg}	95.64^{b}	8.65^{defghi}	0.18^{efghi}	0.11^{cdef}
No.7	239.81^{e}	35.40^{ef}	74.06^{d}	7.56^{ghi}	65.27^{e}	5.62^{hij}	0.26^{cde}*	0.18^{abc}
No.8	236.97^{e}	26.53^{j}	88.60^{c}	12.55^{bc}	56.06^{gh}	10.37^{bcdef}	0.29^{cd}*	0.21^{a}*
No.9	232.66^{e}	43.90^{bc}	65.19^{efg}	19.68^{a}	48.95^{ij}	16.20^{a}	0.49^{b}*	0.07^{ef}
No.10	218.49^{f}	25.67^{j}	53.30^{h}	7.20^{hi}	48.05^{ij}	9.78^{bcdef}	0.47^{b}*	0.13^{bcdef}
No.11	211.80^{f}	32.77^{fgh}	68.61^{e}	6.66^{i}	62.09^{ef}	8.38^{efghi}	0.19^{efghi}	0.15^{abcd}
No.12	193.91^{g}	28.60^{ghij}	62.09^{g}	11.69^{bcd}	55.67^{gh}	10.09^{bcdef}	0.26^{cdef}*	0.14^{abcde}
No.13	189.65^{gh}	44.34^{bc}	74.09^{d}	8.65^{fghi}	48.64^{ij}	7.00^{fghi}	0.17^{ghi}	0.11^{cdef}
No.14	186.06^{gh}	20.33^{k}	63.41^{fg}	6.53^{i}	35.18^{l}	5.69^{ghij}	0.19^{efghi}	0.09^{def}
No.15	184.64^{h}	12.29^{lm}	25.19^{l}	2.31^{j}	29.35^{m}	2.59^{j}	0.32^{c}*	0.20^{ab}
No.16	163.54^{i}	36.40^{ef}	45.06^{i}	8.86^{efghi}	38.88^{kl}	8.14^{efghi}	0.25^{cdefg}*	0.10^{def}
No.17	159.67^{ij}	28.25^{hij}	56.26^{h}	9.06^{defghi}	41.03^{k}	8.14^{efghi}	0.15^{i}	0.10^{def}
No.18	159.31^{ij}	25.08^{j}	56.37^{h}	11.06^{bcdef}	48.19^{ij}	8.69^{defghi}	0.24^{cdefgh}*	0.09^{def}
No.19	156.76^{ijk}	56.25^{a}	40.26^{j}	6.38^{i}	46.36^{j}	9.67^{bcdefg}	0.19^{efghi}	0.11^{cdef}
No.20	154.25^{jk}	15.85^{kl}	32.69^{k}	9.37^{defgh}	48.62^{ij}	5.37^{ij}	0.20^{efghi}	0.12^{cdef}
No.21	150.06^{kl}	10.29^{m}	34.60^{k}	6.56^{i}	52.19^{hi}	5.10^{ij}	0.17^{fghi}	0.06^{f}
No.22	144.22^{l}	28.16^{ij}	57.28^{h}	7.63^{ghi}	59.58^{fg}	8.25^{efghi}	0.16^{hi}	0.10^{def}
No.23	120.27^{mn}	33.04^{fg}	43.40^{ij}	9.68^{defgh}	48.58^{ij}	8.76^{defghi}	0.22^{defghi}*	0.12^{cdef}
No.24	113.23^{n}	27.51^{j}	66.99^{ef}	12.96^{b}	63.18^{ef}	11.09^{bcde}	0.21^{defghi}*	0.12^{bcdef}
No.25	84.17^{o}	34.40^{ef}	65.39^{efg}	8.63^{fghi}	80.13^{d}	7.21^{efghi}	0.15^{i}	0.09^{def}
Mean	210.11	31.50	66.49	9.60	62.08	8.88	0.24	0.12
C.V.	37.8	33.8	35.3	34.8	37.1	33.4	46.9	29.4

Notes: Different letters within the same column indicate significant difference at $p < 0.05$ level according to LSD test; * Varieties that Pb concentrations in grain exceeded the maximal Pb limitation of National Food Hygiene Standard of China (NFHSC) ($Pb \leqslant 0.2$ mg/kg)

Table 2 Correlative coefficients between Pb concentrations of different tissues under Pb treatment and the control

Tissues	Pb treatment			Control		
	Stem	Leaf	Grain	Stem	Leaf	Grain
Root	0.775^{**}	0.644^{**}	0.211	0.382^{**}	0.564^{**}	−0.159
Stem	—	0.834^{**}	0.130	—	0.496^{**}	−0.227
Leaf		—	0.171		—	−0.274

Notes: ** The correlative coefficient was significant at $P < 0.01$ level.

Grain biomasses of the varieties No.1–3 and No. 6 that were with higher Pb concentrations in roots were significantly higher than the others under the Pb treatment. When comparing to the control, the grain biomasses of varieties No.1, No.2 and No.6 with the rather high Pb concentrations in roots had some decrease. The grain biomass of variety No.4 decreased for 5.8%, while variety No.5 had the largest decrement (38.1%). Only little variation in grain biomasses was observed, but variation in the changes caused by the Pb stress was rather great (C.V. = 88.5%).

3.4 Total Pb accumulation in the vegetative tissues of tested varieties

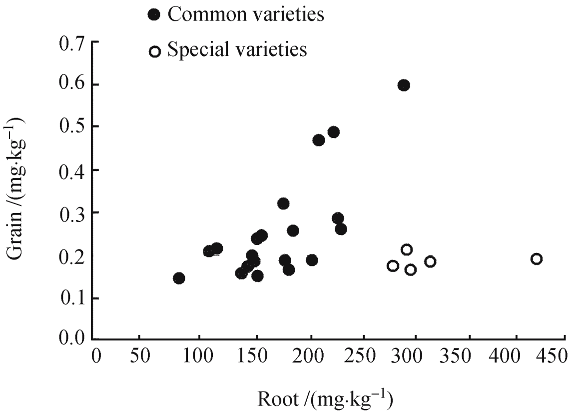

Fig. 1 Relationship for Pb concentrations (mg/kg) between root and grain of the tested maize varieties under the Pb treatment

Table 3 shows the total Pb volumes in the vegetative tissues of tested varieties. Under the control, the total Pb volumes were less than 6.45 mg/plant, and the average was 3.84 mg/plant, and total Pb volumes of varieties No.1–6 were significantly higher than others. While there was averagely six folds higher Pb volume under the Pb treatment when comparing to that under the control, and the average was 24.63 mg/plant. The total Pb volume of variety No.1 had the highest total Pb volume in vegetative tissues, and it was 51.69 mg/plant under the Pb treatment, 10.8 times of that in the control. The total Pb volumes accumulated in the vegetative tissues of varieties No.3, No.5 and No.6 were more

Table 3 Grain biomass and total Pb in the vegetative tissues of the tested maize varieties

Varieties	Grain biomass (g/plant)			Total Pb in the vegetative tissues (mg/plant)		
	Pb treatment	Control	Increment (%)	Pb treatment	Control	Increment (folds)
No.1	115 ^{ab}	116 ^{cde}	–0.9	51.69 ^{a}	4.37 ^{bcdef}	10.8
No.2	120 ^{a}	115 ^{cde}	4.3	41.93 ^{b}	5.05 ^{b}	7.3
No.3	116 ^{ab}	116 ^{cde}	0.0	39.13 ^{c}	5.17 ^{b}	6.6
No.4	109 ^{bc}	176 ^{a}	–38.1	41.36 ^{b}	4.41 ^{bcdef}	8.4
No.5	81 ^{hi}	86 ^{i}	–5.8	33.88 ^{e}	4.86 ^{bc}	6.0
No.6	121 ^{a}	118 ^{cde}	2.5	36.65 ^{d}	3.62 ^{fg}	9.1
No.7	88 ^{fghi}	110 ^{ef}	–20.0	25.82 ^{f}	3.73 ^{efg}	5.9
No.8	95 ^{def}	104 ^{fg}	–8.7	26.61 ^{f}	4.06 ^{cdefg}	5.6
No.9	94 ^{ef}	96 ^{ghi}	–2.1	24.55 ^{fg}	6.45 ^{a}	2.8
No.10	92 ^{efg}	122 ^{def}	–24.6	22.78 ^{gh}	3.36 ^{g}	5.8
No.11	100 ^{cde}	108 ^{ef}	–7.4	25.46 ^{f}	3.74 ^{efg}	5.8
No.12	105 ^{cd}	124 ^{bc}	–15.3	20.23 ^{ij}	3.64 ^{fg}	4.6
No.13	97 ^{def}	111 ^{ef}	–12.6	21.48 ^{hi}	4.57 ^{bcd}	3.7
No.14	83 ^{ghi}	89 ^{hi}	–6.7	18.65 ^{jk}	2.45 ^{h}	6.6
No.15	90 ^{fgh}	108 ^{ef}	–16.7	15.16 ^{mn}	1.22 ^{i}	11.4
No.16	120 ^{a}	132 ^{b}	–9.1	19.38 ^{jk}	4.50 ^{bcde}	3.3
No.17	91 ^{efg}	108 ^{ef}	–15.7	18.82 ^{jk}	3.52 ^{g}	4.3
No.18	92 ^{efg}	111 ^{ef}	–17.1	18.18 ^{jkl}	3.47 ^{g}	4.2
No.19	88 ^{fghi}	96 ^{ghi}	–8.3	14.99 ^{mn}	4.81 ^{bc}	2.1
No.20	104 ^{cd}	115 ^{cde}	–9.6	18.83 ^{jk}	2.37 ^{h}	6.9
No.21	80 ^{i}	104 ^{fg}	–23.1	14.06 ^{n}	0.79 ^{i}	16.8
No.22	81 ^{hi}	86 ^{i}	–5.8	18.17 ^{jkl}	3.47 ^{g}	4.2
No.23	81 ^{hi}	112 ^{def}	–27.7	13.75 ^{n}	3.90 ^{defg}	2.5
No.24	95 ^{def}	97 ^{gh}	–2.1	17.90 ^{kl}	4.15 ^{cdefg}	3.3
No.25	93 ^{ef}	125 ^{bc}	–25.6	16.35 ^{lm}	4.43 ^{bcdef}	2.7
Mean	97	111	–12.6	24.63	3.84	6.0
C.V.	13.5	16.2	88.5	41.7	31.4	55.3

Notes: Different letters within the same column indicate significant difference at $p < 0.05$ level according to LSD test; Increment (%): (Pb treatment/Control – 1) × 100; Increment (folds): Pb treatment/Contriol – 1

than 30 mg/plant, and those of the other varieties ranged from 13–27 mg/plant.

4 Discussion

Pb concentrations in soils conducted in the present experiment were at light and medium contamination levels under the control and the Pb treatment, respectively. There was no Pb added artificially under the control, where the Pb was originally existed in the tested soil, indicating the widespread Pb contamination in agricultural soil. Although the Pb concentrations in grains of the tested varieties were generally at safe level, there was one variety that the Pb level exceeded the maximal Pb limitation of the NFHSC, and there were other three varieties accumulated Pb for more than 0.15 mg/kg, being rather close to the limitation. When the soil was exposed to Pb at medium contaminating level, Pb concentration in grains of almost half of the tested varieties exceeded the limitation. This meant that Pb translocate relatively easily from vegetative tissues to grain for maize which was also reported by Kuang et al. (2002). In variety Luyu No.1, Pb concentrations in grains were 0.20 mg/kg as the Pb concentration in soil was 25.8 mg/kg, and Pb concentrations in grains were 0.44 and 0.41 mg/kg when 500 mg/kg $PbCl_2$ and Pb $(NO_3)_2$ were added, respectively (Kuang et al, 2002). In the irrigated fields using sewage drained from Datong, Shanxi Province, Pb concentrations in grains of maize of all three investigated sites exceeded the limitation of the NFHSC, and the ranges were 0.673–0.886 mg/kg, 1.097–1.746 mg/kg and 0.480–1.221 mg/kg, respectively (Yang, 2002). In the irrigated fields using sewage from Baiyin, Gansu Province, Pb concentrations in grains of all tested samples exceeded the limitation, and the average was 0.660 mg/kg in soil containing 54.1 mg/kg Pb in average, and 1.140 mg/kg in soil containing 95.0 mg/kg Pb (Guo, 2002). Nan and Chen (2001) found that the Pb concentrations in grains of maize in the Baiyin area were 0.27 mg/kg and 2.29 mg/kg when the Pb concentrations in soil were 27.48 mg/kg and 239.71 mg/kg, respectively. Hu et al. (1999) proved that Pb volumes in grains of maize (7.86 mg/kg) were higher than wheat, rice and horsebean. Therefore, a conclusion could be made that there is a high risk of growing maize in soil where is contaminated by Pb, although the concentration in soil is not so high.

Another risk is that when exposed to high Pb concentrations, the growth of maize changed slightly. In the present study, the biomass of grains of more than half of the tested varieties decreased only slightly under high Pb concentrations, which meant that maize still grown well when Pb contamination in soil was at a high level enough to result in grain Pb pullution. Kuang et al. (2002) reported a normal growth of a maize variety (Luba No.1) when grown in the soils where 4000 mg/kg $PbCl_2$ or $Pb(NO_3)_2$ were added. Thus, because Pb contamination cannot be easily warned from the yield change caused by the Pb contamination in soil, there is an extra risk that the maize products polluted by unknown Pb contaminations in soils.

There was great variation of Pb accumulation among the grains of maize varieties. Pb concentrations in grains of 52% of the tested maize varieties did not exceed the limitation of the NFHSC under the 596 mg/kg Pb exposure. It is suggested that the variety used in the above-mentioned cases in the Baiyin area was probably that had high Pb accumulation ability. Therefore, If varieties with lower Pb concentrations in grains were grown in the sites, the risk of Pb contamination upon to food safety would be decreased.

It seems that maize has rather high Pb accumulation ability. Qu et al. (2002) found that Pb concentration in the roots of 14 days old seedling of a maize variety (Gaoyou-15) grown in culture solution containing 100 mg/L of Pb for 80 h was 42.6 mg/g, 100 folds higher than the results gained in the present study. Kuang (2002) found that Pb concentrations in roots and shoots of maize were 2698 mg/kg and 42.9 mg/kg, respectively, when Pb concentration was 4000 mg/kg in soil. Thus, maize was considered to be used for remediation of Pb contaminated soil and water. In the present study, it was observed that the maximal differences of Pb accumaltion in root and shoot (including leave) were more than 4 and 3 folds, respectively, among the tested varieties under the Pb treatment. The total Pb accumulation in the vegetative tissues was tow folds higher in the highest variety than in the lowest one. The Pb volume in vegetative tissues of variety No.1 was 51.69 mg/plant, and 465.2 mg/m^2 in soil could be removed out from soil at every cropping if the planting density was 9 plants/m^2.

Differing from the most tested varieties that followed the positive correlation in Pb concentrations between grain and vegetative tissues, some varieties, such as varieties No.1–3 and No.6, were with low Pb concentrations in grains (less than the NFHSC), but with high Pb concentrations in vegetative tissues, which meant that there was low Pb translocating rate from the vegetative tissues to the grains, although the rate from roots to shoots and leaves was rather high. Therefore, we could infer that there might be a mechanism that hinders the Pb transfer from shoots and leaves to grains. The varieties are possible to be used for both maize production in the filed contaminated by Pb at certain level (fitting to the Pb accumulation in grain of the maize varieties) and bioremediation of the soils, if their genetic stability of Pb accumulation and the adoptability in multi-metal contaminated site were proved by further investigations.

Some other varieties with unique Pb accumulating characters found in this study, such as the extreme low Pb uptake (No.25), the low Pb translocation from roots to shoots and leaves (No.15), the high Pb translocation from tissue to tissue including to grain (No.5), may be useful for studying the Pb absorbing and translocating mechanisms in maize.

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