

Research Article

Difference between Pb and Cd Accumulation in 19 Elite Maize Inbred Lines and Application Prospects

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Received 13 December 2011; Revised 27 February 2012; Accepted 7 March 2012

Academic Editor: Marina Clemente

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In the last two decades, the accumulation of heavy metal in crop grains has become the study hotspot. In this study, 19 representative elite maize inbred lines and 3 hybrid varieties were investigated at the seedling stage, which can accumulate Pb and Cd in the stems and leaves, respectively. The results demonstrated that significant differences are among inbred lines for accumulation of heavy metals, implying that the Cd accumulation is significant correlation between the male parents and their hybrids and some inbred lines have been selected for cross-breeding with low Pb or Cd accumulation, such as S37, 9782, and ES40; Moreover, some inbred lines could be suitable for phytoremediation species for soil bioremediation with high levels of Pb and Cd accumulation, including 178, R08, 48-2, and Mo17ht.

1. Introduction

Heavy metal pollution has become a major global problem, which threatens the environment and human life by its toxicity [1]. And it is becoming more seriously along with urbanization, industrialization, and modern agricultural activities. Heavy metals do not easily degrade or volatilize owing to their stable physical and chemical properties. Therefore, it has led to more serious and possibly irreversible pollution resulting from increasing heavy metals accumulation in soil every year [2]. Among these heavy metals, lead (Pb) and cadmium (Cd) are the most harmful and ubiquitous in everywhere. According to the recent statistics, the area of farming land (contaminated with Cd and Pb) is nearly 2.0×10^7 hm² in China, which accounts for about 1/5 of the total area of that in China [3]. Pb and Cd can enter into soil, and then transferred to crops by the food chain, which

will impose a threat to the health of humans and livestock eaten by them [4–7].

The Chinese Academy of Sciences and Southwest Agricultural University have conducted an investigation of wheat grains in the Liangfeng irrigated area, Beijing, and the results showed that although the concentration of heavy metal accumulation in grains was much lower than that in roots and leaves, the overstandard concentration of Pb and Zn (Zinc) in wheat grains was still 28.16% and 4.18%, respectively. The concentrations of Hg (mercury) and Cd met the standard, and some of the samples have been close to the upper limits of national food hygiene standard [8]. Lucho-Constantino et al. [9] found that crops showed higher concentrations of Cd and Pb that had been irrigated with wastewater for 20 years than the standard concentrations of those in The Netherlands and Germany. Currently, foods, such as vegetables and fruits, produced in industrial and

mining areas of China, which contain high levels of Pb and exceed standard values and even near to the critical values, so it has imposed a great threat to the safety of agricultural products [10–14]. In order to reduce the hazard of foods produced in soil with Pb and Cd concentration, a large number of studies have been conducted worldwide to restore the soil by treatment with hyperaccumulation plants. However, most hyper-accumulation plants are characterized by low biomass, long remediation cycle, and narrow biological adaptability, and insufficient to meet the demands of large-scale applications.

Compared with low-biomass plants, maize is more advantageous for restoring soil with heavy metals pollution [6, 15]. Maize is one of the most important economically food crops in China, and the uptake of Pb or Cd among the maize cultivars can affect the quality of food and fodder. 19 elite maize inbred lines were used as materials in this experiment, which has represented the different heterotic groups and been widely used in commercial breeding in China, including PA, Lancaster, BSSS (Reid), Sipingtuo, Luda Red Cob, and PB, of which, 3 hybrid maize varieties that have been widely grown in southwest China. And then, differences of Cd and Pb accumulation and correlations between the Cd concentration of the hybrid varieties and their male parents were analyzed in different maize germplasms. At last, several maize germplasms were selected for future breeding that accumulate low levels of Cd or Pb and identified for new phytoremediation species with higher biomass and better ecoadaptation for bioremediation of soil with Pb and Cd pollution that accumulate high levels of Cd and Pb.

2. Materials and Methods

2.1. Soil Preparation. Soil samples were taken from Duoying district, Ya'an, and treated by air drying and then digested with HNO₃-HF-H₂O₂ acids system. The Pb concentration in soil was 60.92 mg·kg⁻¹, which was within the range of grade II of the National Soil Environmental Quality Standard (GB15618-1995). Meanwhile, the Cd concentration was 3.23 mg·kg⁻¹, which was higher than grade III standard limits. Measurements of Pb and Cd were conducted by a flame atomic absorption spectrophotometer (SHIMADZU AA-6600, Japan) in soil samples.

2.2. Maize Collection. 19 maize inbred lines and three hybrid varieties were selected for the experiment; all inbred lines and hybrid varieties were provided by the Maize Research Institute of Sichuan Agricultural University (Table 1).

2.3. Experimental Methods. Soil was put into some plastic pots and each pot with 15 kg soil, with a diameter of 22 cm and a depth of 20 cm, and then divided into four groups: (1) high Pb, (2) high Cd, (3) low Pb, and (4) low Cd. High Pb soil contained Pb concentration (750 mg·kg⁻¹) and high Cd soil contained Cd concentration (30 mg·kg⁻¹), respectively, which was created by evenly mixing a certain amount of Pb(NO₃)₂ or CdCl₂·2.5H₂O solution with the soil. Low Pb and Cd soil were untreated. Each group was repeated three

times, for a total of 171 pots. And three concentration levels were set for each hybrid varieties: (1) Cd 15 mg·kg⁻¹, (2) 30 mg·kg⁻¹ and (3) 50 mg·kg⁻¹. Each level was repeated three times, for a total of 27 pots.

The seeds of inbred lines and hybrid varieties were planted in seedling trays and fully saturated with water. When each seed sprouted and grown 2-3 leaves, then the seedlings with similar growth trend will be transferred into plastic pots, with three plants in each pot and arranged in a triangular pattern. Soil was watered and loosened at regular intervals to keep it wet and breathing freely. In this experiment, 12 g of compound fertilizer was applied four times to each pot according to weather conditions and the growth condition of the plants, which contains N, P, and K concentrations of 13.5%, 11.0%, and 9.5%, respectively.

2.4. Sampling and Analysis. Samples were taken after 70 days and washed thoroughly with tap water to remove soil and dirt, then washed with deionized water three times. Plantlets were divided into roots and aboveground parts. Samples were first dried for 3 days at room temperature, then in an oven at 80°C until the weight remained unchanged. Finally, the dried samples were crushed and put into sealed bags for analysis.

During the experiment, all containers were cleaned with tap water, 5% HNO₃, and deionized water. Then, 0.5 g of each sample was taken and digested with HNO₃-HClO₄ (guaranteed reagent, 4:1) and subjected to flame atomic absorption spectrophotometry (SHIMADZU AA-6600, Japan) to determine the concentrations of Pb and Cd.

Microsoft Excel 2003 and SPSS 13.0 were used for data analysis.

3. Results and Analysis

3.1. The Concentrations of Pb and Cd in Roots and Above-ground Parts of Inbred Lines. As shown in Table 2, the Pb concentration range and the average value at low-Pb conditions in roots were 0–11.5 mg·kg⁻¹ and 3.63 mg·kg⁻¹, respectively, and 0–54.0 mg·kg⁻¹ and 28.1 mg·kg⁻¹ in stems and leaves, respectively. Of which, 3 low-accumulation inbred lines (S37, 9782, and ES40) and 4 high-accumulation inbred lines (178, R08, 48-2, and Mo17ht) were obtained. Moreover, the range and average value of Pb concentration in roots were 51.6–312.8 mg·kg⁻¹ and 161.5 mg·kg⁻¹, and 0–222.3 mg·kg⁻¹ and 89.1 mg·kg⁻¹, in stems and leaves under high-Pb conditions, respectively. Of those inbred lines, S37 was the lowest-accumulation inbred line obtained under high-Pb conditions, but no high-accumulation inbred line was obtained. It may be noted that the translocation coefficients of most of inbred lines were greater than 1 at low-Pb conditions, which indicates that the Pb translocation of maize plants is efficient under such a pollution level (Table 3). As shown in Tables 2 and 3, although the Pb concentration in roots, stems, and leaves were increasingly rapidly, the translocation efficiency decreased considerably, it is probably that it is caused by the self-protection mechanism of maize inbred lines under high-Pb conditions.

TABLE 1: Inbred lines and hybrid varieties.

S/N	Description	Remarks	Heterotic groups
1	S37	Inbred line	PA
2	Shen 137	Inbred line	PB
3	Zheng 58	Inbred line	BSSS (Reid)
4	9782	Inbred line	BSSS (Reid)
5	Qi 319	Inbred line	PB
6	Golden 96C	Inbred line	Lancaster
7	178	Inbred line	PB
8	ES40	Inbred line	PA
9	R15	Inbred line	Lancaster
10	P138	Inbred line	PB
11	R08	Inbred line	BSSS (Reid)
12	Moqun 17	Inbred line	Lancaster
13	RP125	Inbred line	BSSS (Reid)
14	Huangzao 4	Inbred line	Sipingtou
15	Mo17ht	Inbred line	Lancaster
16	48-2	Inbred line	PA
17	R18	Inbred line	PB
18	Chang 7-2	Inbred line	Sipingtou
19	Zong 31	Inbred line	Luda red cob
20	Chuandan no. 14	Hybrid variety (R08 × 21-es)	
21	Chuandan no. 10	Hybrid variety (48-2 × R18)	
22	Yayu no. 2	Hybrid variety (S37 × 7922)	

Under low-Cd conditions, the Cd concentration range and average value of inbred lines were 0–12.0 mg·kg⁻¹ and 2.83 mg·kg⁻¹ in roots, and 0–1140 mg·kg⁻¹ and 1.34 mg·kg⁻¹, in stems and leaves respectively. However, no Cd was detected in the stems and leaves, indicating that the aboveground parts of maize are less polluted by Cd under such conditions. At high-Cd conditions, the Cd concentration range and average value were 21.7–175.1 mg·kg⁻¹ and 83.2 mg·kg⁻¹ in roots and 0–614 mg·kg⁻¹ and 22.4 mg·kg⁻¹ in stems and leaves, respectively. Three low-accumulation inbred lines (Golden 96C, R08, and Huangzao 4) and 2 high-accumulation inbred lines (Zheng 58 and 9782) were obtained (Tables 1 and 2).

3.2. Cd Concentrations in Roots and Aboveground Parts of Hybrid Varieties. Cd has been recognized as a trace toxic heavy metal and should be monitored closely. In order to investigate whether low Cd accumulation in inbred lines is related to the parents, we conducted a comparison of (Chuandan no. 14, Chuandan no. 10, and Yayu no. 2) to their male parents (R08, 48-2, and S37, resp.). It is shown that the Cd concentrations in stems and leaves of Chuandan no. 14 were lower than those of the other two hybrid varieties under the three treatment levels (listed in Table 4).

4. Discussion

The accumulation and translocation coefficient of Pb in three inbred lines was as follows in descending order: R08, S37,

and 48-2. It is similarly in the stems and leaves of varieties, such as Chuandan no. 14, Yayu no. 2, and Chuandan no. 10. It is demonstrated that a significant correlation of Cd concentrations was between hybrid varieties and their male parents.

However, Pb could be maintained at low levels in grains of maize under high-Pb conditions (595.6 mg·kg⁻¹), and the concentrations were much lower than nutritional organs [16]. It is demonstrated that the stems and leaves of maize plants are easily polluted with Pb; it will pose a hazard for livestock, especially cattle as silage fodder. Therefore, the selection of maize germplasms with low Pb accumulation in stems and leaves is very important. In this experiment, we obtained three low-Pb inbred lines under low-Pb conditions, S37, 9782, and ES40. Under high-Pb conditions, the Pb concentration in stems and leaves of the other inbred lines was increasing greatly; with the exception of S37, it remained at 0.00 mg·kg⁻¹, indicating that the Pb translocation of S37 is inefficient and stable. Therefore, S37 can be assumed to be a satisfactory inbred line. Due to the highly homozygous genome and high combining ability of maize inbred lines, S37, 9782, and ES40 may be used to cross-breed for low-Pb varieties in stems and leaves.

We obtained three inbred lines (Golden 96C, R08, and Huangzao 4) with low-Cd accumulation in stems and leaves under high-Cd conditions. The Cd concentration in the stems and leaves of Golden 96C and R08 was 0.00 mg·kg⁻¹ respectively, but 0.26 mg·kg⁻¹ in Huangzao 4. Therefore, these three inbred lines may be satisfactory as

TABLE 2: Pb and Cd concentrations in roots and aboveground parts of inbred lines ($\text{mg} \cdot \text{kg}^{-1}$).

Inbred line number	Cd						Pb					
	Roots		Stems and leaves		Roots		Stems and leaves		Roots		Stems and leaves	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1	0.00 ± 0.00 ^f	175.09 ± 9.54 ^a	0.00 ± 0.00 ^e	8.42 ± 0.16 ^l	11.55 ± 0.03 ^a	150.18 ± 0.22 ^{de}	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ^g	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ^g
2	0.00 ± 0.00 ^f	86.43 ± 1.77 ^{cde}	0.00 ± 0.00 ^e	61.38 ± 0.63 ^a	7.16 ± 0.29 ^b	211.84 ± 0.09 ^{bc}	46.88 ± 1.59 ^b	46.88 ± 1.59 ^b	46.88 ± 1.59 ^b	115.63 ± 5.35 ^{bc}	46.88 ± 1.59 ^b	115.63 ± 5.35 ^{bc}
3	11.68 ± 0.21 ^a	47.34 ± 1.94 ^{ghi}	11.40 ± 0.66 ^a	24.86 ± 1.23 ^h	0.00 ± 0.00 ^f	102.26 ± 0.10 ^{fg}	5.78 ± 0.28 ^h	5.78 ± 0.28 ^h	5.78 ± 0.28 ^h	13.47 ± 2.79 ^{efg}	5.78 ± 0.28 ^h	13.47 ± 2.79 ^{efg}
4	6.99 ± 0.33 ^c	43.21 ± 0.18 ^{hi}	4.09 ± 0.12 ^c	46.26 ± 0.50 ^c	1.92 ± 0.08 ^e	136.34 ± 3.02 ^{ef}	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	7.72 ± 1.60 ^{fg}	0.00 ± 0.00 ⁱ	7.72 ± 1.60 ^{fg}
5	2.85 ± 0.45 ^d	75.02 ± 0.86 ^{defg}	0.00 ± 0.00 ^e	51.04 ± 0.05 ^b	5.77 ± 0.26 ^c	109.22 ± 4.47 ^{fg}	13.43 ± 0.45 ^g	13.43 ± 0.45 ^g	13.43 ± 0.45 ^g	40.47 ± 0.87 ^{defg}	13.43 ± 0.45 ^g	40.47 ± 0.87 ^{defg}
6	0.00 ± 0.00 ^f	118.86 ± 1.27 ^b	0.00 ± 0.00 ^e	0.00 ± 0.00 ^o	3.86 ± 0.41 ^d	51.64 ± 1.47 ^h	7.84 ± 0.19 ^b	7.84 ± 0.19 ^b	7.84 ± 0.19 ^b	67.17 ± 1.79 ^{cdef}	7.84 ± 0.19 ^b	67.17 ± 1.79 ^{cdef}
7	11.05 ± 0.93 ^a	60.15 ± 12.17 ^{efgh}	8.74 ± 0.31 ^b	17.84 ± 0.26 ^j	0.00 ± 0.00 ^f	212.03 ± 8.62 ^{bc}	53.31 ± 2.49 ^a	53.31 ± 2.49 ^a	53.31 ± 2.49 ^a	127.19 ± 4.40 ^{bc}	53.31 ± 2.49 ^a	127.19 ± 4.40 ^{bc}
8	12.03 ± 0.03 ^a	122.86 ± 8.85 ^b	0.00 ± 0.00 ^e	25.58 ± 0.70 ^{gh}	5.76 ± 0.37 ^c	82.04 ± 5.55 ^{fg}	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	0.00 ± 0.00 ⁱ	94.52 ± 4.56 ^{bcd}	0.00 ± 0.00 ⁱ	94.52 ± 4.56 ^{bcd}
9	0.00 ± 0.00 ^f	97.59 ± 0.60 ^{bcd}	0.00 ± 0.00 ^e	12.08 ± 0.48 ^k	3.72 ± 0.16 ^d	199.19 ± 1.78 ^{bc}	37.06 ± 3.53 ^{cd}	37.06 ± 3.53 ^{cd}	37.06 ± 3.53 ^{cd}	94.71 ± 3.57 ^{bcd}	37.06 ± 3.53 ^{cd}	94.71 ± 3.57 ^{bcd}
10	0.00 ± 0.00 ^f	57.29 ± 11.82 ^{efgh}	1.18 ± 0.26 ^d	26.78 ± 0.43 ^s	0.00 ± 0.00 ^f	217.71 ± 1.20 ^b	20.41 ± 0.01 ^f	20.41 ± 0.01 ^f	20.41 ± 0.01 ^f	126.43 ± 0.73 ^{bc}	20.41 ± 0.01 ^f	126.43 ± 0.73 ^{bc}
11	0.00 ± 0.00 ^f	79.53 ± 2.05 ^{cde}	0.00 ± 0.00 ^e	0.00 ± 0.00 ^o	0.00 ± 0.00 ^f	186.20 ± 9.09 ^{bc}	48.02 ± 0.31 ^b	48.02 ± 0.31 ^b	48.02 ± 0.31 ^b	72.44 ± 0.51 ^{cde}	48.02 ± 0.31 ^b	72.44 ± 0.51 ^{cde}
12	9.24 ± 0.06 ^b	21.73 ± 0.27 ⁱ	0.00 ± 0.00 ^f	22.57 ± 0.79 ⁱ	11.07 ± 0.09 ^a	109.46 ± 8.61 ^{fg}	31.48 ± 3.94 ^e	31.48 ± 3.94 ^e	31.48 ± 3.94 ^e	77.77 ± 12.34 ^{bcd}	31.48 ± 3.94 ^e	77.77 ± 12.34 ^{bcd}
13	0.00 ± 0.00 ^f	50.75 ± 0.29 ^{fgh}	0.00 ± 0.00 ^f	34.20 ± 0.14 ^e	0.00 ± 0.00 ^f	186.27 ± 0.68 ^{bc}	31.41 ± 0.15 ^e	31.41 ± 0.15 ^e	31.41 ± 0.15 ^e	104.31 ± 13.15 ^{bcd}	31.41 ± 0.15 ^e	104.31 ± 13.15 ^{bcd}
14	0.00 ± 0.00 ^f	124.02 ± 18.88 ^b	0.00 ± 0.00 ^f	0.26 ± 0.03 ^{no}	0.00 ± 0.00 ^f	312.80 ± 6.54 ^a	33.48 ± 2.26 ^{de}	33.48 ± 2.26 ^{de}	33.48 ± 2.26 ^{de}	141.31 ± 3.50 ^b	33.48 ± 2.26 ^{de}	141.31 ± 3.50 ^b
15	0.00 ± 0.00 ^f	49.09 ± 3.33 ^{ghi}	0.09 ± 0.01 ^e	38.97 ± 0.59 ^d	0.00 ± 0.00 ^f	148.95 ± 10.17 ^{de}	54.02 ± 0.48 ^a	54.02 ± 0.48 ^a	54.02 ± 0.48 ^a	79.92 ± 4.74 ^{bcd}	54.02 ± 0.48 ^a	79.92 ± 4.74 ^{bcd}
16	0.00 ± 0.00 ^f	101.94 ± 6.20 ^{bcd}	0.00 ± 0.00 ^f	17.88 ± 0.56 ^j	0.00 ± 0.00 ^f	201.17 ± 11.31 ^{bc}	53.99 ± 0.28 ^a	53.99 ± 0.28 ^a	53.99 ± 0.28 ^a	127.71 ± 0.24 ^{bc}	53.99 ± 0.28 ^a	127.71 ± 0.24 ^{bc}
17	0.00 ± 0.00 ^f	103.67 ± 7.45 ^{bc}	0.00 ± 0.00 ^f	32.62 ± 0.37 ^f	0.00 ± 0.00 ^f	124.80 ± 8.47 ^{ef}	38.81 ± 3.09 ^c	38.81 ± 3.09 ^c	38.81 ± 3.09 ^c	72.73 ± 12.80 ^{cde}	38.81 ± 3.09 ^c	72.73 ± 12.80 ^{cde}
18	0.00 ± 0.00 ^f	87.75 ± 1.38 ^{cde}	0.00 ± 0.00 ^f	1.79 ± 0.51 ⁿ	6.80 ± 0.03 ^b	180.72 ± 13.20 ^{cd}	37.22 ± 0.08 ^{cd}	37.22 ± 0.08 ^{cd}	37.22 ± 0.08 ^{cd}	107.89 ± 11.01 ^{bc}	37.22 ± 0.08 ^{cd}	107.89 ± 11.01 ^{bc}
19	0.00 ± 0.00 ^f	77.86 ± 0.47 ^{cdef}	0.00 ± 0.00 ^f	3.58 ± 0.39 ^m	11.41 ± 0.92 ^a	144.99 ± 1.12 ^{de}	19.98 ± 0.42 ^f	19.98 ± 0.42 ^f	19.98 ± 0.42 ^f	222.28 ± 16.63 ^a	19.98 ± 0.42 ^f	222.28 ± 16.63 ^a
AVG $\text{mg} \cdot \text{kg}^{-1}$	2.83	83.17	1.34	22.43	3.63	161.46	28.06	28.06	28.06	89.14	28.06	89.14
C.V. (%)	162.91	44.04	239.30	81.95	118.18	37.39	68.63	68.63	68.63	59.15	68.63	59.15

Values followed by same letters are not significantly different at ($P < 0.01$). Means ± SE, $n = 3$.

TABLE 3: Accumulation coefficient and translocation coefficient of inbred lines.

Variety number	Cd-stressed		Pb-stressed		Pb-contrast	
	Accumulation coefficient	Translocation coefficient	Accumulation coefficient	Translocation coefficient	Accumulation coefficient	Translocation coefficient
1	0.28	0.05	0.00	0.00	0.00	0.00
2	2.05	0.71	0.15	0.54	0.77	6.54
3	0.83	0.53	0.02	0.13	0.09	∞
4	1.54	1.07	0.01	0.06	0.00	0.00
5	1.70	0.68	0.05	0.37	0.22	2.33
6	0.00	0.00	0.09	1.30	0.13	2.03
7	0.59	0.30	0.17	0.60	0.88	∞
8	0.85	0.21	0.13	1.15	0.00	0.00
9	0.40	0.12	0.13	0.48	0.61	9.96
10	0.89	0.47	0.17	0.58	0.34	∞
11	0.00	0.00	0.10	0.39	0.79	∞
12	0.75	1.04	0.10	0.71	0.52	2.84
13	1.14	0.67	0.14	0.56	0.52	∞
14	0.01	0.00	0.19	0.45	0.55	∞
15	1.30	0.80	0.11	0.54	0.89	∞
16	0.60	0.18	0.17	0.63	0.89	∞
17	1.09	0.31	0.10	0.58	0.64	∞
18	0.06	0.02	0.14	0.60	0.61	5.47
19	0.12	0.04	0.30	1.53	0.33	1.75
AVG	0.75	0.38	0.12	0.59	0.46	—

∞: Pb was nonreadout in roots; Cd-contrast was not listed for nonreadout of Cd in roots and aboveground parts of most inbred lines under contrast condition.

TABLE 4: Cd Concentrations in roots and aboveground parts of hybrid varieties ($\text{mg}\cdot\text{kg}^{-1}$).

Hybrid varieties	Treatment ($\text{mg}\cdot\text{kg}^{-1}$)	Concentration roots ($\text{mg}\cdot\text{kg}^{-1}$)	Concentration stems and leaves ($\text{mg}\cdot\text{kg}^{-1}$)
Chuandan no. 14		18.96 ± 0.66	0.17 ± 0.005
Chuandan no. 10	15	31.16 ± 4.81	8.19 ± 1.03
Yayu no. 2		8.79 ± 1.48	5.89 ± 0.56
Chuandan no. 14		35.24 ± 1.74	11.98 ± 0.66
Chuandan no. 10	30	139.36 ± 6.40	19.40 ± 0.76
Yayu no. 2		4.89 ± 1.65	15.10 ± 2.02
Chuandan no. 14		72.94 ± 5.26	9.95 ± 0.61
Chuandan no. 10	50	63.48 ± 6.35	24.82 ± 3.53
Yayu no. 2		97.80 ± 7.52	23.89 ± 3.80

Means \pm SE; $n = 3$.

parents for low-Cd breeding. Moreover, Chuandan no. 14 is undoubtedly suitable for planting in Cd-polluted soil as a low-Cd variety.

Plant rehabilitation technology is widely advocated all over the world. It is reported that hyper-accumulation plants have high accumulation coefficient and translocation coefficient, but limitation of the capacities of heavy metal absorption as their low biomass, slow growth, and weak eoadaptation. So such plants have not been applied on

a large scale for breeding. At present, attention has been focused on those plants with wider biological adaptability and higher aboveground biomass. As shown in Table 3, though Pb concentration was low in soil, maize inbred lines have also shown a strong Pb translocation ability and the Pb translocation coefficients. The Pb accumulation coefficients of 178, R08, 48-2, and Mo17ht on growth day 70 were 0.86, 0.79, 0.89, and 0.89, respectively, and the growing period of maize was generally 140 days, implying that the accumulation coefficients would be greater than 1 at maturity. Therefore, the 4 inbred lines obtained the two major features of hyper-accumulation plants [17]; making them suitable phytoremediation species for restoring soil slightly polluted by Pb. Under high Pb conditions, the absorption and translocation ability of maize plants decreased largely, probably due to the self-protection mechanism of maize inbred lines. The accumulation coefficients of 19 inbred lines were 0.00–0.30, and the translocation coefficients were also less than 1, with only several exceptions. Therefore, we concluded that maize was incompetent for restoring soil that was severely polluted with Pb. Similarly, Zheng 58 and 9782 might be useful phytoremediation species for restoring soils that were either slightly or severely polluted with Cd. Although the accumulation coefficient and translocation coefficient of maize were lower than those of some reported small hyper-accumulation plants, maize possesses other advantages, such as higher biomass in aboveground parts, better eoadaptation, short growing period, easy cultivation,

and accumulation of a minimum of two heavy metals (Pb and Cd), making maize a suitable phytoremediation plant for restoring Cd-polluted soil and also soil slightly polluted with Pb.

5. Conclusion

There are significant differences of Pb and Cd accumulation in interspecific hybrid of zea mays, so it is feasible to select maize germplasm of low-Pb and low-Cd accumulation in stems and leaves. And three low-Pb inbred lines are obtained under low-Pb conditions, such as S37, 9782, and ES40 in this research and may be used to cross-breed for low-Pb varieties in stems and leaves. On the contrary, those, with high-target metal concentrations, can play an important role in the treatment of polluted soils. However, future studies are required to identify the stability of heredity of the traits in maize germplasm, S37 can be assumed to be a satisfactory inbred line.

Acknowledgments

The authors thank Dr. W. G. Yan and the anonymous reviewers who provided constructive criticism and helped to improve the paper. This project was financially supported by grants from the Program of China's Ministry of Science and Technology (2012AA10A307) and the National Natural Science Foundation of China (31171567). Z. Zhang and F. Jin are contributed equally to this paper.

References

- [1] I. H. Ceribasi and U. Yetis, "Biosorption of Ni(II) and Pb(II) by *Phanerochaete chrysosporium* from a binary metal system—kinetics," *Water SA*, vol. 27, no. 1, pp. 15–20, 2001.
- [2] G. Guo and Q. Zhou, "Analysis on heavy metal pollution to black soil in the Northern part of NorthEast China," *Journal of the Graduate School of the Chinese Academy of Sciences*, vol. 21, no. 3, pp. 386–392, 2004.
- [3] J. Gu, Q. Zhou, and X. Wang, "Treatment method for heavy metal pollution to soil and its study progress," *Journal of Basic Science and Engineering*, vol. 11, no. 2, pp. 143–151, 2003.
- [4] T. Arao and N. Ae, "Genotypic variations in cadmium levels of rice grain," *Soil Science and Plant Nutrition*, vol. 49, no. 4, pp. 473–479, 2003.
- [5] J. Xu and L. Yang, "Advances in the study uptake and accumulation of heavy metal in rice (*Oryza sativa*) and its mechanisms," *Chinese Bulletin of Botany*, vol. 22, no. 5, pp. 614–622, 2005.
- [6] M. Wang, J. Zou, X. Duan, W. Jiang, and D. Liu, "Cadmium accumulation and its effects on metal uptake in maize (*Zea mays* L.)," *Bioresource Technology*, vol. 98, no. 1, pp. 82–88, 2007.
- [7] F. Zhu and Z. Yang, "Variations of Zn absorption and accumulation of 32 tomato varieties," *Acta Scientiarum Naturalium Universitatis Sunyatseni*, vol. 5, pp. 97–101, 2006.
- [8] J. Yang and T. Chen, "Dynamic of heavy metals in wheat grains collected from the Liangfeng Irrigated Area," *Environmental Sciences*, vol. 25, no. 12, pp. 1661–1666, 2005.
- [9] C. A. Lucho-Constantino, F. Prieto-Garcia, L. M. del Razo, R. Rodriguez-Vazquez, and H. M. Poggi-Valardo, "Chemical fractionation of boron and heavy metals in soils irrigated with wastewater in central Mexico," *Agriculture, Ecosystems and Environment*, vol. 108, no. 1, pp. 57–71, 2005.
- [10] H. Xiang and T. Li, "Strengthening agro-environment protection to ensure the safety and the quality of agro-products," *Guangxi Agricultural Sciences*, vol. 35, no. 3, pp. 238–241, 2004.
- [11] D. Zhang, F. Qin, and C. X. Li, "Research on heavy metal contents in vegetables at Guiyang vegetable bases," *Journal of Guizhou Normal University (Natural Science Edition)*, vol. 23, no. 2, pp. 78–80, 2005.
- [12] S. Singh and M. Kumar, "Heavy metal load of soil, water and vegetables in peri-urban Delhi," *Environmental Monitoring and Assessment*, vol. 120, no. 1–3, pp. 79–91, 2006.
- [13] N. Lin, J. He, and Y. Gan, "Impacts of Pb pollution in soils on rice and cabbage in Diaojiang basin," *Guangxi Agricultural Sciences*, vol. 39, no. 4, pp. 507–510, 2008.
- [14] G. Li, H. Su, and X. Sun, "Analyses and Assessment of Heavy Metal Pollution of Vegetables in Xi'an," *Acta Botanica Boreali-Occidentalia Sinica*, vol. 28, no. 9, pp. 1904–1909, 2008.
- [15] D. Peciulyte, J. Repeckiene, L. Levinskaite, and A. Lugauskas, "Growth and metal accumulation ability of plants in soil polluted with Cu, Zn and Pb," *Ekologga*, vol. 1, pp. 48–52, 2006.
- [16] Q. L. Dai, J. G. Yuan, W. Fang, and Z. Y. Yang, "Differences on Pb accumulation among plant tissues of 25 varieties of maize (*Zea mays*)," *Frontiers of Biology in China*, vol. 2, no. 3, pp. 303–308, 2007.
- [17] R. L. Chaney, M. Malik, Y. M. Li et al., "Phytoremediation of soil metals," *Current Opinion in Biotechnology*, vol. 8, no. 3, pp. 279–284, 1997.



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