Pak. J. Agri. Sci., Vol. 57(X), xxx-xxx; 2020
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/20.7305
http://www.pakjas.com.pk

GENETIC ASSOCIATION BETWEEN ACHENE YIELD AND FATTY ACID PROFILE UNDER LEAD TOXICITY IN SUNFLOWER (*Helianthus annuus* L.)

Rizwana Qamar[1], *Amir Bibi[1], Muhammad Ahsan Iqbal[1], Sehar Nawaz[2] and Zeba Ali[1]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad
[2]Centre of Agricultural Biochemistry and Biotechnology, University of Agriculture, Faisalabad
***Corresponding author's email address: ameerbibi@gmail.com**

The research trial was conducted in wirehouse of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad during spring season, to assess the influence of lead toxicity on achene yield and quality related attributes in sunflower. Twenty sunflower genotypes were collected from US National Plant Germplasm System (USDA) and were evaluated under control and lead (Pb) stress conditions. Data were recorded for 100 achene weight (100 AW), achene yield per plant (AYP), oil contents (OC), oleic acid (OA), linoleic acid (LA), palmitic acid (PA) and lead accumulation in plant organs viz; roots (PbR), shoots (PbS), leaves (PbL) and achene (PbA). Highest accumulation of lead was observed in roots and leaves. Substantial extent of genetic variation was present among sunflower genotypes for traits related to yield, oil quality and lead accumulation in plant organs. The genotypes PI599979 and PI536625 showed maximum achene yield under lead stress. Accumulation of lead in leaves and achene had significantly reduced achene yield per plant. Therefore, it is suggested that 100 achene weight, lead accumulation in leaves and achene can be used as selection criteria for development of lead tolerant genotypes in sunflower.
Keywords: Sunflower, genetic variations, lead tolerance, oil quality, abiotic stress, correlation.

INTRODUCTION

Lead toxicity is now considered as serious environmental issue and gained attention by various researchers worldwide. Considerable increase in concentration of lead in upper layer of cultivated soil has been observed in vicinity of industrial and urban areas (De Abreu *et al.*, 1998). Regulatory measures have been adopted in various countries to check input of lead in environment but it is still most important environmental issue in underdeveloped countries. Extensive use of agricultural chemicals (fertilizers, pesticides, herbicides), combustion of leaded gasoline, emission from nonferrous metals and input of industrial and municipal waste causes addition of lead (Pb) to agricultural soils (Davies, 1990). Unfortunately, no major breeding program was organized in the past to minimize losses caused by lead stress. Breeders have to define targets, evaluate natural variability for lead tolerance, select appropriate breeding methods, develop selection criteria on the basis of traits related to lead stress and select potential sources of heavy metal tolerance from wild species.

Sunflower (*Helianthus annuus* L.) is grown all over the world for its finest quality oil. Its oil is considered best for heart patients because of higher proportion of unsaturated fatty acids. Sunflower is the most important oilseed crop of Pakistan after cotton (Govt. of Pakistan, 2017). Although sunflower had ability to withstand various kinds of stresses, but its production reduces when it is practiced on marginal soils where one or another kind of stress offers a limiting environment (Skoric *et al.*, 2000). Sunflower can accumulate toxic heavy metals in its roots and restricts its translocation to aerial parts especially edible portion (Qamar *et al.*, 2018). This research work was executed to evaluate genetic variability among sunflower genotypes for economically important traits in sunflower and their interrelationship especially with respect to accumulation of lead in roots, shoots, leaves and achene.

MATERIALS AND METHODS

A research trial was organized in wirehouse of Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad during spring season. Air dried soil was spiked with 300 $mgkg^{-1}$ lead nitrate $Pb(NO_3)_2$ for one month. Pots were filled with 8 kg of normal (T_1 = no salts) and spiked soil (T_2 = 300 $mgkg^{-1}$) after covering its bottom hole with plastic sheets to avoid leakage of salt. The trial was executed in three replications by following the randomized complete block design. Characteristics of soil used in this trial are given in Table 1.

Twenty genotypes of sunflower were collected from US National Germplasm System (USDA) (Table 2) based upon their characteristics related with higher achene yield and oil contents. Five seeds of each genotype were sown in separate pots. Only two seedlings were kept and maintained till maturity after removing extra seedlings at 5-6 leaf stage.

Standard agronomic and plant protection practices were followed during the conduct of whole trial. Diammonium phosphate and sulphate of potash were applied at pot filling stage, whereas application of three doses of urea were completed till flowering. Pots were irrigated after 2 to 3 days according to weather conditions. Plants were uprooted after completion of physiological maturity.

Table 1. Properties of soil used in the research trial.

Characteristics	Value
pH	7.8
EC	2.25 dS m^{-1}
Nitrogen	0.15 $mgkg^{-1}$
Phosphorous	7.2 $mgkg^{-1}$
Potassium	126 $mgkg^{-1}$
Lead	0.0024 $mgkg^{-1}$
Organic matter	0.56%

Table 2. List of 20 sunflower genotypes collected from US National Plant Germplasm System (USDA)

Sr. No	Genotypes	Sr. No.	Genotypes
1	PI497244	11	PI543743
2	PI505837	12	PI543744
3	PI509051	13	PI546356
4	PI509052	14	PI566826
5	PI536623	15	PI597371
6	PI536624	16	PI599979
7	PI536625	17	PI600724
8	PI536626	18	PI600725
9	PI536627	19	PI607508
10	PI536629	20	PI617099

Roots, shoots, leaves and achene were separated from plants and samples were prepared after oven drying at 80 °C for 2 days. Plant samples were subjected to heavy metal analysis according to Ryan *et al.* (2001) with some modifications. After drying, samples were ground to fine powder and half gram of each sample was used for digestion purpose using tri-acid method. Digestion was done on hot plate, keeping temperature 100^0C for first hour, 150^0C for 2nd hour, 200^0C for 3rd hour and 250^0C 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). Achene yield per plant (AYP) and 100 achene weight (100 AW) were recorded by using digital balance. One gram sample of achene from each genotype under control and stress conditions were prepared and subjected to NIR (System 6500, Software: WINISS version 1.02A) for the determination of oil contents (OC), oleic acid (OA), linoleic acid (LA) and palmitic acid (PA).

The collected data were subjected to analysis of variance as recommended by Steel *et al.* (1997). Liaison between economically important factors were assessed through correlation analysis as suggested by Kwon and Torrie (1964). Path coefficient analysis segregated direct and indirect effects of various traits on achene yield as suggested by Dewey and Lu (1959).

RESULTS

Mean squares of various traits are presented in Table 3. All genotypes had highly significant differences for studied traits, proposing the existence of genetic variability among genotypes not only for achene yield and oil quality but also for accumulation of lead in plant organs. All genotypes showed reduction in 100 AW, AYP, OC and OA whereas LA and PA showed increase in mean values under stress conditions. The Genotypes PI546356, PI536627 and PI617099 showed minimum percent change in values for 100 AW, AYP and OC respectively (Table 4) whereas the

Table 3. Mean square values for various traits under lead stress.

Source of variation	Control Conditions (T_1)		300 ppm Lead (T_2)	
	Replications	Genotypes	Replications	Genotypes
Degree of Freedom	2.000	19.00	2.000	19.00
100 Achene weight (100AW)	0.010	1.93**	0.020	1.92**
Achene yield per plant (AYP)	0.400	146.70**	0.300	132.70**
Oil contents (OC)	0.100	4.96**	0.100	4.96**
Oleic acid (OA)	0.008	22.20**	0.014	22.20**
Linoleic acid (LA)	0.008	18.70**	0.008	18.79**
Palmitic acid (PA)	0.008	1.22**	0.002	1.22**
Lead contents in roots (PbR)	-	-	0.640	67.42**
Lead contents in shoots (PbS)	-	-	0.0004	0.05**
Lead contents in leaves (PbL)	-	-	2.130	41.56**
Lead contents in achene (PbA)	-	-	0.00046	0.988**

genotypes PI509052, PI536624 and PI509051 showed minimum percent change in values for OA, LA and PA. respectively (Table 5).

Table 4. Mean values and percent change in values for achene yield related characters in Sunflower genotypes under control (T_1) and 300 ppm stress (T_2)

Genotypes	100 Achene Weight (g)			Achene Yield per Plant (g)			Oil Contents (%)		
	Control	300 ppm lead	% change	Control	300 ppm lead	% change	Control	300 ppm lead	% Change
PI497244	4.19	3.26	22.20	29.6	19.2	35.1	37.1	31.8	14.29
PI505837	5.86	4.95	15.53	40.5	28.9	28.6	37.4	34.4	8.02
PI509051	3.98	3.23	18.84	28.5	16.9	40.7	38.5	34.6	10.13
PI509052	4.06	3.28	19.21	24.6	17.2	30.1	38.1	32.2	15.49
PI536623	5.99	5.03	16.03	28.5	27.6	3.2	38.2	33.1	13.35
PI536624	4.12	3.40	17.48	23.3	14.2	39.1	40.0	36.2	9.50
PI536625	6.24	5.18	16.99	45.5	34.6	24.0	38.5	35.3	8.31
PI536626	4.60	3.48	24.35	39.6	28.9	27.0	38.6	34.8	9.84
PI536627	5.45	4.66	14.50	29.5	28.6	3.1	37.6	32.7	13.03
PI536629	5.84	4.90	16.10	34.6	29.7	14.2	38.5	34.7	9.87
PI543743	4.42	3.49	21.04	27.6	18.3	33.7	39.3	35.4	9.92
PI543744	5.64	4.74	15.96	42.7	31.4	26.5	39.3	34.1	13.23
PI546356	5.95	5.13	13.78	39.5	31.6	20.0	35.7	32.4	9.24
PI566826	4.94	4.24	14.17	34.5	23.7	31.3	37.1	33.4	9.97
PI597371	6.03	4.76	21.06	29.5	25.7	12.9	37.9	34.2	9.76
PI599979	5.92	4.98	15.88	44.9	34.1	24.1	39.4	35.3	10.41
PI600724	6.05	5.15	14.88	29.6	28.3	4.4	39.8	35.1	11.81
PI600725	4.21	3.27	22.33	24.6	15.0	39.0	38.6	34.6	10.36
PI607508	4.32	3.35	22.45	29.5	18.7	36.6	37.3	33.2	10.99
PI617099	5.83	4.90	15.95	25.8	15.7	39.1	40.1	37.3	6.98
PI497244	4.19	3.26	22.20	29.6	19.2	35.1	37.1	32.7	11.86
Mean	5.12	4.22	-	32.4	24.3	-	38.3	34.1	-
Standard Deviation	0.82	0.79	-	6.76	6.58	-	1.07	1.37	-

Table 5. Mean values and percent change in values for oil quality related characters in Sunflower genotypes under control (T_1) and 300 ppm stress (T_2)

Genotypes	Oleic Acid (%)			Linoleic Acid (%)			Palmitic Acid (%)		
	Control	300 ppm lead	% change	Control	300 ppm lead	%change	Control	300 ppm lead	%change
PI497244	38.5	35.2	8.57	45.7	47.6	3.99	5.63	6.11	7.86
PI505837	42.6	38.5	9.62	40.6	42.5	4.47	5.41	5.89	8.15
PI509051	45.3	41.2	9.05	37.6	39.5	4.81	6.52	7.00	6.86
PI509052	43.6	42.6	2.29	44.5	48.4	8.06	5.63	6.11	7.86
PI536623	46.5	42.1	9.46	39.7	42.6	6.81	4.74	5.22	9.20
PI536624	43.2	41.4	4.17	45.4	46.2	1.73	5.30	5.78	8.30
PI536625	40.4	38.5	4.70	43.7	44.6	2.02	4.61	5.09	9.43
PI536626	38.6	36.2	6.22	46.4	49.2	5.69	5.85	6.33	7.58
PI536627	39.5	35.7	9.62	45.6	48.5	5.98	5.21	5.69	8.44
PI536629	43.5	41.4	4.83	44.7	47.6	6.09	5.80	6.28	7.64
PI543743	44.6	40.6	8.97	42.6	45.5	6.37	4.84	5.32	9.02
PI543744	38.6	36.4	5.70	45.8	48.7	5.95	4.25	4.73	10.15
PI546356	43.6	42.0	3.67	45.6	48.5	5.98	4.74	5.22	9.20
PI566826	45.5	42.8	5.93	42.6	45.5	6.37	4.21	4.69	10.23
PI597371	41.5	38.2	7.95	44.6	47.5	6.11	5.30	5.78	8.30
PI599979	40.5	36.5	9.88	46.2	48.7	5.13	5.45	5.93	8.09
PI600724	45.4	41.6	8.37	40.6	43.5	6.67	5.45	5.93	8.09
PI600725	40.5	37.2	8.15	45.5	48.3	5.80	4.74	5.22	9.20
PI607508	43.1	40.7	5.57	45.4	48.2	5.81	4.52	5.00	9.60
PI617099	37.5	35.3	5.87	45.7	48.6	5.97	6.30	6.78	7.08
PI497244	38.5	34.6	10.13	45.7	48.6	5.97	5.63	6.11	7.86

Mean	41.9	39.0	-	44.0	46.1	-	5.24	5.61	-
Standard Deviation	2.7	2.7	-	2.4	2.5	-	0.61	0.61	-

Average accumulation of lead in roots, shoots, leaves and achene was 49.5 $mgkg^{-1}$, 2.47 $mgkg^{-1}$, 36.9 $mgkg^{-1}$ and 0.61 $mgkg^{-1}$ respectively (Table 6). The Genotype PI536625 had highest 100 AW, AYP whereas genotype PI617099 had highest OC among studied genotypes. The genotype PI536625 had lowest accumulation of lead in shoots, leaves and achene.

Correlation analysis was manipulated to suggest interrelationship of various factors at controlled and stressed environment. Liaison among different factors at genotypic and phenotypic levels against varied conditions are presented in Table 7. Higher genotypic correlations than phenotypic ones for all studied traits suggested the importance of genetic factors in expression of these traits. AYP had significant and positive relationship with 100AW under T_1 and T_2 which suggests no change in relationship of these traits upon the incidence of stress. With increase in AYP, OA increased whereas LA decreased under controlled environment whereas upon the incidence of stress there is no appreciable relationship exists among them. AYP decreased with increase in OC and accumulation of lead in leaves and achene. It also concluded that accumulation of lead in roots and shoots had no significant effect on AYP.

Table 6. Accumulation of lead in roots, leaves, shoot and achene in sunflower genotypes under 300 ppm lead stress.

Genotypes	Lead contents in roots (mg/kg)	Lead contents in shoots (mg/kg)	Lead contents in leaves (mg/kg)	Lead contents in achene (mg/kg)
PI497244	47.5	2.47	34.6	0.59
PI505837	42.9	1.27	34.3	0.03
PI509051	52.0	1.21	33.3	0.73
PI509052	39.3	2.33	33.4	0.93
PI536623	52.0	2.72	40.8	0.90
PI536624	54.2	2.81	38.6	0.63
PI536625	45.9	1.02	32.9	0.01
PI536626	53.9	1.09	34.3	0.52
PI536627	52.0	2.41	34.2	0.57
PI536629	49.0	2.12	41.3	0.63
PI543743	51.4	2.23	39.0	0.74

Table 7. Genotypic (bold) and phenotypic correlation coefficients of various traits under control (T_1) and 300 ppm lead stress (T_2).

		PbR	PbL	PbS	PbA	100AW	OC	OA	LA	PA
PbL	T1	0.00								
		0.00								
	T2	0.23**								
		0.22**								
PbS	T1	0.00	0.00							
		0.00	0.00							
	T2	-0.16*	-0.17*							
		-0.14*	-0.13*							
PbA	T1	0.00	0.00	0.00						
		0.00	0.00	0.00						
	T2	0.00	0.35**	0.09						
		-0.00	0.32**	0.08						
100AW	T1	0.00	0.00	0.00	0.00					
		0.00	0.00	0.00	0.00					
	T2	0.02	-0.11	-0.02	-0.4**					
		0.03	-0.09	-0.01	-0.3**					
OC	T1	0.00	0.00	0.00	0.00	0.01				
		0.00	0.00	0.00	0.00	0.00				
	T2	-0.08	0.05	-0.04	0.03	-0.01				
		-0.07	0.04	-0.02	0.02	-0.01				
OA	T1	0.00	0.00	0.00	0.00	0.03*	-0.16*			
		0.00	0.00	0.00	0.00	0.03*	-0.15*			
	T2	0.08	0.02	0.15*	0.01	0.07	-0.16			
		0.07	0.01	0.14*	0.00	0.06	-0.15			
LA	T1	0.00	0.00	0.00	0.00	-0.04	0.16	-0.74*		
		0.00	0.00	0.00	0.00	-0.04	0.15	-0.74*		
	T2	-0.22**	-0.20*	-0.09	-0.01	-0.09	0.16	-0.74**		
		-0.20**	-0.18*	-0.08	-0.00	-0.08	0.15	-0.72**		
PA	T1	0.00	0.00	0.00	0.00	-0.03*	0.14	-0.58*	0.11	
		0.00	0.00	0.00	0.00	-0.03*	0.13	-0.57*	0.10	
	T2	0.10	0.18*	-0.08	-0.02	-0.05	0.14	-0.58**	0.11	
		0.09	0.17*	-0.06	-0.02	-0.05	0.13	-0.57**	0.10	
AY/P	T1	0.00	0.00	0.00	0.00	0.74*	-0.09*	0.04*	-0.09*	0.05
		0.00	0.00	0.00	0.00	0.71*	-0.08*	0.04*	-0.09*	0.05
	T2	-0.01	-0.3**	-0.02	-0.7**	0.71*	-0.10*	0.01	-0.07	0.07
		-0.00	-0.2**	-0.01	-0.7**	0.68*	-0.09*	0.01	-0.06	0.07

PbR= Lead contents in roots, PbS= Lead contents in shoots, PbL= Lead contents in leaves, PbA= Lead contents in achene, 100AW = 100 achene weight, OC = Oil contents, OA = Oleic acid, LA = Linoleic acid, PA= Palmitic acid, AY/P= Achene yield per plant.

Table 8. Path coefficient analysis of various traits under 300 ppm lead stress.

	100AW	OC	PbR	PbL	PbS	PbA	OA	LA	PA
100AW	**0.38**	0.01	0.01	0.01	0.01	0.02	0.06	0.03	-0.02
OC	0.01	**-0.09**	0.02	0.01	0.01	-0.06	-0.03	0.01	0.03
PbR	0.02	0.02	**-0.07**	0.02	0.01	0.01	0.02	0.01	0.03
PbL	-0.05	0.01	-0.03	**0.03**	0.01	-0.19	0.01	0.01	0.04
PbS	-0.02	0.01	0.02	0.01	**0.01**	-0.06	0.02	0.01	-0.02
PbA	-0.16	0.01	0.01	0.02	0.01	**-0.51**	0.01	0.01	0.01
OA	0.04	0.02	-0.02	0.01	0.01	0.01	**0.10**	0.01	-0.10
LA	-0.04	-0.02	0.03	-0.02	0.01	0.01	-0.08	**-0.01**	0.03
PA	-0.03	-0.02	-0.02	0.01	0.01	0.02	-0.07	0.01	**0.05**

100AW = 100 achene weight, OC = oil contents, PbR= lead contents in roots, PbL= Lead contents in leaves, PbS= Lead contents in shoots, PbA= Lead contents in achene, OA = Oleic acid, LA = Linoleic acid, PA= Palmitic acid

PI543744	44.0	1.17	34.4	0.59
PI546356	49.4	1.12	34.5	0.46
PI566826	52.1	2.25	34.9	0.58
PI597371	55.9	2.25	33.9	0.52
PI599979	53.6	1.15	36.7	0.05
PI600724	53.5	2.36	43.5	0.51
PI600725	40.5	2.18	36.8	0.50
PI607508	51.9	2.15	44.1	0.02
PI617099	50.4	2.24	42.8	0.42
Mean	49.5	2.47	36.9	0.61

So, the genotypes which can accumulate higher contents of lead in roots and shoots can be employed on lead contaminated soil. 100 AW had also significantly negative association with accumulation of lead in achene. Path coefficient analysis was applied to determine the direct and indirect effects of various traits on the expression of economic factor (Table 8). 100 AW and OA had highest positive direct effect and PbA had highest negative direct effect on AY/P. 100 AW had highest positive indirect effects on AYP via PbA, OA and LA whereas OC, PbL and PbS had highest negative indirect effects on AYP through PbA.

DISCUSSION

Abiotic stresses are one of the main reasons for low productivity in crop plants (Munns and Tester, 2008). Existence of genetic variability is imperative for improving plant productivity under any kind of stress, in current scenario of climate change. Plant breeders evaluated and exploited genetic variability for abiotic stresses (drought, salinity and heat etc) since long time ago to improve existing genetic stock. Now breeders have diverted their attention to estimate the influence of heavy metals toxicity on crop growth and development due to continuous increase in pollution and related health issues. Sunflower has capacity of phyto-extraction and has been proved excellent hyper-accumulator of different heavy metals (Zhao *et al.*, 2019). Twenty morphologically different sunflower genotypes were evaluated for achene yield and oil quality related components under lead toxicity. Genotypes showed varied response for 100 AW, AYP, OC, OA, LA and PA under stress conditions. Variable percent change in values also showed the difference in their genetics towards tolerance against lead stress. Wide range of genetic variability was reported in sunflower for yield and oil quality related parameters (Razzaq *et al.*, 2014; Qamar *et al.*, 2015). Moreover, genotypes also showed variable accumulation of lead in roots, shoots, leaves and achene. Various factors related to specie and plants related are involved in uptake and translocation of lead to above ground parts (Shallari, 1998). Accumulation of lead was higher in roots than leaves, shoot and achene (root>leaves>stem>achene) (Paliwal *et al.*, 2014; Kacalkova *et al.*, 2014; Alaboudi *et al.*, 2018). Lead mainly accumulated in roots and very little quantity were translocated to shoots (Kastori *et al.*, 1992) because roots are in direct contact with soil solution to selectively acquire metal ions (Salt *et al.*, 1997). Moreover, concentration of metals is more in epidermis than root cortex as the endodermis presents barrier to ion transport (Hagemeyer and Breckle, 1996). Translocation to above ground parts are low in most of the crop plants but highest translocation of lead was observed in sunflower. Moreover leaves accumulate more lead contents than stalk and almost similar concentration of lead accumulated in grains and stalk of sunflower (Kacalkova *et al.*, 2014). Therefore, selection can be imposed on variable genotypic behavior in sunflower to develop high yielding genotypes with better oil quality under lead toxicity. Differential accumulation of lead in sunflower organs might be helpful in classification of genotypes for edible and phytoremediation purpose.

Heavy metals including lead causes phytotoxic effects on growth and development in sunflower (Paliwal *et al.*, 2014; Lavado, 2006) and other crops (Wahid and Ghani, 2008; Mahmoud *et al.*, 2010). Owing to have high atomic mass and density, heavy metals retards cell division, elongation and differentiation (Soares *et al.*, 2001) and effects metabolic events (photosynthesis, respiration, enzymatic activities) in plants by disturbing amino acid linkages in protein structure, disrupting cellular membranes, functioning of cellular molecules and essential metals (Emamverdian *et al.*, 2015). Moreover, heavy metals are associated with increased production of reactive oxygen species and cytotoxic compounds, which disturbs cellular homeostasis (Sytar *et al.*, 2013). Lead toxicity presented negative effects on all studied characters except for linoleic acid and palmitic acid. High concentration of lead had significantly reduced achene yield per plant (Lavado, 2006). Lead tolerant genotypes had highest achene yield per plant under stress conditions. So, variability among genotypes can be exploited to develop lead tolerant genotypes that can be grown on lead contaminated soils.

Association analysis finds out extent of relationship between two variables and gives a chance to find trend and intensity of inter-relationship necessary for making well-organized and operative crop upgrading strategy (Chandra *et al.*, 2012). When there is positive relationship between primary yield characters, breeding for various components would be fruitful but when these parameters are negatively correlated, it would be problematic to workout in developing a desirable variety (Nemati *et al.*, 2009). Researchers use correlation coefficient and path analysis to determine relationship among seed yield and other desirable traits (Machikowa and Saetang, 2008; Kaya *et al.*, 2009; Mijic *et al.*, 2009). Genotypic association coefficients were greater than phenotypic ones for all characters under normal and stress conditions which indicated little effect of environment on expression of these traits. Higher genotypic correlations than phenotypic correlation was reported in sunflower. 100 achene weight had workable association with achene yield per plant (Razzaq *et al.*, 2014). Negative and significant genotypic association of oil contents, lead contents in achene and lead contents in leaves with achene yield per plant was observed. Accumulation of lead in leaves causes chlorosis, disturbs biosynthesis of chlorophyll and reduces photosynthesis which ultimately effects plant biomass and yield (Sharma and Dubey, 2005). So high accumulation of lead in leaves and achene had effectively reduce achene yield per plant whereas accumulation in roots and stem had little influence on achene yield per plant. Oleic acid (omega-9) had negative association with linoleic acid (omega-6) so concentration of omega-6 and omega-9 fatty acid cannot be improved simultaneously. 100 achene weight had highest positive direct effect on achene yield per plant (Habib *et al.*, 2009; Kolghi *et al.*, 2011). Efficiency in selection for achene yield can be increased through selecting 100 achene weight, lead contents in leaves and achene under lead stress conditions.

***Conclusion*:** Significant genetic variability was reported among sunflower genotypes for achene yield and oil quality related traits under lead stress. Genotypes accumulate varied concentration of lead in roots, shoots, leaves and achene. That's why, it is to be concluded that genotypes having minimum variation in percent values for yield and oil quality traits show more tolerance to lead stress. Highest accumulation of lead was observed in roots and leaves. Therefore, sunflower plant has potential of phytoremediation and could grow on metal effected soils. Achene yield per plant had positive genetic association with 100 achene weight; whereas negative association with lead contents in leaves and achene. 100 achene weight had highest positive direct effect on achene yield per plant. 100 achene weight and lead contents in leaves and achene can be used as a reliable selection criteria for the development of lead tolerant genotypes in sunflower.

REFERENCES

Alaboudi, A.K., B. Ahmed and G. Brodie. 2018. Phytoremediation of Pb and Cd contaminated soils by using sunflower (*Helianthus annuus*) plant. Annals Agric. Sci.63:123-127.

Govt. of Pakistan. 2017. Pakistan Economic Survey 2016-17. Finance and Economic Affairs Division, Ministry of Finance, Govt. of Pakistan, Islamabad, Pakistan.pp.17-40

Chandra, R., Y.P. Joshi and S. Sing. 2012. Correlation studies in multicut forage sorghum grown under different environments. Forage Res. 37:263-265.

Davies, B.E. 1990. Lead. In: B.J. Alloway (ed.), Heavy metals in soils. Blackie and Son, Glasgow, UK. pp.177-196.

De Abreu, C.A., M.F. De Abreu and J.C. De Andrade. 1998. Distribution of lead in the soil profile evaluated by DTPA and Mehlich – 3 solutions. Bragantia. 57:18-192.

Dewey, D.R. and K.H. Lu. 1959. A correlation and path coefficient analysis of components of crested wheat grass grain production. J. Agron. 51:515-518.

Dhiman, S.S., Xin Zhao, Jinglin Li, Dongwook Kim, Vipin C. Kalia, In-Won Kim,Jae Young Kim,[2,*] and Jung-Kul Lee. 2017. Metal accumulation by sunflower (*Helianthus annuus* L.) and the efficacy of its biomass in enzymatic saccharification. PLOS ONE. 12:1-14.

Emamverdian, A., Y. Ding, F. Mokhberdoran and Y. Xie. 2015. Heavy metal stress and some mechanisms of plant defense response. Sci. World J. 2015:18.

Habib, S. 2009. Genetic variation of seedling traits in a random mating population of sunflower. Pak. J. Agri. Res. 18:61-65.

Hagemeyer, J. and S.W. Breckle. 1996. Growth under trace element stress. In: Y. Waisel, A. Eshel and U. Kafkafi (eds.), Plant Roots. The hidden half. Marcel Dekker, Inc, New York, Basel, Hongkong. pp.415-431.

Kacalkova, L., P. Tlustos and J. Szakova. 2014. Chromium, nickel, cadmium, and lead accumulation in maize, sunflower, willow, and poplar. Pol. J. Environ. Stud. 23:753-761.

Kastori, R., M. Petrovic and N. Petrovic. 1992. Effect of excess lead, cadmium, copper, and zinc on water relations in sunflower. J. Plant Nutr. 15:2427-2439.

Kaya, Y., G. Evci, S. Durak, V. Pekcan and T. Gucer. 2009. Yield components affecting seed yield and their relationship in sunflower (*Helianthus annuus*). Pak. J. Bot. 41:2261-2269.

Kolghi, M., I. Bernousi, R. Darvishzadeh and A. Pirzad. 2011. Correlation and path-coefficient analysis of seed yield and yield related trait in Iranian confectionery sunflower populations. Afr. J. Biotech. 61:13058-13063.

Kwon, S.H. and J.H. Torrie. 1964. Heritability and interrelationship among traits of two soybean populations. Crop Sci. 4:196-198.

Lavado, R.S. 2006. Effects of sewage-sludge application on soils and sunflower yield: quality and toxic element accumulation. J. Plant Nutr. 29:1-10.

Machikowa, T. and C. Saetang. 2008. Correlation and path coefficient analysis on seed yield in sunflower. J. Sci. Tech. 15:243-248.

Mahmoud, M.E., M.M. Osman, O.F. Hafez, A.H. Hegazi and E. Elmelegy. 2010. Removal and preconcentration of lead (II) and other heavy metals from water by alumina adsorbents developed by surface-adsorbed-dithizone. Desalination 251:123-130.

Mijic, A., I. Liovic, Z. Zdunic, S. Maric, A. Marjanovic Jeromela and M. Jankulovska. 2009. Quantitative analysis of oil yield and its components in sunflower (*Helianthus annuus L.*). Romanian Agric. Res. 26:41-46.

Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. Annu. Rev. of Plant biol. 59:651-681.

Nemati, A., M. Sedghi, R.S. Sharifi and M.N. Seiedi. 2009. Investigation of correlation between traits and path analysis of corn (*Zea mays* L.) grain yield at the climate of Ardabil region (Northwest Iran). Not. Bot. Hort. Agrobot. Cluj. 37:194-198.

Paliwal, H.B., N. Gupta and A. James. 2014. Study on accumulation of lead in sunflower (*Helianthus annuus L.*). J. Ind. Pollut. Control 30:91-96.

Qamar, R., A. Bibi, H.A. Sadaqat, F.S. Awan and H.M. Akram. 2018. Computation of differential response of sunflower genotypes for achene yield and oil quality against lead toxicity. Int. J. Agri. Biol. 12:2731-2736.

Qamar, R., H.A. Sadaqat, A. Bibi and M.H.N. Tahir. 2015. Estimation of combining abilities for early maturity, yield and oil related traits in sunflower (*Helianthus annuus* L.). Int. J. Sci. Nat. 6:110-114.

Razzaq, H., M.H.N. Tahir and H.A. Sadaqat. 2014. Genetic variability in sunflower (*Helianthus annuus*L.) for achene yield and morphological characters. Int. J. Sci. Nat. 5:669-676.

Ryan, P.R., E. Delhaize and D.J. Jones. 2001. Function and mechanism of organic anion oxidation from plant roots. Annu. Rev. Plant Physiol. Plant Mol. Biol. 52:527-560.

Salt, D.E., I.J. Pickering, R.C. Prince, D. Gleba, S. Dushenkov, R.D. Smith and I. Raskin. 1997. Metal accumulation by aqua cultured seedlings of Indian mustard. Environ. Sci. Tech. 31:1636-1644.

Shallari, S., C. Schwartz, A. Hasko and J.L. Morel. 1998. Heavy metals in soils and plants of serpentine and industrial sites of Albania. Sci. Total Environ. 209:133.

Sharma, P. and R.S. Dubey. 2005. Lead toxicity in plants. Braz. J. Plant Physiol. 17:35-52.

Skoric, D., S. Jocic and I. Molnar. 2000. General (GCA) and specific (SCA) combining abilities in sunflower. Zborniknaucnihradova. Novi. Sad. 6:97-105.

Soares, C.R.F.S., P.H. Grazziotti, J.O. Siquaira and J.H.D. Carvalno. 2001. Zinc toxicity on growth and nutrition of *Eucalyptus muculata* and *Eucalyptus arophylla*. Pesq. Agrop. Brasileira 36:339-348.

Steel, R.G.D., J.H. Torrie and D.A. Dicky. 1997. Principles and procedures of statistics: A biometrical approach, 3rd Ed. McGraw Hill Book Co. Inc. New York.pp. 352-358.

Sytar, O., A. Kumar, D. Latowski, P. Kuczynska, K. Strzałka and M.N.V. Prasad. 2013. Heavy metal induced oxidative damage, defense reactions and detoxification mechanisms in plants. Acta Physiol. Plant. 35:985-999.

Wahid, A. and A. Ghani. 2008. Varietal differences in Mung bean (*Vigna radiata*) for growth, yield, toxicity symptoms and cadmium accumulation. Ann. Applied Biol. 152:59-69.

Zhao, X., J.C. Joo, J.K. Lee and J.Y. Kim. 2019. Mathematical estimation of heavy metal accumulations in *Helianthus annuus* L. with a sigmoid heavy metal uptake model. Chemosphere. 220: 965-973.