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Genetic Variability of Barley (*Hordeum vulgare* L.) Genotypes in Phytoremediation of Heavy Metals-Contaminated Soil

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SOIL contaminated with heavy metals negatively affects both the groundwater quality and the food production system. Heavy metals can be remediated from contaminated soil by phytoextraction. This study aims to illustrate the possible use of barley genotypes as a cheap, effective, safe and sustainable way to remediate contaminated soil. A set of 17 genotypes, including Egyptian and German varieties and wild accessions were sown under heavy metals contaminated and uncontaminated soil in a potted experiment for two years (2015/2016 and 2016/2017). Heavy metals concentrations including Al, Cr, Cu, Fe, Ni and Zn were measured in grains and leaves, separately, for each genotype under contaminated and uncontaminated soils. Results showed that genotypes differed in their capability to accumulate different heavy metals in either grains or leaves. In addition, there were significant positive correlations between Al, Cr, Cu and Zn concentrations in grains under uncontaminated and contaminated soils. In conclusion, mixture of barley's genotypes including Heines-Hanns, ICB 180410, Giza-126, Giza-129, Giza-130, Giza-2000, Pasadena and Barke might be used to remediate contaminated soil.

Keywords: Phytoextraction, Barley, Wastewater, Heavy metals, Variability.

Introduction

Both soils and water may be contaminated with heavy metals because of intensive anthropogenic activities including sewage sludge, wastewater irrigation, industrial effluents, households' activities and agricultural practices (Khan et al., 2008 and Zhang et al., 2010). Heavy metals are defined as inorganic chemical elements. The most common heavy metals found in contaminated soils and water in the investigated site in the current study including chromium (Cr), zinc (Zn), copper (Cu), nickel (Ni), aluminum (Al) and iron (Fe).

Heavy metals contamination by the aforementioned anthropogenic activities cause hazards to humans, farm animals, wild life (*e.g.* immigrant birds) and the ecosystem; in addition, this may lead to dangerous diseases to humans via food chain (cancers, kidney's failure, liver diseases, Alzheimer's disease etc.) (McLaughlin, et al., 2000 and Ling et al., 2007). Therefore, contamination with heavy metals can cause massive economic losses for both agricultural activities and anthropogenic resources (affected by chronic and acute diseases).

Heavy metals-contaminated soils can be remediated using one of the most frequent technologies, such as phytoremediation (Cunningham & Ow, 1996 and Chaney et al., 1997). For example, plant roots uptake heavy metals from the soil and accumulate them to leaves, stems, spikes and grains tissues (*i.e.,* phytoextraction or phytoaccumulation). Plants used in phytoremediation should have the following characteristics: (1) Heavy-metals tolerant, (2) High metal-accumulating ability in the vegetative parts and (3) Possess abundant root systems (Scragg, 2006 and Jadia & Fulekar, 2008). Both diminishing the sources of contamination and improving the remediation of the affected soils are needed to reduce heavy metals contamination (Zhou et al., 2004).

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Phytoremediation methods, including phytostabilization, phytovolatilization and phytoextraction use plants to reduce contaminants in soils by adsorbing, accumulating, transferring, and storing them in the aboveground plant parts preventing them from contaminating both ground water and food chain (Watanabe, 1997; Bizily et al., 1999; Zhenguo & Manhuai 2000 and Wang et al., 2009).

Hyperaccumulators are plants that possess the ability to accumulate heavy metals 100 times more than typically measured in shoots of the common non-accumulator plants (Wuana & Okieimen, 2011). In a potted experiment, among 12 species, five species including sunflower, oat, rye grass, tall fescue and green gram showed high tolerance to heavy metals (*e.g.,* Pb, Cd and Cr) which revealed their potential in phytoremediation (Chirakkara & Reddy, 2015). Both wheat and barley cultivars have been screened for their potential in phytoremediation; however, barley cultivars showed more tolerance to both Cd and Cr than wheat (González et al., 2017). Barley was used in phytoremediation of organic compounds (Nolt et al., 1987). In addition, it was significantly efficient in remedial of oil-contaminated soils (Xu & Johnson, 1995). Barley possesses a higher phytoextraction capability for zinc than Indian mustard (*Brassica juncea*) (Ebbs & Kochian, 1998). Among 12 species used in a study by Wierzbicka (1999), barley was the highest tolerant to lead (Pb). Therefore, it could be an auspicious plant for photomediation. Genetically, a single gene may be responsible for aluminum tolerance in barley (Guoping, 2002). Both triticale and barley accumulated heavy metals less than toxicity levels for animals in grains comparing to *Brassica* spp. under contaminated soils; therefore, both crops are considered potential crops for livestock feed as well as photoextraction (Soriano & Fereres, 2003). Wieczorek et al. (2005) found higher accumulations of lead and cadmium in cereal grains including both wheat and barley, which reveals the potential of these two crops as phytoextraction crops. Wild wheat possesses potential genetic variation of zinc accumulation in grains (Cakmak, 2008); however, controlling zinc concentrations in grains below the toxicity level can be accomplished by reducing their remobilization from leaves and accumulation in grains via plant breeding approaches (Zhao & McGrath, 2009). Barley is known for its tolerance not only to drought, salinity and heat but also to heavy metals including Cr, Zn, Cu, Cd and Pb (Brunetti et al., 2012).

Furthermore, barley successfully used to remediate contaminated soil with heavy metals including Zn and Pb in botth pot and field experiments (Friesl et al., 2006).

Barley is tolerant to diverse abiotic stresses and possesses reasonable root system; thus, it needs to be considered as highly efficient plants in phytoremediation. Wild species may be a candidate of being hyperaccumulator; nevertheless, both the bio-concentration (Brooks, 1998 and Cluis, 2004) and translocation factors (Wei & Zhou, 2004a, b) need to be taken into consideration (Sun et al., 2008).

The objectives of the current study were to: (1) Study the transfer of certain heavy metals to different parts of barley plants, (2) Differentiate between cultivated and wild barley in accumulation of heavy metals, and (3) Grab attention of using barley to remediate contaminated soil.

Materials and Methods

Plant material and growing conditions

A set of 17 genotypes including Egyptian and German cultivars and wild barley accessions were used in the current study (Table 1). The German cultivars and wild barley accessions were obtained from Prof. Leon (Bonn University, Germany); whereas, the Egyptian cultivars were obtained from Barley Department, Agriculture Research Center (ARC), Egypt. The 17 aforementioned genotypes were grown in pots for two years (2015/2016 and 2016/2017) in two different types of soils (contaminated and uncontaminated with [referred as "control" hereafter] wastewater). The sources of contaminated soil is Arab El Madabegh Village (27'16° N, 31'15° W), Assiut, Egypt. This soil was irrigated regularly from a local canal that is contaminated with sewage sludge, industrial effluents, households' activities and agricultural practices. On the other hand, the uncontaminated soil was brought from the Assiut University Agricultural Research Station, Assiut, Egypt.

The contaminated soil was irrigated with wastewater, whereas, the uncontaminated soil was irrigated with tap water. The source of this wastewater is the aforementioned canal. Pots were filled with 4.0 kg soil; and ten seeds from each genotype were sown in a single pot. The characteristics of soil and water used in the current study are presented in Table 2.

TABLE 1. Genotypes used in the current study along with their geographical origin.

No.	Cultivar/Accession no.	Species	Subspecies	Geographical origin
1	Giza 123	*Hordeum vulgare*	*vulgare*	Egypt
2	Giza 126	*Hordeum vulgare*	*vulgare*	Egypt
3	Giza 127	*Hordeum vulgare*	*vulgare*	Egypt
4	Giza 128	*Hordeum vulgare*	*vulgare*	Egypt
5	Giza 129	*Hordeum vulgare*	*vulgare*	Egypt
6	Giza 130	*Hordeum vulgare*	*vulgare*	Egypt
7	Giza 131	*Hordeum vulgare*	*vulgare*	Egypt
8	Giza 2000	*Hordeum vulgare*	*vulgare*	Egypt
9	Barke	*Hordeum vulgare*	*vulgare*	Germany
10	Heines Hanna	*Hordeum vulgare*	*vulgare*	Germany
11	Pasadena	*Hordeum vulgare*	*vulgare*	Germany
12	Quench	*Hordeum vulgare*	*vulgare*	Germany
13	Scarlett	*Hordeum vulgare*	*vulgare*	Germany
14	Thuringia	*Hordeum vulgare*	*vulgare*	Germany
15	ICB 180199	*Hordeum vulgare*	*Spontaneous*	Iran
16	ICB 180410	*Hordeum vulgare*	*Spontaneous*	Syria
17	ISR 42-8	*Hordeum vulgare*	*Spontaneous*	Palestine

TABLE 2. Heavy metals concentrations (mg/L) in soil and water used in the current study.

Element	Contaminated		Uncontaminated	
	Soil	Water	Soil	Water
Al	6388	600	5468	211
Cr	1508	300	1068	150
Cu	453600	80	125980	40
Fe	365200	1198	6388	49
Ni	6388	50	5108	25
Zn	321800	510	171800	64

Statistical analysis

The experiment was conducted using a randomized complete block design with two replications. Both separate and combined analyses were performed with GLM procedure in SAS v9.0 (The SAS Institute Inc., Cary, NC, USA). Variances were homogeneous according to Bartlett's test (P = 0.05). Furthermore, Pearson correlation coefficients were calculated using CORR Procedure in SAS (2003) v9.0.

Soil and water analyses

Heavy metal elements including Al, Cr, Cu, Fe, Ni and Zn were extracted by 1M NH_4HCO_3 in 0.005 M DTPA adjusted to a pH of 7.6 as per Soltanpour (1991).

Plant analysis

Plant analysis were performed as per Soltanpour (1991). At maturity, grains were separated from the straw and then both parts were dried at 60°C for 24 h. Then both grains and straw were ground and a set of six heavy metal elements were measured using constant weight of samples and digesting them in nitric acid and hydrogen peroxide in Microwave Digestion Labstation closed system, Ethos Pro, Milestone, Italy. Then, distilled water was added to raise the digested sample to a known volume. The concentration of elements in the sample was determined by Inductively Coupled Argon Plasma, ICAP 6500 Duo, Thermo Scientific, England. In addition, 1000 mg/L multi-element certified standard solution, Merck, Germany was used as stock solution for instrument standardization.

Results

In grains, the averages accumulation of heavy metals (mg/L) under uncontaminated condition (Table 3) were 215.13, 8.61, 23.48, 946.03, 5.30 and 25.11 for Al, Cr, Cu, Fe, Ni and Zn, respectively. On the other hand, the average accumulation of the same heavy metals under contaminated soil condition (Table 3) were 300.21, 11.60, 72.12, 2710.81, 11.50 and 43.77 for Al, Cr, Cu, Fe, Ni and Zn, respectively. Under contaminated condition, Heines-Hanna accumulated the highest concentration of Al in grains (490.03 mg/L). On the other hand, Barke accumulated the lowest concentration of both Al (181.69 mg/L) and Cr (0.09 mg/L). For Cr and Cu, ICB 180410 and Giza-129 accumulated the highest concentrations with values of 15.21 and 185.53 mg/L, respectively. Two Egyptian cultivated varieties (Giza-2000 and Giza-126) along with a German cultivated variety (Pasadena) accumulated the highest concentrations of Fe, Ni and Zn with values of 5363.31, 18.11 and 66.78, respectively.

The abovementioned results revealed that both cultivated and wild genotypes possess the potential to accumulate heavy metals in grains; however, we found that certain genotypes might be used to remediate specific elements of the heavy metals.

For accumulations of heavy metals in leaves (Table 4), the averages of concentrations (mg/L) under uncontaminated condition were 291.44, 5.24, 12.22, 605.96, 4.75 and 14.43 for Al, Cr, Cu, Fe, Ni and Zn, respectively. Furthermore, under contaminated soil, the concentrations (mg/L) were 457.24, 16.55, 62.44, 1818.29, 6.38 and 24.64 for Al, Cr, Cu, Fe, Ni and Zn, respectively. Our results exhibited that both German and Egyptian cultivated varieties accumulated the highest concentrations of Al (Barke; 1216.25 mg/L), Cr (Giza-2000; 42.26 mg/L), Cu (Giza-130; 254.50 mg/L), Fe (Pasadena; 4615.00 mg/L), Ni (Giza-2000; 8.11 mg/L) and Zn (Heines-Hanna; 43.281mg/L). For more descriptive statistics, follow; Supplemental Table S1 and S2.

Nevertheless, the wild genotypes were not good accumulators of heavy metals in leaves. This implies that more wild genotypes need to be included in the future screening studies.

Our results showed that the Egyptian cultivated variety, Giza-129 accumulated the highest concentrations of Cr and Cu in both leaves and grains, respectively, under contaminated soil. Moreover, The German variety, Pasadena accumulated the highest concentrations of Zn in grains, in addition to Fe, and Ni in leaves.

There were significant correlations between Cr and Ni, Cu and Ni, and Ni and Zn in leaves under uncontaminated (Table 5). In addition, we found very highly significant positive correlation coefficients between Al and Cr and Cu and Zn accumulations in grains under both uncontaminated and contaminated soil (Table 6).

Analysis of variance (Table 7) revealed that genotypes showed highly significant different for all heavy metals in leaves and grains. In addition, genotypes were not significant in the analysis of variance for the second year for Zn. On the other hand, Genotypes exhibited highly significant differences for all heavy metals in either leaves or grains based on the combined analysis of variance over the two years (Table 8).

Discussion

Based on the results, it can be concluded that our genotypes used in the study differ in their capability to remediate heavy metals from soils; however, none of them was solicited as a good accumulator for all heavy metals in the current study. However, for all heavy metal elements, and based on the highest accumulation of contaminants in different parts of plant, we suggest using a mixture of Heines-Hanns, ICB 180410, Giza-126, Giza-129, Giza-130, Giza-2000, Pasadena and Barke as they accumulated the highest concentrations of the six heavy metals in grains and leaves.

Our results showed significant correlation among some heavy metal elements under contaminated soil. These findings were consistent with results of Stanišić Stojić et al. (2016) who reported significant positive correlations among some heavy metal elements in barley and wheat.

TABLE 3. Means (M) and standard deviation (SD) for heavy metals concentrations (mg/L) in grains calculated over two years under uncontaminated soil (U) and contaminated soil (C).

Genotype	Al		Cr		Cu		Fe		Ni		Zn	
	U	C	U	C	U	C	U	C	U	C	U	C
						M SD						
Giza 123	1.3 207.1	1.3 243.1	8.8 0.2	0.5 10.7	0.9 12.7	148.3 14.8	1688.3 16.7	4505.0 12.8	5.3 0.0	0.1 11.74	22.4 0.1	44.7 0.0
Giza 126	8.7 314.5	471.3 11.2	9.5 0.6	0.1 11.4	13.4 0.6	1.4 19.0	469.3 3.2	744.3 8.6	4.9 0.1	0.3 18.1	14.9 0.0	24.2 0.0
Giza 127	3.5 147.3	5.9 393.3	5.8 0.1	11.8 0.6	10.8 0.2	20.3 0.1	739.9 7.8	2659.3 14.1	5.5 0.1	1.7 14.1	21.5 0.1	36.1 0.1
Giza 128	4.9 173.3	4.9 274.4	9.4 0.5	0.2 11.6	27.3 1.4	73.6 4.5	1755.6 27.2	2217.5 14.8	6.2 0.2	0.0 10.5	26.5 0.0	40.0 0.1
Giza 129	7.3 207.5	219.9 20.7	7.2 0.1	10.7 0.1	28.3 1.9	2.3 185.5	509.6 0.4	657.1 0.9	5.7 0.1	8.6 0.6	24.6 0.2	64.4 1.3
Giza 130	397.8 15.7	416.2 23.2	10.6 0.4	0.4 12.5	13.4 0.3	16.2 0.2	828.3 3.6	980.0 10.9	5.1 0.2	0.1 10.6	27.6 0.6	46.71 0.90
Giza 131	2.6 189.2	1.4 228.1	5.7 0.1	9.8 0.1	25.5 1.4	45.1 0.5	557.8 3.4	1878.8 3.9	5.6 0.3	10.0 0.0	32.8 0.3	49.9 0.1
Giza 2000	169.8 1.93	3.5 205.5	9.2 0.5	10.6 0.4	12.0 0.2	15.0 0.4	2692.3 24.6	5363.3 36.8	5.8 0.0	8.9 0.2	21.4 0.2	39.9 0.9
Barke	9.4 146.6	181.7 11.3	5.3 0.1	9.1 0.5	41.3 0.0	74.6 1.5	1205.9 20.2	8.6 3010.0	5.5 0.4	8.3 0.1	23.8 1.1	33.3 0.1
Heines-Hanns	234.9 3. 5	5.8 490.0	13.2 0.1	13.9 0.5	12.1 0.2	13.7 0.4	574.2 1.6	2.7 2537.1	5.9 0.1	11.3 0.1	30.6 0.1	51.7 0.1
Pasadena	1.5 210.2	4.0 253.4	8.2 0.6	10.6 0.1	80.7 3.8	1.9 186.0	732.1 16.3	4617.5 107.4	5.4 0.3	0.1 15.7	44.1 0.1	66. 8 1.8
Quench	7.7 181.3	2.1 197.4	9.7 0.3	11.2 0.5	12.7 0.4	62.3 1.2	656.1 3.9	3749.5 40.8	4.0 0.1	0.1 12.8	23.7 0.1	43.7 0.1
Scarlett	4.5 213.7	4.2 228.5	5.6 0.2	12.2 1.0	10.5 0.3	20.0 0.6	662.8 4.9	1613.5 16.3	5.0 0.1	10.9 0.2	19.4 0.3	65.7 0.1
Thuringia	209.8 3.1	2.0 238.0	9.7 0.2	12.4 0.4	11.2 0.2	45.5 0. 5	807.0 16.5	5.6 3556.9	5.9 0.0	11.8 0.7	22.3 0.0	29.7 0.03
ICB 180199	206.7 1.2	245.5 3.3	8.4 0.4	12.2 1.50	7.8 0.3	109.7 3.4	780.5 5.4	3206.8 49.8	4.7 0.1	9.1 0.1	9.9 0.3	33.5 0.3
ICB 180410	257.3 1.6	367.6 15.1	10.6 0.1	15.2 1.2	66.0 2.0	173.2 8.8	779.3 3.3	1147.6 17.8	4.3 0.1	12.1 0.2	33.5 0.1	42.2 0.1
ISR 42-8	190.4 13.1	449.7 8.5	9.6 0.1	10.6 0.2	13.6 0.2	18.0 0.2	643.6 9.2	3639.5 18.9	5.2 0.1	10.8 0.2	28.1 0.0	31.6 0.0
General mean	215.13	300.12	8.61	11.60	23.48	72.12	946.03	2710.81	5.30	11.50	25.11	43.77
Tukey$_{0.05}$	12.71	13.94	0.83	0.65	2.83	3.97	23.95	82.98	0.16	0.19	0.91	1.29

TABLE 4. Means (M) and standard deviation (SD) for heavy metals concentrations (mg/L) in leaves calculated over two years under uncontaminated soil (U) and contaminated soil (C).

Genotype	Al		Cr		Cu		Fe		Ni		Zn	
	U	C	U	C	U	C	U	C	U	C	U	C
							M SD					
Giza 123	177.1	620.5	8.8	20.1	11.0	72.3	746.2	1136.1	4.5	6.4	11.3	16.5
	1.1	5.2	0.7	0.9	0.7	2.3	3.9	3.5	1.2	0.2	0.1	0.2
Giza 126	184.7	333.2	1.2	12.3	7.2	8.3	796.8	1314.2	4.3	6.8	8.0	8.4
	0.9	4.2	0.4	0.7	0.3	0.2	5.2	1.1	0.2	0.4	0.5	0.4
Giza 127	286.4	346.4	2.7	15.7	11.2	176.8	440.6	1162.1	4.4	7.5	11.3	24.7
	2.5	3.4	0.1	1.3	0.2	0.2	2.9	15.8	0.2	0.4	9.7	3.6
Giza 128	203.3	314.1	6.1	9.0	13.4	30.4	325.5	317.0	4.3	5.7	7.9	13.8
	0.6	5.2	0.2	0.0	0.2	0.6	3.3	56.1	0.2	0.2	0.6	0.4
Giza 129	311.5	502.6	10.6	16.6	10.4	158.9	401. 6	659.7	4.5	6.1	13.2	15.5
	2.9	4.0	0.1	0.2	0.1	2.8	9.0	2.2	0.1	0.3	0.6	0.7
Giza 130	335.0	380.2	8.8	11.6	9.8	254.5	492.3	1765.4	5.6	7.4	23.3	39.9
	4. 9	5.6	0.2	0.2	0.3	0.9	15.4	14.2	0.2	0.2	1.1	23.3
Giza 131	231.9	399.3	0.4	11.3	5.9	11.5	377.9	1355.4	4.3	4.5	15.0	16.9
	2.4	4.2	0.1	0.2	0.2	0.1	6.4	2.6	0.1	0.1	0.9	0.4
Giza 2000	353.9	391.8	6.8	42.3	8.0	9.6	765.6	2910.6	6.1	8.1	14.2	18.7
	9.1	3.7	0.2	0.6	0.1	0.5	3.0	12.3	0.4	0.1	0.6	0.4
Barke	221.3	1216.3	3.0	6.2	12.1	17.9	326.4	2214.7	4.5	4.7	14.2	19.9
	1.7	13.9	0.1	0.2	0.2	0.5	7.6	10.6	0.2	0.1	0.5	2.0
Heines-Hanns	435.3	473.4	4.9	7.9	8.9	10.9	652.6	1666.9	3.9	7.9	15.0	43.3
	4.1	5.1	0.2	0.3	0.3	0.6	10.0	9.8	0.2	0.6	1.1	1.0
Pasadena	286.9	497.5	4.1	8.2	17.2	39.2	1590.1	4615.0	6.4	8.0	21.7	34.7
	13.7	3.0	0.1	0.4	1.2	1.2	19.3	29.7	0.8	0.6	1.1	0.9
Quench	293.3	473.2	5.4	9.2	11.0	16.0	681.8	1421.3	4.2	4.7	10.1	27.4
	6.4	5.4	0.4	0.9	1.0	0.5	13.0	14.4	0.3	0.3	0.8	1.9
Scarlett	236.0	268.0	4.7	9.1	5.6	8.5	547.3	1012.8	4.2	5.8	8.8	20.7
	1.8	5.7	0.1	0.11	0.4	0.6	1.3	2.0	0.1	0.5	0.3	2.9
Thuringia	379.8	430.4	5.7	13.2	16.4	25.4	575.6	3891.4	4.7	5.8	12.8	30.1
	2.6	4.5	0.5	0.3	0.6	0.2	7.2	43.7	0.3	0.6	0.5	0.2
ICB 180199	426.3	491.8	7.8	13.2	30.5	161.1	646.6	1029.6	5.3	7.5	20.8	28.8
	6.6	5.6	0.3	0.2	0.5	1.95	5.7	6.8	0.3	0.4	0.3	3.4
ICB 180410	385.6	482.2	4.4	13.9	20.7	42.5	610.8	1206.0	4.9	5.6	24.3	37.2
	10.9	5.2	0.2	0.2	0.3	0.2	15.6	1.2	0.1	0.4	0.5	1.7
ISR 42-8	206.4	221.7	3.7	6.1	8.5	17.5	323.8	384.9	4.6	6.1	13.5	22.5
	3.0	1.5	0.1	0.1	0.3	0.2	5.0	25.5	0.2	0.4	1.5	1.3
General mean	291.44	457.24	5.24	16.55	12.22	62.44	605.96	1818.29	4.75	6.38	14.43	24.64
Tukey$_{0.05}$	15.86	91.66	0.78	53.54	1.27	2.88	23.21	54.94	1.03	0.75	1.68	17.06

TABLE 5. Pearson correlation coefficients among heavy metals accumulated in grains (upper values) and leaves (lower values) under uncontaminated soil.

	Al	**Cr**	**Cu**	**Fe**	**Ni**	**Zn**
Al	-	0.47*** 0.32**	-0.04 0.52***	-0.30* 0.14	-0.25* 0.23*	0.03 0.54***
Cr		-	-0.07 0.26*	0.05 -0.01	-0.05 0.26*	0.15 0.17
Cu			-	-0.08 0.23	-0.08 0.33**	0.74*** 0.51***
Fe				-	0.36** 0.55***	-0.12 0.28*
Ni					-	0.14 0.51***

*, **, ***Significant at the 0.05, 0.01 and 0.001 probability level, respectively.

TABLE 6. Pearson correlation coefficients among heavy metals accumulated in grains (upper values) and leaves (lower values) under contaminated soil.

	Al	**Cr**	**Cu**	**Fe**	**Ni**	**Zn**
Al	-	0.47*** -0.11	-0.37** -0.06	-0.37** 0.13	0.45** -0.26*	-0.27* 0.01
Cr		-	0.02 0.05	-0.32** 0.10	0.16 0.39**	0.00 -0.20
Cu			-	0.03 -0.24*	-0.02 0.35**	0.40** 0.22
Fe				-	-0.06 0.21	-0.11 0.17
Ni					-	-0.12 0.29*

*, **, ***Significant at the 0.05, 0.01 and 0.001 probability level, respectively.

***TABLE 7. Mean squares for separate analysis under uncontaminated soil (U) and contaminated soil (C).**

Element	Y1						Y2					
			MS						MS			
	Source	**DF**	**Leaves**		**Grains**		**Source**	**DF**	**Leaves**		**Grains**	
			U	**C**	**U**	**C**			**U**	**C**	**U**	**C**
Al	Rep	1	43.0	48.1	3.9	217.3*	Rep	1	119.1	133.3	12.6	173.3*
	Gen	16	14175.4***	95436.7***	7207.3***	21990.9***	Gen	16	14046.3***	95124.2***	8150.9***	22558.1***
	Error	16	34.0	25.0	13.5	27.9	Error	16	37.6	45.1	32.5	27.4
Cr	Rep	1	0.1	0.56	0.3	0.9**	Rep	1	0.5*	0.8	0.1	0.4*
	Gen	16	14.9***	135.0***	9.0***	0.9***	Gen	16	15.0***	145.3***	9.1***	5.8**
	Error	16	0.1	0.17	0.1	0.1	Error	16	0.1	0.1	0.1	0.1
Cu	Rep	1	1.7*	1.7	8.4**	1.1	Rep	1	0.1	7.4*	0.6	8.1
	Gen	16	77.8***	11575.8***	829.0***	7727.9***	Gen	16	76.5***	11546.1***	912.8***	8760.7***
	Error	16	0.4	1.3	0.8	0.8	Error	16	0.1	1.1	1.5	3.7
Fe	Rep	1	8.3	1109.8	1562.7**	6884.2	Rep	1	106.8	309.0	789.85**	876.5
	Gen	16	179689.8***	2702592.6***	672084.5***	4109270.6***	Gen	16	179024.0***	2766107.6***	693707.26***	4036697.5***
	Error	16	77.2	628.5	97.0	1762.2	Error	16	76.3	231.4	66.40	199.2
Ni	Rep	1	0.5	0.4	0.0**	0.0	Rep	1	0.5*	0.2	0.0	0.0
	Gen	16	0.9**	2.5***	0.7***	11.6***	Gen	16	1.3***	3.2***	0.7***	15.8***
	Error	16	0.2	0.1	0.0	0.0	Error	16	0.1	0.1	0.0	0.0
Zn	Rep	1	0.0	0.2	0.2	0.5*	Rep	1	1.5	59.5	0.2	1.2
	Gen	16	52.6***	232.9***	119.0***	311.5***	Gen	16	72.6***	181.8	118.7***	334.3***
	Error	16	0.2	0.4	0.1	0.2	Error	16	0.6	82.6	0.1	0.3

*, **, ***Significant at the 0.05, 0.01 and 0.001 probability level, respectively.

TABLE 8. Mean squares for combined analysis

	Source□	DF	MS			Source	DF	MS	
			Leaves	Grains				Leaves	Grains
Al	Y	1	0.1	1846.9*	**Cr**	Y	1	1.4	3.3*
	T	1	981210.7***	246128.4***		T	1	2202.9***	294.7***
	Y×T	1	1.7	124.7		Y×T	1	1.1	2.7
	Y×T (R)	4	83.1	101.8**		Y×T (R)	4	0.5*	0.4**
	G	16	106544.9***	43796.1***		G	16	185.2***	21.0***
	Y×G	16	31.9	178.4***		Y×G	16	0.2*	0.3***
	T×G	16	112218.4***	15897.6***		T×G	16	124.6***	5.7***
	Y×T×G	16	10.8	35.1		Y×T×G	16	0.2*	0.5***
	E	64	35.2	25.3		E	64	0.1	0.1
	Source	**DF**	**MS**			**Source**	**DF**	**MS**	
			Leaves	**Grains**				**Leaves**	**Grains**
Cu	Y	1	1.5	172.2**	Fe	Y	1	2729.3	923.3
	T	1	85734.1***	80426.2***		T	1	49971066.6***	105890470.7***
	Y×T	1	0.4	53.6*		Y×T	1	39.5	65.0
	Y×T (R)	4	2.7**	4.5*		Y×T (R)	4	383.5	2528.3**
	G	16	12173.6***	12759.7***		G	16	3668478.3***	6620190.2***
	Y×G	16	0.6	26.7***		Y×G	16	243.8	629.9
	T×G	16	11101.4***	5422.8***		T×G	16	2158474.9***	2890283.3***
	Y×T×G	16	0.6	21.2***		Y×T×G	16	217.2	656.4
	E	64	0.7	1.7		E	64	253.3	531.2
	Source	**DF**	**MS**			**Source**	**DF**	**MS**	
			Leaves	**Grains**				**Leaves**	**Grains**
Ni	Y	1	1.9	1.6***	Zn	Y	1	3.7	1.1
	T	1	90.8***	1307.1***		T	1	3547.3***	11835.7***
	Y×T	1	0.3	0.0		Y×T	1	4.9	0.2
	Y×T (R)	4	0.4*	0.01*		Y×T (R)	4	15.3	0.5*
	G	16	5.7***	12.29***		G	16	394.8***	639.1***
	Y×G	16	0.1	0.4***		Y×G	16	25.3	0.3
	T×G	16	1.9***	15.7***		T×G	16	103.4***	243.6***
	Y×T×G	16	0.1	0.4***		Y×T×G	16	16.5	0.4*
	E	64	0.1	0.0		E	64	20.9	0.2

*,**,***Significant at the 0.05, 0.01 and 0.001 probability level, respectively. □ Y= years; T= treatment; R= replication; G=genotypes; E=error.

Phytoremediation, also known as green remediation, is an effective technique for toxicity reduction of heavy metals in contaminated soils (Wuana & Okieimen, 2011). Ebbs & Kochian (1998) indicated that among grass plants both oats and barley can be exploited in photoextraction due to their greater leverage as tolerant and accumulator of zinc and copper in shoots. Photoextraction may be advantageous for gradually decreasing the heavy metals from contaminated soils; furthermore, crops used in phytoextraction form a soil cover avoiding contaminated soil from spreading out via wind and water erosion (Soriano & Fereres, 2003 and Bilski et al., 2012). It is feasible to use species that are tolerant to adverse conditions in phytoremediation to cover contaminated soils under unfavorable environments (Brunetti et al., 2009). Contaminated soils with heavy metals could be used for breeding for biofortification (*i.e.,* increasing micronutrients in grains such as Zn, Cu, Se, etc.) in grain cereals; however, it is paramount to control accumulation of these micronutrients lower than toxicity levels by inhibiting their excess translocation to grains (Zhao & McGrath, 2009). Barley is a promising candidate as phytoremedial crop because of the strong correlation between its shoots growth and reducing heavy metals in soil (Varun et al., 2011). It can be exploited in phytoremediation of Cr, Cu and Fe; in addition, it has the ability to hyper-accumulate heavy metals in roots (Masu et al., 2012).

We suggest using barley as hyperaccumulator; however, using any plant as hyperaccumulator of heavy metals needs to be precedent by evaluating the total content of heavy metals and both bio-accumulation and translocation factors (Sun et al., 2008). Therefore, further investigations and analyses are needed to support our study in the future.

Some studies were consistent with our results indicating that barley might be a promising phytoremediation crop (Varun et al., 2011; Masu et al., 2012 and González et al., 2017); furthermore, certain genotypes of barley might be used in phytoextraction (Masu et al., 2012); however, adaptability and stability issues need to be considered in this case. On the other hand, other studies suggested that other plant species might be more appropriate for phytoremediation, *e.g.* sorghum and *Solanum nigrum* and other wild plant species (Sun et al., 2008; Brunetti et al., 2009 and Angelova et al., 2011).

Our results revealed that different genotypes are good accumulators of heavy metals but none of them can be considered as a good accumulator for all of heavy metals in the current study. This was consistent with the findings of Masu et al. (2012). Moreover, our genotypes differ in their ability to accumulate heavy metals in different parts of the plant. In this context, we propose to use a mixture of different genotypes of barley to remediate heavy metals from soil. The harvested plants will be contaminated with high levels of heavy metals; therefore, we suggest using them as biofuel rather than as food or feed. Moreover, they can be used as fuel for baking and cooking for the local farmers in rural areas where sites are contaminated with heavy metals. In addition, straw may be exploited in manufacturing papers and low quality wood.

Conclusion

Unsolicited genotypes as accumulators of all heavy metals in one genotype or in one part of the plants implies the idea of using mixture of these genotypes as phytoremediation rather than using a sole genotype or variety. Local farmers in rural areas might use the harvested plants with high levels of heavy metals as fuel and biofuel In conclusion, green remediation might help along with other remedial approaches to reduce toxicity in sites prone to contamination with heavy metals. However, the green remediation approaches in conjunction with the exploiting harvest plants from contaminated soils can be one of the best methods for sustainable agriculture.

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TABLE S1. Descriptive statistics for heavy metals concentrations (mg/L) in grains calculated over two years for uncontaminated soil (U) and contaminated soil (C).

Genotype	Al (U)					Al (C)				
	Mean	SE	Min	Max	CV	Mean	SE	Min	Max	CV
Giza 123	207.113	0.649	205.250	208.000	0.627	243.144	0.656	241.175	243.825	0.540
Giza 126	314.450	4.326	305.500	323.300	2.751	471.313	5.577	455.000	480.250	2.366
Giza 127	147.344	1.734	142.250	150.000	2.353	393.250	2.947	385.000	397.500	1.499
Giza 128	173.300	2.452	169.725	180.250	2.830	274.375	2.459	269.500	280.750	1.792
Giza 129	207.469	3.659	201.375	216.250	3.527	219.938	10.366	202.425	244.325	9.427
Giza 130	397.750	7.844	382.500	412.500	3.944	416.188	11.608	394.750	437.500	5.578
Giza 131	189.163	1.320	186.650	192.500	1.396	228.125	0.696	226.750	230.000	0.610
Giza 2000	169.844	0.967	168.125	172.500	1.139	205.519	1.732	202.075	208.500	1.685
Barke	146.550	4.710	138.825	158.025	6.428	181.688	5.640	170.000	191.350	6.208
Heines-Hanns	234.863	1.727	230.800	239.025	1.471	490.031	2.894	482.500	495.000	1.181
Pasadena	210.163	0.771	208.075	211.400	0.733	253.388	1.998	249.875	258.100	1.577
Quench	181.338	3.842	176.375	192.800	4.238	197.444	1.047	195.350	199.800	1.061
Scarlett	213.700	2.230	209.800	218.625	2.087	228.506	2.098	224.650	233.575	1.836
Thuringia	209.775	1.532	206.650	213.575	1.460	237.981	1.020	235.800	240.525	0.858
ICB 180199	206.731	0.610	205.625	208.000	0.590	245.525	1.651	241.600	248.500	1.345
ICB 180410	257.269	0.787	255.000	258.575	0.612	367.563	7.557	352.250	385.000	4.112
ISR 42-8	190.400	6.551	178.225	203.075	6.882	449.650	4.258	437.500	455.850	1.894
Tukey$_{0.05}$	12.712					13.936				
			Cr (U)					Cr (C)		
Giza 123	8.838	0.093	8.625	9.075	2.098	10.650	0.252	10.150	11.350	4.730
Giza 126	9.456	0.279	8.625	9.825	5.909	11.403	0.066	11.325	11.600	1.158
Giza 127	5.750	0.044	5.675	5.850	1.547	11.788	0.315	11.125	12.350	5.339
Giza 128	9.400	0.230	8.900	9.850	4.890	11.588	0.082	11.425	11.800	1.415
Giza 129	7.200	0.042	7.075	7.250	1.169	10.669	0.062	10.550	10.800	1.170
Giza 130	10.563	0.198	10.000	10.875	3.750	12.525	0.175	12.250	13.025	2.790
Giza 131	5.700	0.049	5.575	5.800	1.717	9.844	0.053	9.725	9.975	1.085
Giza 2000	9.213	0.256	8.750	9.750	5.559	10.631	0.180	10.200	11.025	3.377
Barke	5.344	0.061	5.275	5.525	2.272	9.094	0.252	8.400	9.600	5.546
Heines-Hanns	13.175	0.061	13.025	13.275	0.930	13.919	0.272	13.350	14.500	3.912
Pasadena	8.225	0.305	7.625	8.900	7.425	10.594	0.072	10.475	10.800	1.354
Quench	9.694	0.163	9.300	9.975	3.372	11.219	0.256	10.775	11.800	4.572
Scarlett	5.625	0.104	5.425	5.850	3.683	12.156	0.483	11.225	13.300	7.951
Thuringia	9.725	0.078	9.500	9.850	1.599	12.388	0.214	12.000	13.000	3.462
ICB 180199	8.406	0.213	8.025	8.900	5.078	12.244	0.769	10.825	13.575	12.568
ICB 180410	10.581	0.060	10.475	10.750	1.131	15.213	0.594	14.125	16.350	7.811
ISR 42-8	9.550	0.059	9.475	9.725	1.228	10.575	0.081	10.425	10.800	1.532
Tukey$_{0.05}$	0.8253					0.6531				
			Cu (U)					Cu (C)		
Giza 123	12.738	0.449	11.550	13.550	7.052	148.281	7.414	135.550	163.500	10.000
Giza 126	13.388	0.291	12.800	14.125	4.341	19.038	0.703	17.800	20.525	7.384
Giza 127	10.800	0.097	10.575	11.050	1.803	20.294	0.039	20.225	20.400	0.381
Giza 128	27.306	0.719	25.150	28.075	5.266	73.638	2.270	70.150	80.250	6.165
Giza 129	28.338	0.969	26.025	30.750	6.838	185.525	1.158	183.700	188.575	1.248
Giza 130	13.356	0.134	13.025	13.575	2.012	16.231	0.108	16.025	16.475	1.333
Giza 131	25.494	0.715	24.300	27.550	5.611	45.088	0.264	44.525	45.575	1.172
Giza 2000	12.038	0.103	11.800	12.300	1.708	14.950	0.195	14.675	15.525	2.609
Barke	41.306	0.021	41.250	41.350	0.103	74.619	0.740	72.450	75.750	1.984
Heines-Hanns	12.106	0.118	11.775	12.300	1.955	13.661	0.235	13.075	14.125	3.447
Pasadena	80.688	1.913	76.450	85.750	4.742	186.044	0.929	183.775	188.300	0.999
Quench	12.713	0.222	12.300	13.300	3.494	62.292	0.585	61.150	63.300	1.877
Scarlett	10.494	0.150	10.175	10.750	2.861	19.956	0.321	19.400	20.525	3.219
Thuringia	11.150	0.122	10.850	11.350	2.197	45.519	0.225	44.975	46.075	0.987
ICB 180199	7.756	0.157	7.425	8.025	4.055	109.700	1.693	105.525	113.575	3.086
ICB 180410	65.975	1.008	63.225	68.075	3.055	173.181	4.377	165.450	180.775	5.055
ISR 42-8	13.588	0.093	13.425	13.850	1.365	18.031	0.086	17.850	18.250	0.956
Tukey$_{0.05}$	2.8282					3.9739				

TABLE S1. Cont.

Genotype	Fe (U)					Fe (C)				
	Mean	**SE**	**Min**	**Max**	**CV**	**Mean**	**SE**	**Min**	**Max**	**CV**
Giza 123	1688.320	8.352	1672.500	1705.250	0.989	4504.950	6.409	4492.500	4522.500	0.285
Giza 126	469.250	1.614	465.500	473.000	0.688	744.325	4.318	731.500	750.300	1.160
Giza 127	739.875	3.887	730.000	747.250	1.051	2659.250	7.025	2640.000	2673.500	0.528
Giza 128	1755.560	13.618	1728.500	1780.000	1.551	2217.450	7.406	2204.250	2230.300	0.668
Giza 129	509.556	0.191	509.225	510.000	0.075	657.094	0.455	655.875	658.000	0.138
Giza 130	828.325	1.820	825.250	832.500	0.439	980.000	5.444	971.000	995.750	1.111
Giza 131	557.750	1.711	555.250	562.500	0.613	1878.810	6.938	1858.000	1885.750	0.738
Giza 2000	2692.250	12.318	2660.000	2719.000	0.915	5363.310	18.412	5330.750	5400.000	0.687
Barke	1205.940	10.088	1181.500	1222.500	1.673	3010.040	4.295	3002.500	3019.600	0.285
Heines-Hanns	574.206	0.793	572.300	575.525	0.276	2537.140	1.346	2533.500	2540.000	0.106
Pasadena	732.125	8.123	716.500	747.250	2.219	4617.530	53.703	4545.000	4775.000	2.326
Quench	656.125	1.959	652.750	660.750	0.597	3749.450	20.417	3720.000	3807.800	1.089
Scarlett	662.813	2.431	656.000	667.500	0.734	1613.500	8.153	1597.000	1635.750	1.011
Thuringia	807.000	8.253	791.250	830.250	2.045	3556.890	2.776	3550.000	3563.300	0.156
ICB 180199	780.500	2.706	775.750	788.000	0.693	3206.810	24.917	3150.000	3250.500	1.554
ICB 180410	779.313	1.644	775.750	783.500	0.422	1147.630	8.880	1132.000	1163.500	1.547
ISR 42-8	643.638	4.581	635.750	653.000	1.423	3639.520	9.453	3615.000	3658.000	0.519
Tukey$_{0.05}$	23.951					82.977				
			Ni (U)					Ni (C)		
Giza 123	5.306	0.021	5.250	5.350	0.805	11.744	0.031	11.675	11.825	0.532
Giza 126	4.895	0.057	4.755	5.000	2.331	18.106	0.142	17.850	18.400	1.572
Giza 127	5.481	0.055	5.375	5.600	2.018	14.119	0.864	12.525	15.700	12.241
Giza 128	6.244	0.083	6.100	6.475	2.663	10.519	0.021	10.475	10.575	0.406
Giza 129	5.700	0.060	5.525	5.800	2.119	8.556	0.294	8.025	9.125	6.862
Giza 130	5.119	0.092	4.925	5.300	3.597	10.556	0.057	10.475	10.725	1.087
Giza 131	5.575	0.161	5.250	5.900	5.789	9.963	0.007	9.950	9.975	0.145
Giza 2000	5.794	0.021	5.750	5.850	0.737	8.944	0.074	8.800	9.125	1.652
Barke	5.506	0.192	5.125	5.850	6.988	8.344	0.047	8.250	8.475	1.131
Heines-Hanns	5.925	0.027	5.875	6.000	0.911	11.388	0.053	11.250	11.500	0.923
Pasadena	5.350	0.142	5.050	5.650	5.301	15.744	0.055	15.625	15.850	0.703
Quench	4.019	0.034	3.950	4.100	1.713	12.775	0.053	12.650	12.875	0.830
Scarlett	5.000	0.027	4.925	5.050	1.080	10.869	0.091	10.700	11.100	1.673
Thuringia	5.856	0.012	5.825	5.875	0.409	11.775	0.369	11.075	12.425	6.267
ICB 180199	4.744	0.028	4.700	4.825	1.168	9.125	0.051	9.000	9.250	1.118
ICB 180410	4.331	0.047	4.250	4.425	2.179	12.069	0.115	11.825	12.300	1.901
ISR 42-8	5.169	0.071	5.025	5.325	2.747	10.825	0.119	10.575	11.075	2.199
Tukey$_{0.05}$	0.1607					0.1905				
			Zn (U)					Zn (C)		
Giza 123	22.407	0.025	22.353	22.450	0.226	44.725	0.010	44.700	44.750	0.046
Giza 126	14.878	0.013	14.850	14.913	0.173	24.181	0.019	24.125	24.200	0.155
Giza 127	21.513	0.041	21.425	21.625	0.385	36.113	0.031	36.025	36.175	0.174
Giza 128	26.463	0.016	26.425	26.500	0.122	39.975	0.027	39.900	40.025	0.135
Giza 129	24.563	0.104	24.275	24.750	0.850	64.444	0.654	63.575	66.350	2.031
Giza 130	27.569	0.300	27.000	28.100	2.178	46.713	0.451	45.800	47.500	1.931
Giza 131	32.794	0.136	32.500	33.050	0.831	49.906	0.028	49.850	49.975	0.111
Giza 2000	21.388	0.118	21.075	21.625	1.107	39.931	0.458	39.125	40.750	2.296
Barke	23.838	0.535	22.875	24.850	4.493	33.338	0.024	33.300	33.400	0.144
Heines-Hanns	30.613	0.058	30.500	30.725	0.380	51.650	0.027	51.600	51.725	0.105
Pasadena	44.056	0.033	44.000	44.125	0.149	66.781	0.913	65.175	68.375	2.734
Quench	23.679	0.027	23.625	23.725	0.227	43.695	0.039	43.580	43.750	0.178
Scarlett	19.369	0.136	19.100	19.650	1.404	65.675	0.037	65.575	65.750	0.112
Thuringia	22.307	0.021	22.253	22.350	0.186	29.688	0.016	29.650	29.725	0.109
ICB 180199	9.913	0.139	9.650	10.250	2.797	33.500	0.127	33.250	33.850	0.761
ICB 180410	33.531	0.069	33.400	33.725	0.410	42.200	0.023	42.150	42.250	0.108
ISR 42-8	28.056	0.019	28.025	28.100	0.134	31.600	0.018	31.550	31.625	0.112
Tukey$_{0.05}$	0.9083					1.285				

TABLE S2. Descriptive statistics for heavy metals concentrations (mg/L) in leaves calculated over two years for uncontaminated soil (U) and contaminated soil (C).

Genotype	Al (U)					Al (C)				
	Mean	SE	Min	Max	CV	Mean	SE	Min	Max	CV
Giza 123	177.131	0.569	175.475	178.075	0.643	620.500	2.606	613.000	625.000	0.840
Giza 126	184.725	0.468	183.500	185.750	0.507	333.188	2.080	327.750	337.500	1.249
Giza 127	286.388	1.259	283.550	288.750	0.879	346.394	1.674	342.500	350.250	0.966
Giza 128	203.313	0.273	202.500	203.675	0.269	314.125	2.579	308.500	319.750	1.642
Giza 129	311.500	1.429	308.500	315.000	0.917	502.625	1.975	498.250	507.500	0.786
Giza 130	335.000	2.447	330.000	341.250	1.461	380.188	2.820	372.500	385.750	1.483
Giza 131	231.888	1.209	229.500	235.000	1.043	399.250	2.074	395.000	404.750	1.039
Giza 2000	353.875	4.572	345.000	364.250	2.584	391.750	1.831	387.500	395.500	0.935
Barke	221.150	0.863	219.500	223.250	0.781	1216.250	6.948	1199.500	1230.000	1.142
Heines-Hanns	435.313	2.065	431.250	440.000	0.949	473.438	2.571	468.750	480.000	1.086
Pasadena	286.938	6.839	275.000	300.000	4.767	497.500	1.497	493.500	500.250	0.602
Quench	293.250	3.218	287.500	300.000	2.195	473.188	2.703	468.250	480.000	1.142
Scarlett	235.969	0.878	234.575	238.500	0.744	268.000	2.823	262.750	273.250	2.107
Thuringia	379.750	1.233	376.500	382.500	0.649	430.438	2.251	425.750	435.000	1.046
ICB 180199	426.250	3.307	417.500	432.500	1.552	491.813	2.786	485.000	497.500	1.133
ICB 180410	385.625	5.437	375.000	400.000	2.820	482.188	2.621	475.000	487.500	1.087
ISR 42-8	206.469	1.493	203.000	210.000	1.447	221.656	0.744	219.500	222.750	0.671
Tukey$_{0.05}$	15.86					91.664				
			Cr (U)					Cr (C)		
Giza 123	8.769	0.354	8.125	9.500	8.075	20.075	0.471	18.800	21.000	4.697
Giza 126	1.181	0.177	0.850	1.500	29.999	12.256	0.368	11.250	13.000	6.006
Giza 127	2.675	0.023	2.625	2.725	1.706	15.731	0.664	14.475	17.000	8.441
Giza 128	6.056	0.103	5.750	6.200	3.410	8.981	0.012	8.950	9.000	0.267
Giza 129	10.588	0.063	10.475	10.750	1.196	16.569	0.083	16.375	16.750	0.996
Giza 130	8.838	0.090	8.625	9.000	2.046	11.588	0.083	11.400	11.750	1.426
Giza 131	0.444	0.028	0.375	0.500	12.492	11.300	0.108	11.000	11.500	1.912
Giza 2000	6.844	0.084	6.675	7.000	2.448	42.263	0.313	41.550	43.000	1.482
Barke	2.975	0.023	2.925	3.025	1.534	6.244	0.092	6.100	6.500	2.931
Heines-Hanns	4.894	0.076	4.750	5.025	3.104	7.919	0.148	7.600	8.250	3.748
Pasadena	4.138	0.060	4.000	4.250	2.898	8.194	0.186	7.975	8.750	4.542
Quench	5.381	0.184	5.075	5.850	6.842	9.150	0.423	8.350	10.000	9.241
Scarlett	4.738	0.047	4.600	4.800	1.998	9.125	0.053	9.025	9.250	1.162
Thuringia	5.719	0.262	5.000	6.250	9.166	13.181	0.123	12.975	13.500	1.867
ICB 180199	7.750	0.131	7.500	8.000	3.373	13.225	0.105	13.000	13.500	1.589
ICB 180410	4.356	0.119	4.000	4.500	5.472	13.944	0.119	13.625	14.125	1.703
ISR 42-8	3.681	0.040	3.600	3.750	2.174	6.119	0.051	6.000	6.250	1.680
Tukey$_{0.05}$	0.7824					53.541				
			Cu (U)					Cu (C)		
Giza 123	11.025	0.350	10.400	11.750	6.355	72.256	1.172	69.275	75.000	3.243
Giza 126	7.163	0.144	6.875	7.525	4.015	8.331	0.091	8.150	8.500	2.183
Giza 127	11.200	0.114	11.000	11.500	2.029	176.838	0.090	176.625	177.000	0.102
Giza 128	13.356	0.077	13.200	13.500	1.148	30.375	0.298	29.750	31.000	1.959
Giza 129	10.400	0.044	10.325	10.525	0.856	158.938	1.393	155.000	161.250	1.753
Giza 130	9.838	0.160	9.475	10.250	3.245	254.500	0.456	253.500	255.500	0.359
Giza 131	5.856	0.092	5.725	6.125	3.144	11.475	0.057	11.375	11.625	0.990
Giza 2000	8.038	0.031	7.975	8.125	0.783	9.569	0.230	8.925	10.000	4.805
Barke	12.113	0.097	11.900	12.300	1.594	17.925	0.268	17.375	18.500	2.989
Heines-Hanns	8.863	0.137	8.575	9.175	3.094	10.906	0.277	10.375	11.500	5.072
Pasadena	17.238	0.607	15.450	18.025	7.048	39.213	0.601	37.500	40.050	3.066
Quench	10.981	0.521	10.150	12.500	9.492	15.988	0.229	15.600	16.500	2.871
Scarlett	5.588	0.222	5.000	6.000	7.949	8.538	0.275	8.000	9.025	6.453
Thuringia	16.400	0.299	15.850	17.250	3.642	25.419	0.121	25.200	25.725	0.955
ICB 180199	30.500	0.228	30.000	31.000	1.497	161.081	0.975	158.575	162.750	1.211
ICB 180410	20.713	0.133	20.500	21.075	1.287	42.519	0.087	42.325	42.750	0.411
ISR 42-8	8.481	0.153	8.050	8.750	3.597	17.544	0.078	17.375	17.750	0.889
Tukey$_{0.05}$	1.2699					2.8824				

TABLE S2. Cont.

Genotype	**Fe (U)**					**Fe (C)**				
	Mean	**SE**	**Min**	**Max**	**CV**	**Mean**	**SE**	**Min**	**Max**	**CV**
Giza 123	746.188	1.956	741.500	750.750	0.524	1136.060	1.763	1131.750	1140.000	0.310
Giza 126	796.813	2.613	792.250	802.500	0.656	1314.190	5.547	1304.250	1325.000	0.844
Giza 127	440.563	1.430	438.500	444.750	0.649	1162.130	7.922	1139.000	1175.000	1.363
Giza 128	325.500	1.658	322.000	330.000	1.019	3165.000	28.062	3110.000	3225.000	1.773
Giza 129	401.563	4.489	392.500	412.500	2.236	659.688	1.096	657.250	662.500	0.332
Giza 130	492.250	7.720	470.000	505.000	3.137	1765.380	7.086	1752.250	1780.000	0.803
Giza 131	377.875	3.217	374.000	387.500	1.703	1355.440	1.276	1352.250	1357.500	0.188
Giza 2000	765.625	1.509	762.250	768.750	0.394	2910.630	6.156	2895.000	2925.000	0.423
Barke	326.375	3.793	318.000	335.000	2.325	2214.690	5.313	2203.750	2225.000	0.480
Heines-Hanns	652.625	5.022	643.000	662.500	1.539	1666.940	4.884	1655.250	1675.000	0.586
Pasadena	1590.130	9.662	1573.000	1612.500	1.215	4615.000	14.860	4575.000	4640.000	0.644
Quench	681.750	6.498	667.000	695.000	1.906	1421.310	7.214	1407.750	1440.000	1.015
Scarlett	547.250	0.669	545.500	548.750	0.245	1012.810	0.997	1010.250	1015.000	0.197
Thuringia	575.625	3.590	567.500	585.000	1.247	3891.250	21.854	3827.500	3925.000	1.123
ICB 180199	646.625	2.839	640.000	652.500	0.878	1029.560	3.413	1022.500	1036.250	0.663
ICB 180410	610.813	7.782	595.000	625.750	2.548	1206.000	0.621	1204.750	1207.500	0.103
ISR 42-8	323.813	2.515	318.000	330.000	1.554	384.875	12.740	350.000	407.500	6.620
Tukey$_{0.05}$	23.213					54.939				
			Ni (U)					Ni (C)		
Giza 123	4.506	0.586	3.750	6.250	26.023	6.375	0.114	6.125	6.625	3.580
Giza 126	4.300	0.085	4.100	4.475	3.943	6.750	0.203	6.250	7.150	6.018
Giza 127	4.375	0.078	4.150	4.500	3.553	7.500	0.220	6.950	8.025	5.869
Giza 128	4.338	0.083	4.150	4.500	3.809	5.719	0.092	5.450	5.850	3.220
Giza 129	4.500	0.037	4.425	4.600	1.636	6.144	0.136	5.850	6.400	4.437
Giza 130	5.625	0.080	5.475	5.775	2.834	7.363	0.073	7.225	7.500	1.970
Giza 131	4.288	0.067	4.125	4.450	3.104	4.513	0.039	4.400	4.575	1.723
Giza 2000	6.144	0.220	5.700	6.625	7.160	8.106	0.051	7.975	8.200	1.268
Barke	4.494	0.074	4.375	4.700	3.287	4.744	0.062	4.600	4.900	2.595
Heines-Hanns	3.875	0.114	3.625	4.125	5.889	7.850	0.316	7.150	8.500	8.040
Pasadena	6.431	0.387	5.850	7.500	12.025	7.969	0.319	7.500	8.850	8.000
Quench	4.156	0.146	3.775	4.475	7.038	4.650	0.133	4.375	4.975	5.740
Scarlett	4.206	0.073	4.025	4.375	3.478	5.844	0.226	5.275	6.350	7.735
Thuringia	4.656	0.128	4.300	4.900	5.482	5.838	0.308	5.000	6.350	10.569
ICB 180199	5.338	0.133	5.000	5.575	4.994	7.463	0.180	7.225	8.000	4.835
ICB 180410	4.850	0.037	4.750	4.925	1.517	5.588	0.174	5.150	5.925	6.227
ISR 42-8	4.600	0.076	4.375	4.700	3.291	6.048	0.193	5.850	6.625	6.367
Tukey$_{0.05}$	1.0254					0.7512				
			Zn (U)					Zn (C)		
Giza 123	11.281	0.040	11.225	11.400	0.709	16.534	0.093	16.350	16.750	1.127
Giza 126	8.006	0.270	7.250	8.500	6.747	8.363	0.200	8.000	8.850	4.774
Giza 127	11.341	4.849	2.808	19.975	85.520	24.719	1.787	21.625	27.900	14.455
Giza 128	7.863	0.286	7.250	8.575	7.262	13.756	0.186	13.325	14.125	2.701
Giza 129	13.219	0.316	12.725	14.100	4.778	15.519	0.341	14.900	16.350	4.397
Giza 130	23.281	0.547	22.225	24.500	4.701	39.875	11.628	5.750	58.000	58.323
Giza 131	14.956	0.468	14.125	16.250	6.252	16.863	0.179	16.358	17.200	2.121
Giza 2000	14.194	0.287	13.850	15.050	4.038	18.713	0.216	18.100	19.100	2.313
Barke	14.213	0.228	13.650	14.750	3.213	19.933	1.007	17.725	21.900	10.106
Heines-Hanns	14.988	0.551	13.650	16.350	7.356	43.281	0.488	42.375	44.125	2.254
Pasadena	21.663	0.569	20.550	23.250	5.251	34.738	0.468	33.500	35.750	2.694
Quench	10.081	0.408	9.400	11.250	8.103	27.394	0.935	26.000	30.000	6.825
Scarlett	8.781	0.162	8.500	9.200	3.700	20.648	1.449	17.825	24.125	14.038
Thuringia	12.781	0.261	12.250	13.500	4.082	30.063	0.088	29.950	30.325	0.586
ICB 180199	20.825	0.129	20.500	21.125	1.236	28.769	1.687	25.850	32.500	11.731
ICB 180410	24.275	0.227	23.750	24.825	1.867	37.194	0.872	34.975	38.600	4.691
ISR 42-8	13.469	0.759	11.325	14.725	11.266	22.500	0.656	20.875	23.625	5.827
Tukey$_{0.05}$	1.6784					17.062				

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الاختلافات الوراثية في قدرة التراكيب الوراثية للشعير على معالجة العناصر الثقيلة في التربة الملوثة

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تؤثر التربة الملوثة بالعناصر الثقيلة سلبيا على كل من الماء الجوفي والسلسة الغذائية. ويمكن معالجة العناصر الثقيلة في التربة الملوثة عن طريق استخدام النباتات التي لها القدرة على امتصاص العناصر الثقيلة من التربة. وتهدف هذه الدراسة إلى جذب الانتباه إلى إمكانية استخدام الشعير كوسيلة غير مكلفة وفعالة وآمنة ومستدامة لمعالجة التربة الملوثة بالعناصر الثقيلة. ولتحقيق هذا الهدف تم زراعة 17 تركيب وراثي من الشعير شملت أصناف مصرية وألمانية وتراكيب وراثية برية لمدة عامين (2015/2016 و2016/2017) في تربة ملوثة وغير ملوثة بالعناصر القيلة. وتم قياس تركيزات العناصر الثقيلة المتضمنة الإلمنيوم والكروم والنحاس والحديد والنيكل والزنك في كل من الحبوب والأوراق لكل تركيب وراثي تحت ظروف التربة الملوثة وغير الملوثة بالعناصر الثقيلة. وقد أظهرت النتائج أن التراكيب الوراثية تختلف في قدرتها على تراكم العناصر الثقيلة في كل من الحبوب والأوراق. بالإضافة إلى أنه ظهر ارتباط معنوي موجب بين الإلمنيوم والكروم والنحاس والزنك في الحبوب تحت ظروف التربة الملوثة بالعناصر الثقيلة. وفي المجمل نوصي باستخدام خليط من التراكيب الوراثية تتضمن Heines-Hanns, ICB 180410, Giza-126, Giza-129, Giza-130, Giza-2000, Pasadena and Barke لمعالجة التربة الملوثة بالعناصر الثقيلة.