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Inheritance Pattern of Some Quality Parameters in *Solanum lycopersicum* L. under Lead Stress

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Abstract: Eight lead (Pb) tolerant and five Pb-intolerant genotypes along with their 40 F_1 crosses were evaluated with two lead levels, i.e., 300 ppm, 600 ppm, and control. Significant variation was found in lines, testers, crosses and line × tester interactions for all the traits under study in both levels of stress. For lycopene contents, maximum positive and significant general combining ability (GCA) effects were observed in line Picdeneato, while line 006231 depicted maximum negative effects. Estimates of specific combining ability (SCA) effects showed that under 300 ppm lead stress, cross combination 9086 × Marmande exhibited maximum positive significant SCA effect for total soluble solids (TSS). Cross combination Sitara TS-01×17882 revealed maximum significant heterosis for total soluble solids. Positive heterosis for lycopene contents, ascorbic acid contents and total soluble solids could be considered good criterion and these quality traits may be exploited by hybrid breeding programs.

Key words: Ascorbic acid, Combining ability, Lead (Pb), Lycopene, Tomato.

INTRODUCTION

Quality of vegetables is determined by their nutritive contents as well as contaminants present in them. The unplanned industrialization and untreated disposal of industrial effluents has led to increase the pollutants in the ecosystem. Most of the industrial effluents contain heavy metal ions; constantly adding up the metal ion concentration in the environment that is highly toxic for terrestrial and aquatic organisms. As heavy metals are not biodegradable and can accumulate in human organs, so ingestion of vegetables irrigated with water possessing heavy metals may be a possible serious risk to human health.

The source of lead uptake in plants is mainly through soils receiving untreated sewage water (Uzu *et al*., 2009; Wang *et al.*, 2013) and from aerial parts (Uzu *et al*., 2010) near roads and smelting industries (Liu *et al.*, 2013). Adsorption of lead takes place onto roots and, then, it bounds to the polysaccharides of the rhizoderm cell surface or to carboxyl groups of mucilage uronic acid. Many plant species have been reported to have lead adsorption onto their roots, such as, *Vigna unguiculata* (Kopittke *et al*., 2007), *Festucarubra* (Ginn *et al*., 2008), *Brassica juncea* (Meyers *et al*., 2008), *Lactuca sativa* (Uzu *et al*., 2009) and *Funariahygrometrica*. After adsorption, lead follows passive pathway of water translocation to enter into the plant. Observations of root apex for lead concentration gradient indicated that absorption of lead is not uniform in plant roots. Lower pH of rhizodermic cells and thin cell walls increase solubility and absorption of lead in soil solution, that is why lead concentration is found more in root apical cells than others. From roots, it moves to apoplast and follows water streams until it reaches the endodermis. Here, it is choked by casparian strip and follows symplastic transport. Plant detoxification system acts here to get rid of the lead.

Tomato (*Solanum lycopersicum* L.) is a very important food crop and mainly exposed to sewage water sites due to irrigation around big cities by raw sewage water. Water purification is an expensive task for developing countries; therefore, the economical approach is to develop such genotypes, which accumulate heavy metals in non-edible portion of the plants instead of edible portion. Tomato crop suits best for this approach as the edible part of tomato crop

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is its fruit. Identification of suitable parents for hybrids of economic importance is an important task as most of the tomato grower community prefers hybrid tomatoes due to high yield.

However, the reports on identification of vegetable plants applicable to grow in contaminated soils are still sparse (Wiszniewska *et al*., 2015) and tomato genotypes have not been investigated in this respect to date. For this reason, the experimental work was laid out to study the influence of lead chloride concentrations on quality parameters, such as, lycopene content, ascorbic acid content and total soluble solids of tomato plant. Moreover, the inheritance of lead tolerance to discriminate into fruit of tomato could only be achieved when we cross two extreme genotypes and this is effective in line × tester mating design. Estimates of general combining ability and specific combining ability provide information about selection of parents and hybrids for future breeding programs, therefore, objective of the current study was to investigate the inheritance of lead accumulation in tomato plants and its possible impact on the quality of tomato fruit.

MATERIALS AND METHODS

Plant material and experimental design: Eight Pb-tolerant (9086, Roma, Sitara TS-01, Pak-0010990, Picdeneato, CLN-2123A, 006231, 7035) and five Pb-intolerant (42-07, 17883, BL-1176-Riostone-1-1, 17882) genotypes were used for hybridization program as indicated in Table 1. Selection was made for tolerant and intolerant genotypes on the basis of metal contents in the edible part of the plant, i.e., tomato fruit (Hussain *et al.,* 2015). During 1st year, these thirteen genotypes were transplanted in the field and at flowering stage, the crosses were made keeping tolerant lines as female and susceptible as male. Emasculation was performed when female flowers were at turning stage (cream to yellow). Anther cones were collected in butter paper bag of size 8 × 8 cm from male plants and dried for 24 hours at 30 °C in oven. Next day, pollens were collected by shaking anther cones in plastic jar and were applied to already emasculated flowers by camel hair brush. After pollination, flowers were covered with butter paper bag of size 4 × 3 cm and the seeds were extracted from successful fruits and dried up to 12% moisture and stored.

Next year, the nursery of 53 tomato genotypes was raised in compost-filled trays of size 15 × 15 cm Seeds were grown in growth chamber (16 h light/8 h dark) under mercury lamps, providing a light intensity of 150 mmol/m^2 per sec., day/night temperature of 25/20°C and 65(95)% relative humidity. Forty-days old nursery of thirteen genotypes (eight tolerant and five intolerant) along with their 40 F_1 hybrids was shifted in plastic bags each of size 30 × 10 cm; filled with one kg soil having pH 7.6, organic matter 1.3%, sand : silt : clay (47 : 22 : 31), EC (2.026 dS m^{-1}), TSS (22.6 mmol L^{-1}), Cl^- (8.25 Me L^{-1}), Pb (0.269 ppm) and Cd (0.046 ppm). Experiment was laid-out in triplicate Complete Randomized Design with two factors (factorial) and three treatments. Six plants/bags were used in each replication for each genotype. Thus, the whole experiment comprised 477 pots, arranged in completely randomized design in glass house (under relative humidity 70% and average temperature 25 ± 5 °C). Water holding capacity of soil was determined as 250 ml/Kg of soil. After one week of transplanting, lead chloride ($PbCl_2$) was applied in solution form (250 ml) only once at a concentration of 300 ppm and 600 ppm along with the control (no salt). Concentrations were decided on the basis of safe limit of lead for plants in soil and the 2nd double level for future breeding, if safe limit exceeds up to double. Normal agronomic (watering, hoeing, fertilization (i.e., NPK 20:20:20) and plant protection measures (pesticides and fungicides) were adopted during the whole experiment. Seventy days after transplanting, fruits of six plants were picked up from each genotype in each replication separately and weighed with electric balance.

Table 1: Names of lines and testers with code name.

Code	Lines	Code	Testers
L1	9086	T1	42-07
L2	Roma	T2	17883
L3	Sitara TS-01	T3	BL-1176-RIOSTONE-1-1
L4	Pak0010990	T4	17882
L5	Picdeneato	T5	Marmande
L6	CLN-2123A		
L7	006231		
L8	7035		

Total soluble solids (TSS %): It was measured with the help of refractometer (Bench type refractometer 3t ATAGO, Japan) from composite juice of two samples having five fruits per plant. These fruits were collected separately from each genotype in each replication.

Ascorbic acid contents: Extraction of ascorbic acid was done according to Cerhata *et al.* (1994). Leaf

tissues were homogenized in perchloric acid and the volume was adjusted to 1 ml by adding double-distilled water (ddH_2O). The mixture was centrifuged at 4500 rpm for 5 min at 4 °C. The supernatant was filtered and the ascorbic acid level was determined with the method of Tavazzi *et al*. (1992) by HPLC utilizing a column (250 × 4.6 ID) packed with Li–60 reversed-phase material (10 µm particle size) with mobile phase (3.7 mM phosphate buffer, pH 4.0) at one ml min^{-1} flow rate.

Lycopene content: For extraction of lycopene from tomato products 5 mg of sample (tomato powder) was homogenized in 50 ml methanol, one gram calcium bicarbonate and 5 g of celite. The sample was then filtered through Whatman No.1 and No.42 filter papers. Lycopene was extracted using a sample of hexane: acetone (1:1, v/v), and quantified spectrophotometrically at 472 nm and expressed in mg/100 g fresh weight (FW).

Heavy metal analysis: Fruits, leaves, roots and shoots were collected in kraft paper bags separately and shifted to oven for drying purpose. Plant samples were subjected to heavy metal analysis according to Ryan *et al*. (2001) with some modification. After drying, samples were ground to fine powder and half gram of each sample was used for digestion purpose, using tri-acid method, i.e., HNO_3, $HClO_4$ and H_2SO_4 in 5:2:1 ratio to form digestion mixture. Digestion was done on hot plate keeping temperature 100 °C for first hour, 150 °C for 2nd hour, 200 °C for 3rd hour and 250 °C for 4th hour, using 15 ml of digestion mixture. After digestion, samples were filtered with Whatman filter paper No. 42 and volume was made accordingly by adding distilled water. The filtered samples were stored in air tight plastic bottles and subjected to heavy metal analysis in atomic absorption spectrophotometer (Model Thermo Electron S-Series).

Statistical analysis: The individual plant data regarding all the traits were analyzed, using analysis of variance technique (Steel *et al*., 1997) to determine the significance of genotypic differences regarding heavy metals stress. The characters showing significant differences were further subjected to Line × Tester analysis as outlined by Kempthorne (1957) to obtain the information about gene action, general combining ability (GCA), specific combining ability (SCA) and better parent heterosis by Falconer and Mackay (1996). Percent heterosis over better parent (Heterobeltiosis) was computed after calculating heterosis on respective parents, using formulae based on the amount of heterosis, expressed as the difference between F_1 and the better parent values, proposed by Falconer and Mackay (1996) for heterosis.

RESULTS AND DISCUSSION

Formal analysis of variance portioned the treatments into parents, crosses and parents vs crosses; parents were further portioned into lines, tester and line × tester (Table 2). Significant differences among lines, testers and their interaction have been found, which allow further processing for estimation of GCA, SCA and heterosis. Under 300 ppm lead (Pb) stress, all lines and testers showed significant GCA effects for lycopene contents (Table 3). For ascorbic acid contents, maximum positive and significant GCA effects were shown by L5 (Picdeneato) while L4 (PAK 0010990) revealed maximum negative effects. Under 600 ppm lead (Pb) stress, all lines and testers depicted significant GCA effects for total soluble solids (Table 3). Crosses exhibited variable magnitude of SCA effects for total soluble solids (Table 4). Estimates of SCA effects showed that under 300 ppm lead stress, cross combination L1 × T5 (9086 × Marmande) exhibited maximum positive significant SCA effect for total soluble solids along with 18 other crosses, while cross combination L8 × T2 (7035 × 17883) showed maximum SCA effects for ascorbic acid contents along with thirteen other crosses. The cross combination L3 × T1 (Sitara TS-01 × 42-07) proved good for lycopene contents (Table 4).

Estimates of heterosis showed that under 300 ppm lead stress, cross combination L3 × T4 (Sitara TS-01 × 17882) along with 38 other crosses exhibited maximum significant heterosis for total soluble solids while cross combination L3 × T5 (Sitara TS-01 × Marmande) showed significant heterosis for ascorbic acid contents along with 12 crosses (Table 5). For lycopene contents, maximum significant heterosis was observed in cross combination L3 × T1 (Sitara TS-01×42-07) along with 22 other cross combinations (Table 5). The heterotic studies under 600 ppm lead stress indicated that cross combination L3 × T4 (Sitara TS-01 × 17882) showed maximum heterosis for total soluble solids along with 20 other crosses, the cross combination L3 × T1 (Sitara TS-01 × 42-07) exhibited the highest heterotic effects for ascorbic acid contents with 18 other crosses and cross L8 × T2 (7035 × 17883) proved the best regarding heterotic effects for lycopene contents along with 22 other cross combinations, which yielded positive significant results. Heterosis studies under control depicted that cross combination L4 × T3 (PAK 0010990 × BL-1176-Riostone-1-1) exhibited maximum negative significant heterosis for total soluble solids, followed by cross combination L3 × T4 (Sitara TS-01 × 17882). Minimum significant heterotic effects were shown by cross combination L5 × T4 (Picdeneato × 17882), followed by cross combination L5 × T5 (Picdeneato × Marmande), while cross combination L6 × T5 (CLN-2123A × Marmande) showed significant heterosis for ascorbic acid contents along with 24 other crosses and the cross combination L8 × T4 (7035 × 17882) revealed positive significant heterosis for lycopene contents along with 30 other crosses.

Similarly, under 600 ppm lead stress, cross combination L1 × T5 (9086 × Marmande) showed positive significant effects for total soluble solids, while negative significant SCA effects were shown by cross combination L5 × T4 (Picdeneato × 17882), followed by cross combination L1 × T4 (9086 × 17882). Out of forty crosses, twenty crosses depicted positive significant results for this trait. Cross combination L1 × T5 (9086 × Marmande) exhibited maximum positive significant SCA effects for ascorbic acid contents along with 19 other crosses, which displayed positive significant results, while negative significant results were exhibited by 12 cross combinations. For lycopene contents, cross combination L1 × T1 (9086 × 42-07) showed maximum positive significant SCA effects.

Under both 300 and 600 ppm lead stress, significant SCA variances were observed for total soluble solids, while dominance variance was found significant for ascorbic acid contents under 600 ppm lead stress (Table 6). Overall, the quality traits showed high SCA variances and the same trend was observed for dominance variances where they were found more than that of additive type for all traits under study (Table 6).

Table 2: Mean squares for various traits of F_1 generations of 13 tomato accessions under 300 ppm, 600 ppm lead and control.

	300 ppm			600 ppm			Control	
SOV	**DF**	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**	**TSS**	**AaC**
Treatments	0.42**	286.4**	3.42**	0.35**	2279.77**	11.83**	0.39**	2070.45**	7.32**
Parents	0.28**	279.67**	7.05**	0.32**	3803.34**	21.25**	0.38**	4017.41**	18.51**
Crosses	0.36**	254.5**	2.35**	0.28**	1816.91**	9.16**	0.31**	1515.8**	4.06**
Parents vs Crosses	4.09**	1611.43**	1.2**	3.68**	2048.38**	2.95**	3.64**	338.4**	0.23**
Females	0.37**	145.37**	1.61**	0.39**	499.5**	4.01**	0.37**	505.24**	1.67**
Males	0.66**	662.97**	13.83**	0.29**	3624.13**	27.64**	0.55**	4927.41**	7.64**
F vs M	1.49**	7.6NS	14.64**	2.95**	761.18**	0.65**	3.12**	2992.39**	131.9**
Line × Tester	0.32**	223.43**	0.9**	0.25**	1888.08**	7.81**	0.26**	1281.06**	4.15**
Error	0.0000219	8.53	0.00038	0.0000219	7.41	0.000383	0.000022	6.18	0.00038

NS = non-significant, * = significant at α 5%, **= highly significant at α = 1%, TSS = total soluble solids (°Brix), LC= lycopene contents (µg/100 g), AaC=Ascorbic acid contents (µg/100 g).

Table: 3: General combining ability estimates of various tomato quality traits under 300 ppm, 600 ppm lead and control.

	300 ppm			600 ppm			Control		
Lines	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**
L1	–0.15**	1.16^{NS}	0.15**	–0.15**	3.06**	0.38**	–0.14**	–8.02**	0.36**
L2	–0.04**	1.07^{NS}	0.31**	–0.05**	6.32**	0.25**	–0.03**	–7**	0.44**
L3	0.13**	$–1^{NS}$	–0.09**	0.14**	4.46**	0.27**	0.15**	–2.18**	0.17**
L4	0.09**	–4.73**	0.14**	0.08**	–8.2**	0.22**	0.09**	0.53^{NS}	–0.07**
L5	–0.3**	5.08**	0.48**	–0.3**	0.17^{NS}	0.66**	–0.31**	9.17**	0.05**
L6	0.14**	–2.32**	–0.22**	0.12**	–9.16**	–0.65**	0.11**	2.02**	–0.5**
L7	0.06**	$–1.91^{NS}$	–0.43**	0.09**	$–0.21^{NS}$	–0.52**	0.06**	5.38**	–0.38**
L8	0.05**	2.64**	–0.34**	0.06**	3.54**	–0.61**	0.05**	0.09^{NS}	–0.07**
Testers									
T1	0**	–2**	1.33**	–0.02**	–2.52**	1.88**	0^{NS}	–4.43**	0.41**
T2	0.06**	–6.5**	–0.55**	0.06**	–16.44**	–0.27**	0.06**	8.99**	–0.66**
T3	0.19**	7.94**	–0.26**	0.13**	–3.87**	–0.32**	0.18**	–10.25**	0.71**
T4	–0.01**	0.95^{NS}	–0.17**	–0.02**	6.35**	–0.51**	–0.01**	–14.46**	–0.07**
T5	–0.25**	$–0.38^{NS}$	–0.34**	–0.15**	16.48**	–0.77**	–0.22**	20.15**	–0.38**
SE Line	0.00121	0.75442	0.00505	0.00121	0.70319	0.00505	0.00121	0.64229	0.00505
SE Tester	0.00096	0.59642	0.004	0.00096	0.55592	0.004	0.00096	0.50778	0.004

NS = non-significant, * = significant at α 5%, ** = highly significant at α = 1%, TSS = total soluble solids (°Brix), LC = lycopene contents (µg/100 g), AaC = Ascorbic acid contents (µg/100 g).

Table 4: Specific combining ability estimates of various tomato quality traits under 300 ppm, 600 ppm lead and control.

	300 ppm			600 ppm			Control		
Crosses	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**
L1×T1	–0.37**	0.2^{NS}	0.3**	–0.26**	–16.83**	3.01**	–0.28**	–1.36^{NS}	–1.47**
L2×T1	0.11**	–5.39**	0.53**	0.06**	–12.12**	1.11**	0.1**	–7.42**	0.76**
L3×T1	–0.1**	12.27**	0.88**	–0.13**	37.92**	0.77**	–0.17**	38.76**	1.35**
L4×T1	–0.25**	1.37^{NS}	0.57**	–0.1**	–0.38^{NS}	1.47**	–0.1**	–17.61**	0.54**
L5×T1	0.35**	–15.59**	–0.01^{NS}	0.32**	–5.51**	0.56**	0.41**	–19.26**	–0.74**
L6×T1	–0.12**	8.24**	–0.91**	–0.06**	–9.69**	–0.6**	–0.09**	–5.43**	–1.42**
L7×T1	0.38**	–3.04^{NS}	–0.8**	0.24**	–15.87**	–3.25**	0.29**	–19.06**	0.28**
L8×T1	0.42**	1.94^{NS}	–0.56**	–0.08**	22.51**	–3.08**	–0.15**	31.4**	0.69**
L1×T2	0.16**	7.14**	0.53**	0.23**	–0.21^{NS}	–1.48**	0.2**	–13.89**	0.05**
L2×T2	0.29**	–6.56**	0.36**	0.17**	–6.88**	–1.57**	0.23**	–14.6**	–0.95**
L3×T2	–0.16**	–0.62^{NS}	–0.3**	–0.08**	–20.36**	1.64**	–0.14**	8.78**	–1.49**
L4×T2	0.11**	–0.9^{NS}	–0.37**	0.05**	1.95^{NS}	–0.55**	0.05**	2.72^{NS}	0.84**
L5×T2	0.29**	–4.2^{NS}	–0.73**	0.26**	32.69**	–1.27**	0.19**	36.45**	1.06**
L6×T2	–0.27**	–2.35^{NS}	0.07**	–0.12**	0.12^{NS}	0.85**	–0.15**	–1.39^{NS}	0.72**
L7×T2	–0.14**	–5.93**	0.19**	–0.21**	–1.59^{NS}	0.43**	–0.14**	6.36**	–0.38**
L8×T2	–0.29**	13.45**	0.24**	–0.29**	–5.7**	1.95**	–0.22**	–24.43**	0.14**
L1×T3	0.13**	–4.87**	–0.33**	0.06**	–9.52**	–1.21**	0.11**	–1.83^{NS}	0.46**
L2×T3	0.07**	–8.02**	–0.63**	0.03**	16.58**	–1.46**	0^{NS}	29.75**	0.62**
L3×T3	–0.36**	–2.37^{NS}	–0.2**	–0.25**	–14.33**	–0.75**	–0.24**	–11.03**	–0.06**
L4×T3	0.02**	–7.74**	–0.15**	–0.03**	–0.35^{NS}	–0.62**	0.05**	–8.63**	–0.43**
L5×T3	0.33**	6.07**	–0.03**	0.4**	–12.59**	2.07**	0.36**	–11.05**	–1.56**
L6×T3	0.01**	5.66**	0.36**	–0.04**	2.56^{NS}	0.66**	–0.02**	–11.2**	0.59**
L7×T3	–0.03**	7.89**	0.64**	–0.1**	28.86**	0.35**	–0.15**	24.22**	0.94**
L8×T3	–0.18**	3.38^{NS}	0.35**	–0.07**	–11.19**	0.95**	–0.1**	–10.23**	–0.55**
L1×T4	–0.33**	–7.23**	0.08**	–0.44**	–29.64**	0.26**	–0.37**	–3.01^{NS}	–0.8**
L2×T4	0.09**	9.68**	0.06**	0.13**	–19.65**	1.25**	0.09**	7.73**	–1.55**
L3×T4	0.39**	–4.82**	0.24**	0.26**	–20.73**	–1.42**	0.3**	–13.42**	0.41**
L4×T4	–0.01**	4.9**	0.19**	–0.09**	30.54**	–1.42**	–0.14**	26.28**	1.23**
L5×T4	–0.76**	11.21**	0.36**	–0.68**	1.94^{NS}	–0.64**	–0.68**	–5.77**	0.62**
L6×T4	0.3**	–13.5**	0.16**	0.22**	–10.44**	–0.45**	0.3**	–17.15**	–0.64**
L7×T4	0^{NS}	2.06^{NS}	–0.61**	0.2**	18.96**	2.28**	0.14**	–0.39^{NS}	–0.54**
L8×T4	0.31**	–2.31^{NS}	–0.5**	0.38**	29.03**	0.14**	0.35**	5.75**	1.27**
L1×T5	0.4**	4.76**	–0.58**	0.41**	56.22**	–0.58**	0.34**	20.1**	1.76**
L2×T5	–0.58**	10.3**	–0.32**	–0.41**	22.07**	0.67**	–0.43**	–15.46**	1.11**
L3×T5	0.23**	–4.44**	–0.61**	0.2**	17.5**	–0.24**	0.27**	–23.08**	–0.2**
L4×T5	0.12**	2.36^{NS}	–0.25**	0.17**	–31.74**	1.13**	0.13**	–2.75^{NS}	–2.18**
L5×T5	–0.21**	2.5^{NS}	0.42**	–0.32**	–16.51**	–0.72**	–0.28**	–0.35^{NS}	0.62**
L6×T5	0.07**	1.94^{NS}	0.31**	0.01**	17.44**	–0.46**	–0.03**	35.18**	0.74**
L7×T5	–0.21**	–0.98^{NS}	0.57**	–0.14**	–30.35**	0.17**	–0.13**	–11.12**	–0.3**
L8×T5	0.17**	–16.46**	0.46**	0.07**	–34.64**	0.02^{NS}	0.13**	–2.5^{NS}	–1.55**
S.E	**0.0027**	**1.6869**	**0.0113**	**0.0027**	**1.5724**	**0.0113**	**0.0027**	**1.4362**	**0.0113**

NS = non-significant, * = significant at α 5%, ** = highly significant at α = 1%, TSS = total soluble solids (°Brix), LC = lycopene contents (µg/100 g), AaC = Ascorbic acid contents (µg/100 g)

Table 5: Estimates of heterosis for heavy metal tolerance in tomato under 300 ppm, 600 ppm lead and control

	300 ppm			600 ppm			Control		
Crosses	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**	**TSS**	**AaC**	**LC**
L1×T1	–20.45*	–3.77^{NS}	–31.93**	–22.61*	–6.88^{NS}	–15.94*	–20.61*	–10.38^{NS}	–39.2*
L2×T1	–8.71*	–11.49**	30**	–14.28*	21.92*	3.61*	–11.46*	–24.42*	7.38*
L3×T1	–9.53*	9.66**	125.29**	–14.28*	103.36*	–0.49*	–13.11*	–17.2*	21.67*
L4×T1	–13.29*	–10.17**	82.15**	–14.85*	27.74*	7.99*	–12.97*	3.68*	–24.21*
L5×T1	–9.03*	–23.6**	53.65**	–14.24*	32.56*	1.97*	–10.87*	15.38*	–22.86*
L6×T1	–9.64*	2.41^{NS}	–2.9**	–13.29*	–11.85^{NS}	–31.08*	–12.43*	26.56*	–35.17*
L7×T1	–1.18*	–12.34**	52.81**	–8.11*	–53.9*	–64.46*	–6.32*	–21.81*	–24.36*
L8×T1	–9.14*	0.61^{NS}	9.02**	–14.98*	54.6*	–63.44*	–14.58*	–22.89*	28.98*
L1×T2	–16.39*	19.88**	–52.43**	–14.04*	–3.77^{NS}	–72.74*	–14.88*	–9.21*	–34.43*
L2×T2	–12.17*	–9.62**	–15.6**	–13.12*	–2.42^{NS}	–2.75*	–12.58*	–17.11*	–29.68*
L3×T2	–17.19*	3.62^{NS}	–2.99**	–14.31*	–21.08*	39.49*	–15.82*	–29.06*	–35.22*
L4×T2	–12.89*	–10.1**	–7.73**	–12.79*	–9.34^{NS}	20.31*	–13.32*	67.76*	–32.27*
L5×T2	–16.96*	–14.69**	–19.25**	–16.17*	38.24*	–22.25*	–18.07*	151.91*	–13.64^{NS}
L6×T2	–19.05*	–8.23^{NS}	–25.45**	–15.35*	–16.62*	47.16*	–16.64*	71.28*	–21.09*
L7×T2	–17.99*	–11.84**	2.4**	–17.66*	–53.68*	11.88*	–17.38*	24.67*	–43.84*
L8×T2	–20.99*	31.1**	–19.55**	–19.62*	–4.37^{NS}	84.61*	–18.89*	–52.48*	1.02*
L1×T3	–6.78*	–0.66^{NS}	–59.7**	–9.62*	–46.52*	–70.75*	–5.11*	–54.05*	–15.62^{NS}
L2×T3	–5.96*	–4.91^{NS}	–31.25**	–7.98*	–28.46^{NS}	19.15*	–5.25*	–30.4*	9.61*
L3×T3	–10.95*	–0.23^{NS}	10.8**	–9.81*	–48.63*	–15.27*	–6.31*	–57.04*	5.44*
L4×T3	–4.11*	–12.14**	8.39**	–6.57*	–47.82*	17.16*	–1.57*	–52.78*	–31.26*
L5×T3	–5.93*	17.3**	8.45**	–5.69*	–50.2*	47.49*	–3.58*	–48.26*	–29.32*
L6×T3	–3.27*	8.58**	–10.93**	–6.1*	–46.61*	66.85*	–2.78*	–53.56*	–4.81*
L7×T3	–5.82*	12.04**	28.87**	–7.85*	–28.45*	8.79*	–6.21*	–25.43*	–13.7*
L8×T3	–8.95*	12.11**	–8.9**	–7.81*	–47.26*	80.17*	–5.46*	–56*	–0.45*
L1×T4	–16.01*	–2.43^{NS}	–53.37**	–23.78*	–11.4*	–59.82*	–20.57*	–25.4*	–37.27*
L2×T4	–6.2*	22.27**	–13.94**	–10.48*	10.58*	41.01*	–9.78*	–18.42^{NS}	–29.86*
L3×T4	5.21*	–2.08^{NS}	31.08**	–3.94*	6.98*	–34.61*	–2.35*	–61.76*	0.93*
L4×T4	–5.38*	6.74^{NS}	22.18**	–12.11*	54.29*	–27.64*	–11.87*	67.93*	–22.11*
L5×T4	–29.47*	14.9**	22.05**	–31.37*	29.51*	–13.95*	–29.63*	32.07*	–11.81*
L6×T4	–1.39*	–16.75**	–13.91**	–5.17*	–2.41^{NS}	–25.19*	–2.96*	–0.88^{NS}	–31.44*
L7×T4	–4.41*	6.71^{NS}	–11.98**	–6.18*	–28.25^{NS}	47.37*	–7.04*	–11.48*	–39.16*
L8×T4	1.85*	6.96^{NS}	–29.51**	–3.31*	66.83*	–8.92*	–3.14*	–47.78*	30.5*
L1×T5	–14.84*	27.22**	–63.82**	–12.2*	99.07*	–69.27*	–15.86*	48.91*	–13.41*
L2×T5	–31.33*	25.27**	–26.34**	–25.86*	80.79*	40.28*	–27.91*	–5.05*	1.52*
L3×T5	–12.56*	36.91**	0.32^{NS}	–10.33*	72.6*	–13.98*	–11.98*	–43.88*	–12.53*
L4×T5	–15.44*	4.09^{NS}	2.47**	–11.97*	–6.15^{NS}	52.81*	–15.44*	77.71*	–60.61*
L5×T5	–29.24*	1.9^{NS}	18.91**	–28.92*	23.88*	–20.96*	–30.13*	105.12*	–15.69*
L6×T5	–15.48*	7.58^{NS}	–14.22**	–14.19*	41.79*	–20.59*	–18.01*	159.13*	–17.28*
L7×T5	–22.19*	5.2^{NS}	32.47**	–17.94*	–51.24*	–8.19*	–20.83*	17.09*	–39.87*
L8×T5	–15.23*	–7.35^{NS}	–8.32**	–14.38*	5.08*	–4.72*	–16.04*	–29.39*	–23.36*
L1	4.61	60.6	8.05	4.5	86.9	11.74	4.84	77.69	9.5
L2	4.9	65.9	4.52	4.68	72.9	2.09	4.92	85.47	7.53
L3	4.68	48	2.58	4.61	57.2	4.46	4.8	139.63	6.91
L4	4.89	66.1	3.15	4.66	67.3	3.29	5.07	57.05	9.7
L5	4.93	77.3	3.57	4.7	64.1	4.75	5	54.81	8.03
L6	5.07	65.8	3.99	4.87	86.03	2.28	5.14	54.34	7.65
L7	4.77	64.9	2.11	4.96	170.5	3.76	5.08	83.58	8.97
L8	4.37	61.9	3.77	4.41	78.1	2.54	4.5	143.33	5.81
T1	5.08	73.7	2.47	5.29	67.4	7.56	5.49	59.74	1.61
T2	5.55	61.2	2.83	5.44	82.2	3.06	5.77	47.94	5.82
T3	5.09	76.3	2.82	5.06	162.5	2.55	5.21	137.87	6.58
T4	4.83	68.1	2.79	5.13	81.6	3.95	5.35	47.4	4.57
T5	5.35	44.3	2.63	5.28	78.6	3.38	5.66	51.97	2.58

Ns = non-significant, * = significant at α 5%, ** = highly significant at α = 1%, TSS = total soluble solids (°Brix), LC = lycopene contents (µg/100 g), AaC = Ascorbic acid contents (µg/100 g)

Table 6: Estimates of variances due to GCA, SCA, additive variance, dominance variance, ratio to GCA and SCA under control, 300 ppm and 600 ppm lead.

Effects	300 ppm			600 ppm			Control		
	TSS	AaC	LC	TSS	AaC	LC	TSS	AaC	LC
σ^2GCA	0.010	9.269	0.350	0.004	8.909	0.411	0.010	73.603	0.026
σ^2SCA	0.324	220.586	0.907	0.257	1885.615	7.810	0.261	1279.004	4.150
σ^2 GCA/σ^2SCA	0.031	0.042	0.386	0.017	0.005	0.053	0.040	0.058	0.006
σ^2D	0.020	18.538	0.699	0.009	17.819	0.823	0.021	147.206	0.052
σ^2A	0.324	220.586	0.907	0.257	1885.615	7.810	0.261	1279.004	4.150

In the current study, significant differences among parents with respect to all characters indicated that the breeding material had sufficient genetic variability and may be exploited in future breeding program for the improvement of quality related traits in tomatoes, grown under different lead stress conditions. Gene action, involved in inheritance of lead tolerance, is mostly dominant type, because variances, due to GCA and SCA, are always found less than unity. This kind of gene action suggests breeding for hybrids, which accumulate less Pb in edible portion of the plant. In second category of genotypes, where lycopene and ascorbic acid contents and total soluble solids are affected significantly; Pb reaches to the leaves through vascular flow (Krzesłowska *et al*., 2010) and it forms complexes with amino acids or organic acids (Maestri *et al*., 2010). Liu *et al.* (2010) suggested translocation factor for flow of Pb to aerial parts from roots. Results of this translocation factor mostly indicate a lower value, which shows lower transfer rate of Pb to aerial parts. Metal transport to grain tissues or fruit is restricted and most of the quantity is deposited in roots. However, when it reaches the grain or fruit, it disturbs the metabolic process such as lycopene, ascorbic acid and total soluble solids. Various vegetable species differed in metal uptake and accumulation due to level in soil, metal characteristics, metal speciation, presence of other counter species of ions, environmental growth condition and crop genetic factors (Murtaza *et al*., 2008). The results of the present study suggest that such kind of research is very important to know about the behaviour of metals and response of genotypes within species. Genotypes, which behaved well in 300 ppm lead stress, also have ability to show performance in 600 ppm, but a gradual decrease in tolerance can be observed, which suggests that for each genotype, the threshold level should be determined separately. The presence of non-additive gene action for these traits requires maintenance of heterozygosity in the population. Hence, it is necessary to follow the modified breeding methods, such as, bi-parental cross or triple test cross design or any other form of recurrent selection method in early generations, which is more useful for exploitation of non-additive gene action in order to recover breaking linkages, releasing concealed variability, improving the concentration of favorable genes and changing linkage equilibrium, otherwise heterosis breeding would be a main breeding method for the improvement of these traits. As the ratio GCA/SCA was lower than 1, it may be concluded that the non-additive gene action (dominance and epistasis) played an important role in the inheritance of all the traits either quality or morphology. In a study in tomato, the means of F_1 crosses were found intermediate between both parents in fruit set percentage, average fruit weight, and total soluble solids indicating incomplete dominance (Hegazi *et al*., 1995). Other means of F_1 surpassed the better parent for many morphological and quality parameters in tomato. Metwally *et al*. (2005) reported that over dominance effects regulate the inheritance of various yield related traits in *Solanum lycopersicum* L. Dordevic *et al*. (2010) and Solieman (2009) also reported that total fruit yield per plant was inherited by dominance or over dominance type of gene action.

CONCLUSION

Considering higher per se performance and significant SCA effects for total soluble solids, lycopene and ascorbic acid contents, the cross combination 9086 × Marmande, Roma × 17883 and Picdeneato × Marmande can be safely used in soils irrigated by raw sewage water and for future breeding programs. Moreover, the traits like high metal contents in non-edible portion (leaf, shoot and root), less metal contents in edible portion (fruit) can be used as selection criteria for developing heavy metal tolerant tomato varieties.

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