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Differential responses of one hundred tomato genotypes grown under cadmium stress

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ABSTRACT. Due to increased global concern over the deleterious effects of toxic heavy metals in the environment, it has become necessary to develop plant genotypes that limit the uptake of heavy metals to aerial edible parts. To address this concern, we performed a glasshouse experiment to assess variations within tomato germplasm for cadmium (Cd) tolerance under control conditions and under simulated stress conditions. Significant differences ($P < 0.01$) were observed among all genotypes at both Cd levels (3 ppm and 6 ppm). Our analyses showed that the genotypes 9086, Roma, Sitara TS-01, pak0010990, CLN-2123A, Picdeneato, 0.006231, and 7035 gave the best yields with minimum Cd content in their fruit, whereas the genotypes 42-07, 17883, BL-1176-Riostone-1-1, Marmande, and 17882 had relatively low yields with higher metal contents. The heavy metal was found to accumulate first in the shoot, then fruit, leaf, and finally root in tolerant genotypes; in susceptible genotypes, the order was fruit, shoot, leaf, and root. The inter-genotype differences in Cd uptake indicated the possibility of manipulating tomato genotypes to develop Cd tolerant tomato varieties or hybrids that allow safe use of a tomato crop grown on Cd contaminated soils.

Key words: Cadmium; Genetic variability; *Solanum lycopersicum*; Tomato

INTRODUCTION

Plants are subjected to a wide range of stresses during their life cycles. Heavy metal stress is becoming a major challenge to crop plants, particularly to vegetable crops, because of soil contamination. These heavy metals are derived from city/industrial effluent (Cai et al., 2010, 2012; Wang et al., 2013), electronic waste recycling/dismantling activities (Luo et al., 2011; Zheng et al., 2011; Liu et al., 2013), mining and smelting (Zhao et al., 2012; Tai et al., 2013), fertilizers and pesticides (Brady and Weil, 1996; Atafar et al., 2010; Cakmak et al., 2010; Nacke et al., 2013; Yu et al., 2013), and auto mobile depositions (Turer et al*.,* 2001, 2003); additionally, waste water/sewage water can be a major source of heavy metals in areas where raw sewage water is used for irrigation (Li et al., 2013; Wang et al., 2013). As heavy metals are not biodegradable and can accumulate in human organs, ingestion of vegetables that have been irrigated with contaminated water poses a serious risk to human health.

Cadmium is taken up by plants as Cd^{2+} and in normal plants, it ranges from 0.1-2.4 mg/kg (Alloway, 1995). At increased concentrations, Cd severely reduces plant growth and dry biomass production. Gratão et al. (2008) reported increased peroxidation of lipids, catalase activity, glutathione reductase (GR) activity, and a reduction in glutathione peroxidase (GPOX) enzyme activity (Ammar et al., 2007) in tomato plants under cadmium stress. Ammar et al. (2008) found that heavy metals could move to the upper parts of the plant, such as fruit, and that their amounts in leaves were low in comparison to the fruits. Interestingly, Cd levels reached their maximum in leaves, roots, and fruits of 75-day-old plants but were low in the leaves of 204-day-old plants. This suggests that Cd is transported to these organs after development. Plant genetics, physiology, and morphology can also control the bioavailability of heavy metals. In cereal crops, transport of metals to grain tissues is restricted and most remains in the roots; this pattern is seen in wheat, barley, oat, rye, and corn. Different vegetable species (Murtaza et al., 2008), peanut (Su et al., 2013) hot pepper (Xin et al., 2013), rice varieties (Abbas et al., 2006), mungbean (Wahid and Ghani, 2008), potato (Dunbar et al., 2003), soybean and other bean species (Metwally et al., 2005; Bell and Gonzalez, 2009), and wheat cultivars (Jalil et al., 1994) differ in their capacities for metal uptake and accumulation depending on the levels in the soil, the metal type and characteristics, presence of counter species of ions (Hernandez et al., 1996; Obata and Umebayashi, 1997), environmental growth conditions, and crop genetic factors. Crop plant species show wide genetic variation due to breeding; identifying the accessions that are tolerant to Cd, or those that accumulate lower levels of metal in their fruit can be achieved more easily than determining the genes that influence plant responses to the metal. Selection of tolerant and non-tolerant varieties for heavy metal stress is a possible solution for growing crops on metal contaminated sites (Piotto et al., 2014). The objective of the present study was to use this approach to characterize the comparative metal tolerance of a large number of tomato genotypes (Grant et al., 2008).

MATERIAL AND METHODS

A total of 100 accessions of tomato (*Solanum lycopersicum* L.) were used in this study, which were obtained from the Vegetable Research Institute, Ayub Agricultural Research Institute, Faisalabad, the Nuclear Institute for Agriculture & Biology, Faisalabad, and the Plant Genetic Resources Program, NARC Islamabad. Seeds of each genotype were placed in compost-filled trays and incubated under the appropriate germination conditions. After germination, the tomato plants were grown in soil of known composition. One kilogram of soil was placed in plastic bags (12'' x 4''). Forty-day-old plants were transplanted into the plastic bags (one plant per bag). One week after transplantation, cadmium salt ($CdCl_2$) solution was applied at concentrations of 3 ppm or 6 ppm. The experimental set-up contained control (untreated) and the two cadmium treatments; three replicate experiments were performed. Normal agronomic and plant protection measures were adopted during the entire experiment. At maturity, fruits from six plants of each genotype (and from each replicate experiment) were picked and weighed on an electric balance.

Fruits, leaves, roots, and shoots were collected in paper bags and oven dried. The plant samples were subjected to heavy metal analysis according to Ryan et al. (2001) with some modification. After drying, samples were ground to a fine powder and 0.5 g of each sample was digested using the tri-acid method (HNO_3, $HClO_4$, and H_2SO_4 at a 5:2:1 ratio). Digestion was carried out using 15 mL of the digestion mixture on a hot plate at 100°C for the first hour, at 150°C for the second hour, at 200°C for the third hour, and at 250°C for the fourth hour. After digestion, samples were filtered using Whatman filter paper No. 42 and the volume was restored to 15 mL using distilled water. The filtered samples were stored in air tight plastic bottles and subjected to heavy metal analysis in an atomic absorption spectrophotometer (Model Thermo Electron S-Series).

Statistical analysis

The data from all 100 genotypes were subjected to an analysis of variance (ANOVA) to identify genotypic differences in responses.

RESULTS

Data for metal contents showed that all genotypes have different behavior for metal accumulation. Minimum cadmium content were found in edible part of genotypes 9086, Roma, Sitara TS-01, Pak 0010990, Picdeneato, CLN-2123A, 006231, 7035 with high yield while genotypes 42-07, 17883, BL-1176-Riostone-1-1, 17882 and Marmande showed high metal contents in edible part with lower yield. When means of all genotypes for leaf metal content, root metal content, shoot metal content, fruit metal contents and yield were compared; different responses were exhibited by all genotypes.

Mean sum of squares from two levels of cadmium and control showed significant variation among 100 genotypes (Table 1) for leaf, root, and shoot and fruit cadmium contents at both levels. i.e. 3 ppm and 6 ppm. In control conditions, yield showed significant differences for 100 genotypes (Figure 1). Under control conditions, highest yield per plant was observed in genotype 9086 (3.75 kg) followed by Roma (3.64 kg), Sitara TS-01 (3.45 kg), Pak 0010990 (3.27 kg), Picdeneato (3.10 kg), CLN-2123A (3.09 kg) & 006231(3.09 kg), 006231 (3.01 kg), while lowest values were observed by genotypes 42-07 (0.95 kg), 17883 (1.03 kg), BL-1176-Riostone-1-1 (1.16 kg), 17882 (1.26 kg) and Marmande (1.36 kg). Due to non-detection of metals in any part of plant, under control conditions no values were observed.

Under 3 ppm cadmium stress, lowest values for leaf metal content were observed (Table 2) in genotype 9086 (0.1008 mg/kg) while highest values were observed in genotype 42-07 (0.3496 mg/kg). Root metal content were observed minimum in 9086 (0.0037 mg/kg) while maximum values were observed in 42-07 (0.7454 mg/kg), followed by 17883 (0.6409 mg/kg). For shoot metal contents under 3 ppm cadmium stress, the genotype 9086 (0.0010 mg/kg) showed less metal contents. Similarly, lowest fruit metal contents were observed in 9086 (0.0107 mg/kg). Yield response under 3 ppm cadmium stress was also variable and highest yield per plant was found in the genotype 9086 (3.35 kg) while lowest yield was observed in the genotype 42-07 (0.21 kg) followed by 17883 (0.27 kg), BL-1176-Riostone-1-1 (0.72 kg) and 17882 & Marmande (0.75 kg).

Table 1. Mean squares values of metal accumulation in non-edible and edible parts of 100 tomato genotypes grown in control and two levels of cadmium.

SOV	Leaf		Root		Shoot		Fruit		Yield	
	Between	Within	Between	Within	Between	Within	Between	Within	Between	Within
DF	99	2	99	2	99	2	99	2	99	2
Control	0	0	0	0	0	0	0	0	9076.06**	43603.7
3 ppm Cd	0.008894**	0.000057	0.043208**	0.00011	0.000063**	0.000015	0.00125**	0.00014	10317.44**	1407.8
6 ppm Cd	0.063058**	0.00001	0.195565**	0.00607	0.000244**	0.000007	0.004796**	0.00062	14513.75**	354.555

**= significant at P > 0.01, *= significant at P > 0.5, ns = non-significant, Leaf = leaf metal contents, Root = root metal contents, Shoot = shoot metal contents, Fruit = fruit metal contents.

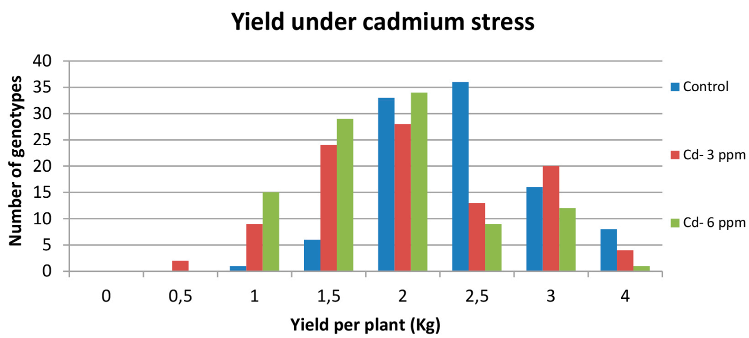

Figure 1. Yield groups of hundred tomato genotypes expressed at 3 ppm, 6 ppm cadmium and control.

Under 6 ppm cadmium stress, elevated cadmium contents were found in all genotypes which indicates that metal uptake increases by increasing cadmium concentration in soil. Most of genotypes which have higher metal contents at 3 ppm in leaf, root, shoot and fruit also have higher values at 6 ppm cadmium stress (Table 2). Genotypes 9086 showed maximum yield per plant (3.33 kg) with minimum leaf metal contents (0.0071 mg/kg) while in case of root metal contents lowest values were observed in genotype 9086 (0.2022 mg/kg), followed by Roma (0.2022 mg/kg) and Sitara TS-01 (0.2028 mg/kg).

Leaf metal contents indicates more than half of the genotypes (Figure 2) have metal contents in the range of 0-0.05 mg/kg while under high cadmium stress i.e 6 ppm, this trend decreased and only 22 genotypes fall in this region indicating that most of the genotypes start tolerance behavior in response to increasing dose. On contrary, 4 genotypes showed higher metal contents at 3 ppm concentration and 6 genotypes at 6 ppm. Root metal contents were found in majority of the genotypes at increased level of cadmium while highest metal contents in roots i.e. in the range of 2 mg/kg were found only in 6 genotypes (Figure 3). This increased concentration in roots is directly correlated with increased concentration in soil. The analysis of individual plant indicates that significant differences exist among genotypes for shoot metal contents and these were found minimum in all genotypes and majority of genotypes fall in the region of 0.015 mg/kg at both cadmium levels (Figure 4). Similarly, as a tolerance index, fruit metal contents were also measured as show in Figure 5. Fruit metal contents as low as 0.025 mg/kg were found only in one genotype at higher concentration of 6 ppm in soil while majority of genotypes have fruit metal contents in the range of 0.05-0.1 mg/kg. Higher contents were found in eight genotypes which were regarded as non-tolerant to cadmium in terms of fruit metal contents. Yield per plant was found maximum under control conditions while this reduced to half at low concentration of cadmium and almost near zero at higher cadmium stress as shown in Figure 1.

Table 2. Mean values for cadmium contents in different parts of tomato genotypes.

Genotypes	LEAF		ROOT		SHOOT		FRUIT	
	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm
7005	0.0349	0.0701	0.2250	0.8040	0.0038	0.0078	0.0218	0.0476
7012	0.0827	0.1658	0.2237	0.4422	0.0043	0.0089	0.0433	0.0884
NAGINA	0.0854	0.1715	0.1228	0.2532	0.0124	0.0245	0.0374	0.0816
ADVANTA-121	0.0239	0.0474	0.1566	0.3166	0.0019	0.0041	0.0317	0.0674
7009	0.0793	0.1590	0.1754	0.3568	0.0066	0.0137	0.0150	0.0350
9088	0.0574	0.1141	0.1969	0.3974	0.0057	0.0118	0.0383	0.0458
ROMA	0.0046	0.0076	0.1021	0.2022	0.0011	0.0025	0.0110	0.0256
FESTON EARLY	0.0235	0.0474	0.1869	0.3760	0.0031	0.0064	0.0439	0.0906
PAKIT	0.0725	0.1452	0.1103	0.2250	0.0064	0.0124	0.0177	0.0322
BSX-935-3-7-1	0.0242	0.0487	0.1215	0.2478	0.0045	0.0086	0.0239	0.0518
NUTAN	0.0875	0.1755	0.1400	0.2850	0.0026	0.0055	0.0214	0.0462
TOM RED	0.0365	0.0733	0.1387	0.2810	0.0048	0.0093	0.0204	0.0846
8520	0.0593	0.1188	0.1376	0.2760	0.0038	0.0078	0.0185	0.0408
AUSTRA-717	0.0272	0.0548	0.1303	0.2644	0.0023	0.0040	0.0293	0.0526
ADVANTA-1202	0.0393	0.0791	0.2303	0.4624	0.0111	0.0224	0.0289	0.0520
PO-07	0.0376	0.0071	0.2939	0.5993	0.0113	0.0237	0.0219	0.0414
DT-1-66-B	0.0803	0.1612	0.2359	0.4750	0.0121	0.0245	0.0257	0.0538
SITARA TS-01	0.0052	0.0125	0.1025	0.2028	0.0014	0.0030	0.0119	0.0266
108-N	0.0244	0.0483	0.1633	0.3290	0.0090	0.0184	0.0157	0.0342
RIOGRANDE	0.0283	0.0755	0.2442	0.2376	0.0118	0.0266	0.0525	0.1110
CLN-16212	0.0950	0.1895	0.2342	0.2172	0.0152	0.0259	0.0852	0.0724
7048	0.0872	0.1746	0.1564	0.3162	0.0136	0.0175	0.0358	0.0780
ADVANTA-1210	0.0749	0.1501	0.1094	0.2156	0.0087	0.0054	0.0439	0.0806
9088	0.0046	0.0569	0.1211	0.2470	0.0128	0.0116	0.0251	0.0544
TITANO(B)	0.0923	0.1840	0.1160	1.0775	0.0056	0.0188	0.0653	0.1382
10133	0.0298	0.0593	0.4649	0.4834	0.0135	0.0259	0.0653	0.1276
ROAM	0.0269	0.0541	0.1103	0.2262	0.0032	0.0065	0.0247	0.0464
PS-15035	0.0230	0.0463	0.2257	0.4562	0.0016	0.0184	0.0441	0.0834
42-07	0.3496	0.4115	0.7454	1.4778	0.0219	0.0441	0.0970	0.1922
PICDENEATO	0.0059	0.0206	0.1039	0.2060	0.0016	0.0035	0.0127	0.0270
9090	0.0645	0.1297	0.1514	0.3070	0.0034	0.0066	0.0165	0.0364
7012	0.0272	0.0547	0.1172	0.2384	0.0098	0.0199	0.0190	0.0410
9080	0.0382	0.0768	0.1871	0.3780	0.0065	0.0134	0.0449	0.0828
MARMANDE	0.1417	0.2725	0.5392	1.1317	0.0161	0.0318	0.0879	0.1788
ADVANTA-1208	0.0323	0.0650	0.1900	0.3850	0.0111	0.0226	0.0270	0.0586
9086	0.0037	0.0071	0.1008	0.2022	0.0010	0.0023	0.0107	0.0248
BL-1176-RIOSTONE-1-1	0.2675	0.5211	0.5834	1.1746	0.0172	0.0341	0.0953	0.1892
CLN-2123A	0.0089	0.0274	0.1043	0.2086	0.0017	0.0035	0.0131	0.0280
8520	0.0359	0.0724	0.1747	0.4396	0.0033	0.0070	0.0204	0.0456
7039	0.0633	0.1263	0.1638	0.3242	0.0043	0.0088	0.0256	0.0566
LYP # 1	0.0262	0.0528	0.1057	0.4708	0.0076	0.0155	0.0339	0.0626
NTH-242	0.0418	0.0831	0.1113	0.2232	0.0029	0.0061	0.0170	0.0394
CCHAUS	0.0322	0.0648	0.1875	0.3778	0.0116	0.0233	0.0261	0.0546
H.T.P.C.	0.0550	0.1104	0.1257	0.2570	0.0059	0.0121	0.0393	0.0738
7035	0.0220	0.0435	0.1050	0.2106	0.0018	0.0038	0.0138	0.0304
7030	0.0236	0.2064	0.3835	0.7555	0.0055	0.0264	0.0199	0.0466
EXECELLANCE CHINA	0.0294	0.0591	0.1516	0.3070	0.0068	0.0139	0.0429	0.0898
TETAS	0.0248	0.0499	0.1253	0.2554	0.0047	0.0096	0.0367	0.0762
7009	0.0343	0.0681	0.1957	0.3964	0.0078	0.0161	0.0232	0.0500
RED BALL	0.0266	0.0529	0.1676	0.3400	0.0114	0.0225	0.0433	0.0902
RIOFUEGO	0.0228	0.0459	0.1655	0.3392	0.0118	0.0239	0.0391	0.0810
ADVANTA-1206	0.0762	0.1521	0.1729	0.3526	0.0034	0.0070	0.0153	0.0342
KAFILA	0.0251	0.0508	0.2341	0.4636	0.0029	0.0054	0.0509	0.1046
7015	0.0928	0.1860	0.2172	0.4280	0.0057	0.0118	0.0339	0.0714
12770	0.0374	0.0750	0.1083	0.2126	0.0070	0.0145	0.0402	0.0858
12585	0.0666	0.1334	0.1697	0.3358	0.0056	0.0117	0.0253	0.0528
AUQAAB	0.0273	0.0550	0.1457	0.2938	0.0077	0.0156	0.0471	0.0974
DT-05-151	0.0253	0.1810	0.2678	0.4504	0.0127	0.0271	0.0560	0.1113
SWEETY	0.0304	0.0611	0.1857	0.3744	0.0093	0.0039	0.0275	0.0594
7032	0.0340	0.0677	0.1571	0.3184	0.0039	0.0075	0.0281	0.0512

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Table 2. Continued.

Genotypes	LEAF		ROOT		SHOOT		FRUIT	
	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm	Cd 3 ppm	Cd 6 ppm
0.006231	0.0145	0.0287	0.1048	0.2100	0.0018	0.0037	0.0134	0.0302
0.006232	0.0989	0.1979	0.1082	0.2134	0.0036	0.0078	0.0332	0.0698
0.006233	0.0774	0.0541	0.2641	0.5380	0.0156	0.0114	0.0735	0.1560
0.006234	0.0824	0.1651	0.1099	0.2166	0.0057	0.0118	0.0256	0.0562
0.017856	0.0553	0.1111	0.1691	0.3322	0.0112	0.0228	0.0276	0.0586
17859	0.0826	0.1655	0.1135	0.2252	0.0018	0.0040	0.0295	0.0568
17862	0.0262	0.0528	0.1060	0.2176	0.0040	0.0077	0.0169	0.0366
17863	0.0285	0.0571	0.1162	0.2394	0.0025	0.0255	0.0223	0.0476
17865	0.0281	0.0568	0.1065	0.2110	0.0115	0.0234	0.0225	0.0508
17867	0.0546	0.1099	0.2289	0.4332	0.0061	0.0125	0.0432	0.0922
17868	0.1031	0.0445	0.2201	0.4466	0.0096	0.0194	0.0378	0.0692
17869	0.0774	0.1551	0.1978	0.3966	0.0030	0.0060	0.0433	0.0818
17870	0.0249	0.0495	0.2249	0.4440	0.0061	0.0124	0.0399	0.0744
17872	0.0303	0.0608	0.2128	0.4328	0.0041	0.0086	0.0149	0.1630
17873	0.0248	0.0497	0.1181	0.2324	0.0058	0.0119	0.0146	0.0362
17874	0.3160	0.5211	0.2547	0.5003	0.0113	0.0223	0.0477	0.0987
17876	0.0677	0.1361	0.2150	0.4342	0.0114	0.0226	0.0427	0.0888
17877	0.0283	0.0563	0.1076	0.2196	0.0024	0.0044	0.0376	0.0702
17878	0.0671	0.1349	0.2197	0.4344	0.0112	0.0227	0.0163	0.0368
17882	0.1609	0.3231	0.5649	1.1424	0.0165	0.0324	0.0941	0.1821
17883	0.3160	0.6886	0.6409	1.2815	0.0184	0.0353	0.0960	0.1910
17887	0.0234	0.0471	0.1114	0.2258	0.0057	0.0118	0.0173	0.0388
17888	0.0829	0.1655	0.1139	0.2240	0.0086	0.0174	0.0168	0.0440
17889	0.0253	0.0512	0.1353	0.2756	0.0049	0.0101	0.0344	0.0694
17890	0.0268	0.0540	0.2161	0.6624	0.0117	0.0237	0.0269	0.0568
pak0010990	0.0056	0.0143	0.1028	0.2052	0.0015	0.0033	0.0121	0.0270
4435(2)pak0011006	0.0570	0.1137	0.1137	0.2308	0.0118	0.0239	0.0393	0.0766
4431(1)pak0010998	0.0236	0.0481	0.2169	0.3422	0.0061	0.0126	0.0331	0.0594
4425(7)pak0010976	0.0904	0.0551	0.3645	0.7366	0.0141	0.0315	0.0877	0.1786
pak0011016	0.0249	0.0501	0.1134	0.2278	0.0033	0.0069	0.0446	0.0854
pak0010977	0.0278	0.0558	0.1411	0.2868	0.0073	0.0148	0.0231	0.0412
pak0010584	0.0383	0.0761	0.2374	0.4776	0.0042	0.0085	0.0425	0.0896
pak0010306	0.0677	0.1359	0.2187	0.4606	0.0080	0.0166	0.0179	0.0380
Lo-2752	0.0581	0.1166	0.1622	0.3284	0.0139	0.0281	0.0424	0.0886
LO-2831	0.0544	0.1090	0.1462	0.2962	0.0113	0.0231	0.0291	0.0486
LO-2846	0.0301	0.0607	0.1108	0.2246	0.0032	0.0062	0.0169	0.0364
LO-4841	0.0688	0.1374	0.4035	0.4550	0.0028	0.0057	0.0379	0.0312
LO-4379	0.0244	0.0484	0.2081	0.4136	0.0042	0.0082	0.0208	0.0460
pak0010991	0.0828	0.1651	0.1151	0.2328	0.0068	0.0140	0.0327	0.0704
pak0010575	0.0252	0.0512	0.1075	0.2126	0.0052	0.0109	0.0260	0.0562

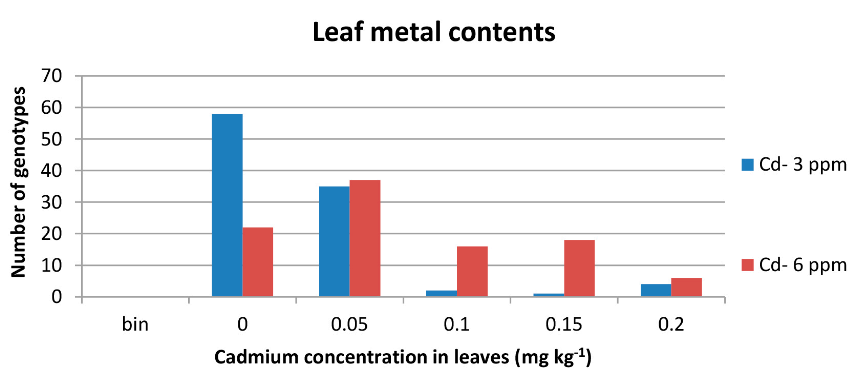

Figure 2. Cadmium contents in leaves of 100 tomato genotypes expressed in mg/kg, grouped according to their metal contents.

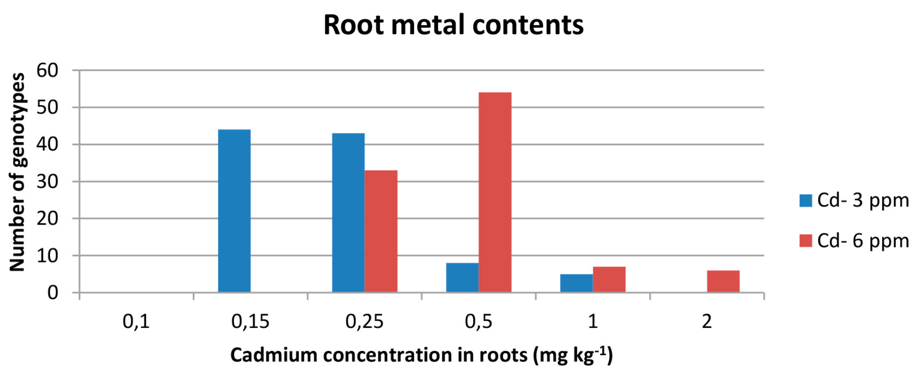

Figure 3. Cadmium contents in leaves of 100 tomato genotypes expressed in mg/kg, grouped according to their metal contents. Few genotypes exist in group 1, i.e., 0.1 mg/kg, while maximum genotypes lie in group 4 at higher level of cadmium.

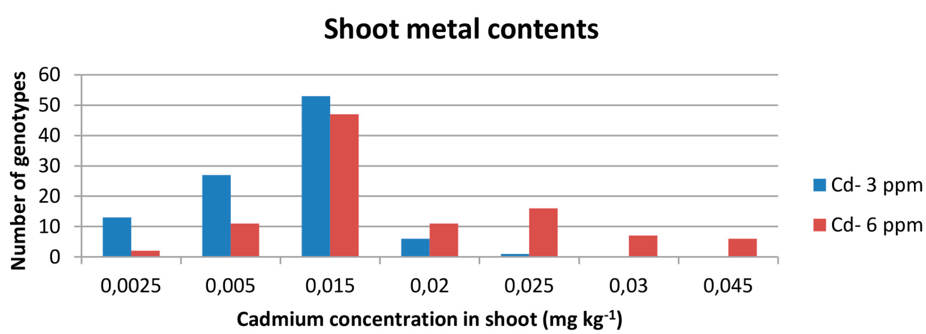

Figure 4. Cadmium contents in shoot of 100 tomato genotypes expressed in mg/kg, grouped according to their metal contents. Group 6 and 7 have no genotypes which exist in low cadmium contetns while maximum genotypes have matal contetns in the range of 0.005 - 0.015 mg/kg.

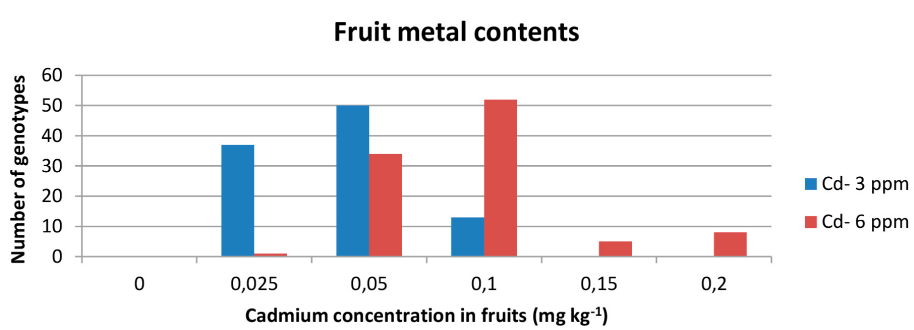

Figure 5. Cadmium contents in fruits of 100 tomato genotypes expressed in mg/kg, grouped according to their metal contents. Maximum genotypes have matal contetns in the range of 0.05 - 0.10 mg/kg.

DISCUSSION

In tolerant genotypes, higher yields of fruit with relatively low levels of Cd were obtained; however, non-tolerant genotypes gave lower yields of fruit with comparatively high levels of Cd.

Although the Cd content of roots was also higher in tolerant genotypes, they did not transport the metal to the aerial parts plants especially to the fruit.

There are no reported studies on Cd tolerance in tomato genotypes. However, Cd tolerance in pea genotypes has been examined and differences for tolerance of Cd and for uptake of heavy metals from the soil were found (Belimov et al., 2003).

In the present study, the significant reduction in yield per plant and the higher Cd content in fruit indicated that the plants were exposed to severe stress. Cadmium tolerance was negatively correlated with Cd concentration in leaves and fruits. A low metal content in some genotypes indicated that they could prevent excessive Cd translocation from roots to leaves and ultimately to the fruit. Although Cd accumulation in the leaves of tolerant genotypes was minimal compared to non-tolerant genotypes, some of the former accumulated Cd at similarly high concentrations as non-tolerant genotypes. In such genotypes, a Cd tolerance mechanism may be present in the leaves or even in fruit to cope with higher contents of the toxic metal. Our findings suggest that different mechanisms may exist within a species or among genotypes for Cd tolerance; these different mechanisms may prevent Cd accumulation, may enable detoxification of cells, or produce metabolic resistance to toxic metals (Prasad and Hagemeyer, 1999; di Toppi and Gabrielli, 1999; Cobbett, 2000).

There have been few previous attempts to assess correlations between phenotypic characteristics and heavy metal accumulation: Zn tolerance in *Anthoxanthum odoratum* (L.) was assessed on the basis of flowering time and culm length (Antonovics and Bradshaw, 1970); twenty three morphological characters were examined in Cu-tolerant, Zn-tolerant and non-tolerant populations of *Festuca rubra* (L.) cultivars (Davies et al., 1995); and flower color in pea genotypes (Belimov et al., 2003). Cadmium distribution was found to vary among species; for example Cd levels in seeds of eleven peanut cultivars varied by a factor of 2 compared to seeds of two corn hybrids, also in seeds of two wheat cultivars and of fifteen barley cultivars (Pettersson, 1977), shoot Zn concentration of soybean cultivars and Mn concentration in shoot of cowpea cultivars. So the distribution in plant parts varies accordingly either higher in lower portion of plant of upper top leaves. The bar graph indicates that there is considerable genetic variability among genotypes in relation to cadmium tolerance and offers the possibility of selecting extreme genotypes for further inheritance studies. At one extreme, the genotypes show minimum metal contents in leaf, root, shoot, and fruits; at the other, they show maximum concentrations in these tissues. Some genotypes respond slowly to changes in Cd levels in the soil, but their behavior changes abruptly indicating that expression of some genes might be triggered to induce tolerance mechanism in tomato plants.

CONCLUSION

In conclusion, significant variation was found among tomato genotypes for their tolerance to Cd and these differences were especially clear when individual plant tissues were studied. Genotype-dependent tolerance mechanisms influence the levels of accumulation of Cd among the tested 100 tomato genotypes. Independent genetic controls for Cd tolerance may exist in the genotypes as there was no correlation in metal uptake and translocation to the fruit; if these traits can be confirmed, they could be incorporated into a single genotype in breeding programs. Inheritance study might also determine which genotypes would be safe to use on metal contaminated soils.

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