Research Article

Effect of Lead (Pb^{2+}) on Different Morpho-Physiological and Yield Traits of Mungbean (*Vigna Radiata* L. Wilzeck) under Water Deficit Conditions

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Abstract | Plant growth and development are adversely affected by different abiotic stress especially lead and water stress. Therefore, present study was conducted with the aim to investigate the response of two mungbean varieties to three different Pb^{2+} concentrations under two water stress conditions. Different morpho-physiological and yield traits were studied. Both varieties showed gradual reduction in morphological traits at increasing concentration of lead and water stress. Moreover, morphological traits were more severely affected by combined lead and water stress treatment (80 mg Pb^{2+} 50% FC) as compared to single lead (40 mg Pb^{2+} 100% FC and 80 mg Pb^{2+} 100% FC) and single water stress treatment (0 mg Pb^{2+} 50% FC). The negative effect of Pb^{2+} and water stress on growth of shoot, root length, shoot, and root fresh and dry weight was observed more during 2nd harvest interval as compared to the 1st harvest interval. Highly significant differences were observed among treatments for all physiological and yield traits except chlorophyll b. Shoot phosphorus contents, shoot sodium contents and number of pods/plant also showed significant differences among varieties. All physiological and yield parameters showed gradual reduction with increasing concentration of lead and water stress. Uptake of Na^+, K and P was reduced significantly in all treatments but lead accumulation in shoot was increased in single lead treatment (80 mg Pb^{2+} 100% FC) as compared to combined lead and water stress treatment. Combined lead and water stress treatment (80 mg Pb^{2+} 50% FC) showed adverse effects on plant growth and development as compared to other stress treatments. Comparison between varieties showed that AZRI Mung 2006 performed better than NM 2006 under heavy metal (Pb^{2+}) and water deficit conditions. Therefore, AZRI Mung 2006 proved to be a useful germplasm source against lead and water stress.

Received | June 20, 2018; **Accepted** | August 12, 2018; **Published** | August 29, 2018
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Citation | Ahmad, F., M. Hussain, G. Abbas, M.J. Asghar and M. Rizwan. 2018. Effect of lead (pb^{2+}) on different morpho-physiological and yield traits of mungbean (*Vigna radiata* L. wilzeck) under water deficit conditions. *Pakistan Journal of Agricultural Research,* 31(3): 223-233.
DOI | http://dx.doi.org/10.17582/journal.pjar/2018/31.3.223.233
Keywords | Growth, Heavy metals, Harvest interval, Lead toxicity, Water stress

Introduction

Plant growth and development are adversely affected by various biotic and abiotic stresses (Foranzier et al., 2002; Johnson and Eaton, 1980). Environmental pollution is global issue especially in Asia due to discharge of untreated chemical wastes by different industries that include heavy metals in addition to other pollutants (Sharma and Dubey, 2005). Most of the heavy metals precipitate readily in soil. Some metals are considered more hazardous to plants than those which cannot precipitate and dissolve with the passage of time.

Toxicity symptoms observed in plants in the presence of excessive amounts of heavy metals leads to inhibition of protein activity or disruption of structure due to the formation of free radicals and reactive oxygen species (Foranzier et al., 2002). Lead is a non-essential element that negatively affects plant growth and development and has become a cosmopolitan environmental pollutant. The main sources of lead pollution include exhaust from the chimneys of factories, automobiles, storage battery, Pb^{+2} ores, metal plating, finishing operations, pesticide and fertilizer etc. Other sources of Pb^{+2} pollution are paints, untreated disposal of municipal sewage sludge, mining and smelting activities. Although it is a non-essential element for plants but they show a high tendency to uptake and accumulation in different plant organs (Sharma and Dubey, 2005). Toxic effect of Pb^{+2} on plants when grown on soil contaminated with Pb^{+2} include inhibition of photosynthesis, deficient mineral nutrition uptake and problem of water imbalance, which may reduce the vegetative and reproductive growth of plants (Johnson and Eaton, 1980).

In addition, water deficiency is the major abiotic stress which badly affects the crop growth and yield than other environmental factors. Water stress can reduce overall performance of mature plants, germinating seeds and seedlings (Burke and Mahony, 2001). Crops can attain less than 25 % of the potential yield due to the adverse environmental conditions and low water availability. In mungbean reproductive stage is more severely affected than other stages (Thomas et al., 2004).

Many factors including environmental pollution and water stress are responsible for reduction in mungbean yield as compared to the potential yield. Globally, most of the areas are being irrigated with polluted water containing high proportion of heavy metals. Keeping in view the above facts, the present study was undertaken to examine the toxicity of lead (Pb^{+2}) on various morpho-physiological and yield traits of mungbean under normal and water stress conditions.

Materials and Methods

Present study was conducted at Old Botanical Garden, University of Agriculture, Faisalabad with the aim to investigate various morpho-physiological and yield traits of two mungbean varieties (NM, 2006; AZRI, 2006) to three lead concentrations under two water stress conditions during the year 2012. The experiment was laid out in a completely randomized design (CRD) with factorial arrangement in five replicates. Following six treatments were applied as a soil application, 20 days after germination under two water regimes. Water stress was applied at 100% and 50% field capacities (FC). Lead was used in the form of Lead acetate Pb $(NO_3)_2$.

T_1	100% FC	+	0 mg Pb^{2+} Kg^{-1} soil
T_2	100% FC	+	40 mg Pb^{2+} Kg^{-1}soil
T_3	100% FC	+	80 mg Pb^{2+} Kg^{-1} soil
T_4	50% FC	+	0 mg Pb^{2+} Kg^{-1}soil
T_5	50% FC	+	40 mg Pb^{2+} Kg^{-1} soil

Plastic pots were used and each pot size was 25 cm high with 20 cm diameter. Each pot contained 6 kg soil. Soil used was sandy loam in texture having 19% field capacity, 11.68 ms/cm electrical conductivity and 7.95 pH. Ten seeds were sown in each pot after making 2cm deep holes with the help of wooden stick having 1.5 cm diameter. Each hole was covered with small amount of soil. After complete germination, plants were thinned to maintain five seedlings in each pot.

Data for the morphological parameters i.e. root length (cm), shoot length (cm), root fresh weight (g), shoot fresh weight (g), root dry weight (g) and shoot dry weight (g) were recorded seven days after treatment application. Three plants from each pot were randomly harvested and data for root and shoot dry weight were recorded after drying the harvested roots and shoots in an oven at 70 °C for 72 hours. Three harvests were taken at an interval of seven days.

The chlorophyll a, b and total carotenoid contents were determined 21 days after the treatment application followed by Arnon (1949) and Davies (1976). Photosynthetic and transpiration rates were determined 20 days after the treatment application by using IRGA Model (Cl-34, USA). For the determination of P^+, K^+, Na^+ and Pb^{2+} the plant material was ground and digested following Yoshida et al. (1976), 21 days after the treatment application. The material was ground in a grinder and digested according to the method of. Na^+, P^+ and K^+ ions were determined by flame photometer (Jenway, Pep-7). Graded series of standards (ranging from 5- 40mg/L) of P^+, K^+ and Na^+ prepared and standard curve were drawn. The readings of P^+, K^+ and Na^+ from flame photometer were compared with slandered curve and total quantities were computed. Pb^{2+} was determined by atomic absorption spectrophotometer (Nova AA 400 analytic Jena). Graded series of 10, 20 and 30mg/ L^{-1} Pb^{2+} was run for concentrations of standard curve. Data for seed yield/plant, number of seeds per pod, number of pods per plant, pod length and 100-seed weight were recorded for each treatment at maturity.

The data were analyzed by using the analysis of variance (ANOVA) technique under two factors completely randomized design (CRD) and treatment means were compared by least significant difference (LSD) test at 0.05 probability levels (Steel and Torrie, 1997).

Results and Discussion

Morphological traits

Data pertaining to the response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in shoot length, root length and shoot fresh weight is presented in Table 1. NM 2006 during harvest interval 1-2 showed maximum shoot length (0.75cm) in control (T_1). Lead treatments T_2 and T_3 showed 4.18% and 5.11% reduction over control respectively. While water stress treatment T_4 showed 5.51% decrease. The combined application of lead and water stress T_5 and T_6 showed maximum reduction in shoot length i.e. 6.67% and 7.47% respectively over control. In AZRI Mung 2006, maximum shoot length (0.67cm) was observed in control (T_1) while combined treatment T_6 showed maximum reduction (8.96%). Similar trend was found in 2nd harvest interval in both varieties. Moreover, water stress alone showed more reduction in AZRI Mung 2006 as compared to NM 2006. The negative effect of lead and water stress on growth of shoot length in both varieties was observed more during 2nd interval as compared with 1st interval. The results are in accordance with the findings of Pervez et al. (2009).

Root length (0.54cm) was observed to be highest in control (T_1) in 1st harvest interval in NM 2006, while maximum reduction (9.74%) was observed in combined application of lead and water stress (T_6). Simple lead treatments T_2 and T_3 showed 4.21% and 6.05% decrease over control respectively. Simple water treatment T_4 brought minimum decrease (1.63%) over control. In AZRI 2006, root length was found to be maximum (0.43cm) in control as compared to other treatments. The combined lead and water stress T_6 showed maximum decrease 11.63% over control, while single water stress showed lowest reduction (0.27%) in comparison with other stress treatments. Similar trend was found in 2nd harvest interval in both varieties. These results are similar to those observed by Hussain et al. (2006). The negative effect of lead and water stress on growth of root length per day was observed more during 2nd interval as compared with 1st interval. Growth rate of root length for NM 2006 was slightly higher as compared to AZRI Mung 2006.

Shoot fresh weight (0.42g) was found to be highest in control during harvest interval 1-2 in NM 2006. Lead application T_2 and T_3 reduced shoot weight to 0.39g and 0.38g per day respectively. While in single water stress T_4, it decreased to 8.59% over control. T_5 and T_6 showed maximum reduction in shoot fresh weight by 10.10% and 11.06% respectively as compared to control. In AZRI Mung 2006, during 1st harvest interval shoot fresh weight (0.50g) was observed to be highest in T_1 (control), while lowest reduction (3.45%) over control was observed in T_2. Combined treatment T_6 caused maximum reduction (11.40%). Reduction rate in shoot fresh weight in 2nd harvest interval in both varieties was found almost similar as compared with 1st harvest interval. In the treatment means during harvest interval 1-2 as compared with harvest interval 2-3 shoot fresh weight was lower in both varieties. Overall, shoot fresh weight was reduced in all treatments over control in both varieties during both harvest intervals.

Data regarding the effect of lead and water stress on growth of the root fresh weight, shoot and root dry weight is presented in Table 2. Lead caused negative effect on the growth of root. Root fresh weight (0.030g) was found to be highest in control (T_1) during harvest interval 1-2 in NM 2006. Lead application T_2 and T_3 reduced root fresh weight to 10.0% and 16.67% respectively. Simple water stress showed 3.33% reduction over control. Maximum reduction in root fresh weight was observed 23.33% in combined treatment of lead and water stress (T_6) as compared to control. In AZRI Mung 2006, root fresh weight (0.024g) was highest over all other treatments during harvest interval 1-2. Simple water stress (T_4) showed minimum reduction (1.18%) while combined lead and water stress (T_6) showed maximum reduction (19.71%) in root fresh weight over control.

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Table 1: *Response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in different seedling traits.*

Relative change in Shoot Length (cm)												
Harvests	Treatments (NM 2006)						Treatments (AZRI 2006)					
	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5	T_6
1-2	0.75	0.72	0.71	0.71	0.70	0.69	0.67	0.63	0.62	0.62	0.61	0.61
% decrease over control		-4.18	-5.11	-5.51	-6.67	-7.47		-6.17	-8.40	-7.66	-8.96	-8.96
2-3	1.15	1.05	1.01	0.98	0.97	0.96	1.20	1.08	0.99	1.00	0.97	0.96
% decrease over control		-8.58	-12.06	-14.68	-15.65	-16.52		-10.00	-17.50	-16.90	-19.17	-20.00
Relative change in Root Length (cm)												
1-2	0.54	0.52	0.51	0.53	0.50	0.49	0.43	0.41	0.40	0.43	0.39	0.38
% decrease over control		-4.21	-6.05	-1.63	-7.89	-9.74		-4.01	-6.35	-0.27	-9.30	-11.63
2-3	0.61	0.54	0.50	0.59	0.46	0.48	0.49	0.44	0.42	0.47	0.41	0.39
% decrease over control		-12.09	-18.60	-3.95	-20.12	-21.31		-9.41	-13.53	-3.24	-15.59	-20.41
Relative change in Shoot Fresh Weight (g)												
1-2	0.416	0.390	0.382	0.380	0.374	0.370	0.500	0.480	0.451	0.453	0.447	0.443
% decrease over control		-6.19	-8.11	-8.59	-10.10	-11.06		-3.45	-9.48	-8.68	-10.60	-11.40
2-3	0.573	0.520	0.500	0.510	0.493	0.490	0.630	0.600	0.590	0.590	0.575	0.57
% decrease over control		-9.23	-12.72	-10.97	-13.96	-14.49		-5.19	-6.77	-6.14	-8.73	-9.05

Table 2: *Response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in different seedling traits.*

Relative change in Root Fresh Weight (g)												
Harvests	Treatments (NM 2006)						Treatments (AZRI 2006)					
	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5	T_6
1-2	0.030	0.027	0.025	0.029	0.024	0.023	0.024	0.021	0.020	0.024	0.021	0.0205
% decrease over control		-10.00	-16.67	-3.33	-20.00	-23.33		-11.77	-17.65	-1.18	-13.53	-19.71
2-3	0.036	0.030	0.027	0.034	0.032	0.029	0.034	0.029	0.028	0.032	0.027	0.026
% decrease over control		-16.00	-24.00	-4.80	-10.40	-18.80		-16.66	-18.33	-6.66	-21.25	-24.17
Relative change in Shoot Dry Weight (g)												
1-2	0.137	0.117	0.115	0.116	0.110	0.107	0.134	0.122	0.110	0.110	0.100	0.099
% decrease over control		-14.58	-16.15	-15.42	-9.79	-21.98		-9.15	-18.08	-18.08	-25.53	-26.12
2-3	0.190	0.160	0.153	0.152	0.145	0.140	0.216	0.190	0.180	0.184	0.170	0.165
% decrease over control		-15.79	-19.47	-20.00	-23.68	-26.32		-11.92	-16.56	-14.70	-21.30	-23.61
Relative change in Root Dry Weight (g)												
1-2	0.016	0.014	0.013	0.016	0.013	0.013	0.013	0.012	0.011	0.013	0.012	0.011
% decrease over control		-9.09	-17.27	-1.36	-18.47	-19.28		-6.67	-14.44	-2.78	-10.85	-16.27
2-3	0.021	0.018	0.016	0.020	0.016	0.016	0.010	0.009	0.008	0.010	0.008	0.008
% decrease over control		-16.00	-25.33	-6.67	-26.67	-27.10		-14.00	-20.00	-2.00	-24.00	-25.00

Similar trend was observed in 2nd harvest interval in both varieties. Simple water stress in both varieties showed lowest reduction in 1st and 2nd harvest interval which represented that plant tried to adopt in water deficient condition by increasing root biomass. These results were in accordance with Faheed (2005) who reported that shoot and root length, fresh and dry weights of root and shoot were significantly reduced by increasing the concentration of $Pb2^+$. Moreover, negative effect of lead and water stress in both varieties was observed more during 2nd harvest interval as compared with 1st interval.

Shoot dry weight was observed to be reduced in all treatments over control (T_1) during both harvest intervals in both varieties. Combined treatment of lead

Table 3: *Analysis of variance of investigated traits in two mungbean varieties at different levels of soil mixed Pb^{2+} and water stress.*

Traits	Treatments	Varieties	Treatment × Varieties	Error
Chlorophyll a	0.383**	0.000NS	0.110*	0.043
Chlorophyll b	0.298NS	0.003NS	0.015NS	0.194
Carotenoids	0.091*	0.001NS	0.026NS	0.035
Photosynthetic rate	50.244**	0.000NS	2.804NS	2.563
Transpiration rate	1.529**	0.090NS	0.313NS	0.133
Shoot potassium (K^+) contents	0.011*	0.000NS	0.001NS	0.003
Shoot phosphorus (P) contents	0.2090**	0.2250*	0.0313NS	0.0479
Shoot sodium (Na^+) content	0.2238**	0.3835*	0.0524NS	0.0595
Shoot lead (Pb^{2+}) contents	48.7576**	0.245NS	3.235**	0.451
No. of pods/plant	84.14**	9.204*	11.524**	1.792
Pod length	9.820**	0.417NS	0.967NS	0.767
100 seed weight	1.094**	0.632NS	0.136NS	0.214
No. of seeds/pod	29.787**	0.267NS	1.627NS	3.175
Yield/plant	41.958**	3.011NS	3.597**	0.787

(Degrees of freedom: **Treatment:** *5,* **Varieties:** *1,* **Treatment × Genotypes:** *5 and* **Error:** *24); ** Significant at P≤0.01 level; * Significant at P≤0.05 level and NS Non-significant.*

and water stress (T_6) showed maximum reduction in shoot dry weight in both varieties during both harvest intervals. Treatment means of both varieties showed that shoot dry weight was lower during harvest interval 1-2 as compared with harvest interval 2-3. The results are in accordance with the findings of Manjru et al. (2007).

Root dry weight was also reduced in all treatments over control. Maximum reduction occurred at combined treatment of lead and water stress (T_6) in NM 2006 during harvest interval 1-2 (19.28%) and harvest interval 2-3 (27.10%). Similar trend was found for AZRI Mung 2006. The lowest reduction was observed in single water stress followed by single lead treatment. Sanchez et al. (1997) also observed the effect of Pb^{2+} in *Phaseolus vulgaris* and found that high concentration of lead significantly reduced the dry weight of plants. Moreover, it was found that root length and root fresh and dry weight of single water stress treatment not significantly differed from control while all the lead treatments gradually reduced the root length, root fresh and dry weight.

In general it was concluded that growth attributes of both varieties of mungbean were reduced at all levels of lead and combined effect of lead and water stress Figure 1. Combined effect of lead and water stress showed more adverse effect on growth attributes as compared to simple water stress and lead treatment.

Physiological traits

Analysis of variance for physiological traits is presented in Table 3 and response of varieties to change in physiological traits in Table 4 and 5. For chlorophyll a, analysis of variance revealed highly significant differences among treatments, significant differences among treatment × varieties but non-significant among varieties. A comparison among treatment means indicated highest chlorophyll a contents for control (T_1). Lowest lead treatment (T_2) varied non-significantly from control (T_1) and simple water stress treatment (T_4), while significantly differed from all other treatments. The treatment T_3, T_5 and T_6 differed non-significantly from each other and simple water stress treatment T_4 but were significant to control. Lead and water stress individually and in combination reduced the chlorophyll a contents as compared to control. Combined effect of lead and water stress T_5 and T_6 showed maximum reduction i.e. 26.24% and 27.91% respectively over control. A comparison between varieties showed that chlorophyll a contents differed non-significantly and stood at the same level. For chlorophyll b, analysis of variance showed non-significant differences among all the sources of variation. Simple lead treatment T_2 and T_3 reduced the chlorophyll b content to 28.94% and 42.95% respectively over control (T_1). Simple water stress (T_4) caused 38.23% reduction. Combined effect of lead and water stress T_5 and T_6 showed highest reduction 46.38% and 52.77% as compared to control.

Table 4: *Response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in different physiological traits.*

Treatments	Control	40 mg Pb^{2+} 100% FC	80 mg Pb^{2+} 100% FC	0 mg Pb^{2+} 50% FC	40 mg Pb^{2+} 50% FC	80 mg Pb^{2+} 50% FC	Mean
	Chlorophyll a (mg g^{-1} fresh weight)						
NM 2006	1.80	1.63	1.61	1.43	1.23	1.25	1.49
AZRI 2006	1.79	1.60	1.94	1.51	1.42	1.34	1.49
Mean	1.80	1.65	1.40	1.47	1.32	1.29	
% Decrease		-8.36	-22.01	-18.22	-26.24	-27.91	
	Chlorophyll b (mg g^{-1} fresh weight)						
NM 2006	1.11	1.01	0.80	0.86	0.83	0.68	0.88
AZRI 2006	1.17	0.99	0.82	0.88	0.68	0.67	0.87
Mean	1.41	1.00	0.81	0.87	0.76	0.67	
% Decrease		-28.94	-42.55	-38.23	-46.38	-52.77	
	Carotenoids (mg g^{-1} fresh weight)						
NM 2006	0.61	0.53	0.50	0.53	0.47	0.46	0.52
AZRI 2006	0.79	0.42	0.43	0.50	0.49	0.43	0.51
Mean	0.70	0.48	0.47	0.52	0.48	0.45	
% Decrease		-32.10	-33.52	-26.71	-31.68	-36.79	
	Photosynthetic rate (μmol/m^2/s)						
NM 2006	13.75	10.56	8.29	8.24	8.01	7.73	9.43
AZRI 2006	12.40	11.93	9.35	8.39	7.27	7.26	9.44
Mean	13.08	11.24	8.82	8.32	7.64	7.50	
% Decrease		-14.01	-32.53	-36.39	-41.55	-42.67	
	Transpiration rate (mmol/m^2/s)						
NM 2006	1.55	1.51	1.51	1.31	1.12	0.52	1.25
AZRI 2006	2.11	1.44	1.11	1.51	0.94	0.87	1.33
Mean	1.83	1.48	1.31	1.41	1.03	0.70	
% Decrease		-19.33	-28.40	-23.10	-43.85	-62.04	

Comparison among varieties showed the same level for the effect of lead and water stress and differed non-significantly from each other. It was observed that AZRI Mung 2006 showed better chlorophyll b contents as compared to NM 2006. Prasad et al. (1987) also reported adverse effect of lead and mercury on chlorophyll contents in mungbean.

Lead and water stress showed excessive reduction in carotenoid contents. Analysis of variance showed significant differences among treatments while differences among varieties and treatment × varieties interaction were found non-significant. Comparison among treatment means showed highest carotenoid contents in control (T_1) and minimum for combined lead and water stress treatment (T_6). All treatments showed gradual reduction in carotenoids with increasing concentration of lead and water stress. The difference among the treatments was significant to control while all the treatments were non-significant to each other. Simple lead treatment T_2 and T_3 reduced the carotenoid content to 32.10% and 33.52% respectively over control (T_1). Simple water stress (T_4) caused 26.70% reduction. Combined effect of lead and water stress (T_6) showed highest reduction 36.79% in carotenoid contents as compared to control.

Highly significant differences were observed among treatments for photosynthetic rate while varieties and treatment × varieties showed non-significant differences. Comparison among treatment means showed that T_1 (control) differed significantly from all other treatments. T_2 also differed significantly from all other treatments while the treatments T_3, T_4, T_5 and T_6 were differed non-significantly from each other. A substantial reduction was noted in net photosynthetic rate due to lead and water stress application. Highest decrease was observed in treatments T_5 and

Table 5: *Response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in different physiological traits.*

Treatments	Control	40 mg Pb^{2+} 100% FC	80 mg Pb^{2+} 100% FC	0 mg Pb^{2+} 50% FC	40 mg Pb^{2+} 50% FC	80 mg Pb^{2+} 50% FC	Mean
	Shoot potassium (K^+) contents (mg g^{-1} dry weight)						
NM 2006	0.31	0.28	0.28	0.22	0.20	0.18	0.24
AZRI 2006	0.28	0.26	0.25	0.24	0.24	0.17	0.24
Mean	0.29	0.27	0.26	0.23	0.22	0.13	
% Decrease		-7.17	-10.23	-22.52	-24.23	-56.65	
	Shoot phosphorus (P) contents (mg g^{-1} dry weight)						
NM 2006	1.03	0.95	0.95	0.92	0.87	0.80	0.92
AZRI 2006	1.03	1.01	0.97	0.95	0.95	0.92	0.97
Mean	1.03	0.98	0.96	0.93	0.91	0.86	
% Decrease		-4.85	-6.88	-9.31	-11.74	-16.65	
	Shoot sodium (Na^+) contents (mg g^{-1} dry weight)						
NM 2006	0.57	0.51	0.49	0.38	0.35	0.32	0.45
AZRI 2006	0.59	0.53	0.51	0.49	0.49	0.49	0.52
Mean	0.58	0.52	0.50	0.44	0.42	0.40	
% Decrease		-11.32	-14.18	-24.65	-28.09	-30.51	
	Shoot lead (Pb^{2+}) contents (mg g^{-1} dry weight)						
NM 2006	2.21	3.41	4.79	1.97	3.19	3.53	3.18
AZRI 2006	2.32	3.70	3.93	2.03	3.56	3.86	3.23
Mean	2.26	3.56	4.36	2.00	3.37	3.69	
% Increase		57.18	92.75	-11.56	49.09	63.2	

T_6 i.e. 41.55% and 42.67% respectively as compared to control. The results are in accordance with Ahmed et al. (2008) who observed that higher concentration of Pb^{2+} caused inhibition of photosynthesis and transpiration rate in mungbean. For transpiration rate, highly significant differences were observed among treatments while varieties and treatment × varieties were non-significant. Comparison among treatment means showed that T_2, T_3 and T_4 were differed significantly from control but non-significant to each other. T_5 differed significantly from all other treatments except T_3. T_6 differed significantly from all other treatments including control (T_1). A substantial reduction was noted in transpiration rate due to lead and water stress application. Minimum decrease was observed in treatment T_2 (19.33%) and maximum in T_6 (62.04%) as compared to control. Hussain et al. (2007) reported significant reduction in transpiration rate to applied lead and chromium stress in black gram.

For shoot potassium (K^+) contents, significant differences were present among treatments while varieties and treatment × varieties interaction were found non-significant. Highest shoot potassium contents were observed in control (T_1) and minimum for combined lead and water stress treatment (T_6). All treatments showed gradual reduction in shoot potassium contents with increasing concentration of lead and water stress treatment. Comparison between treatment means showed that all treatments differed non-significantly from each other except T_6 which differed significantly from all the treatments including control. Shoot phosphorus contents showed significant differences among treatments and varieties. Highest shoot phosphorus contents were examined in control while minimum in treatment T_6. All treatments showed reduction in shoot P contents viz. T_2 (4.85%), T_3 (6.88%), T_4 (9.31%), T_5 (11.74%) and T_6 (16.65%). Comparison between treatment means showed that treatments T_2, T_3 and control differed non-significantly from each other. Treatments T_4 and T_5 differed non-significantly from each other as well as from T_2 and T_3 but significantly differed from control and treatment T_6. Comparison between variety means indicated greater accumulation of P in AZRI Mung 2006 than NM 2006 and differed significantly from each other. Shoot sodium contents showed significant differences among treatments and varieties

Table 6: *Response of two varieties of mungbean to soil mixed Pb^{2+} and water stress for relative change in different yield traits.*

Treatments	Control	40 mg Pb^{2+} 100% FC	80 mg Pb^{2+} 100% FC	0 mg Pb^{2+} 50% FC	40 mg Pb^{2+} 50% FC	80 mg Pb^{2+} 50% FC	Mean
	No. of pods/plant						
NM 2006	9.70	6.60	6.60	5.80	4.40	3.60	6.12
AZRI 2006	12.00	11.00	6.80	4.80	4.20	2.60	6.90
Mean	10.85	8.80	6.70	5.30	4.30	3.10	
% Decrease		-18.89	-38.25	-51.15	-60.37	-71.43	
	Pod length (cm)						
NM 2006	8.30	8.10	7.80	7.60	7.40	6.20	7.57
AZRI 2006	9.50	8.50	8.20	7.30	7.00	5.90	7.73
Mean	8.90	8.30	8.00	7.45	7.20	6.05	
% Decrease		-6.74	-10.11	-16.29	-19.10	-32.02	
	100-seed weight (g)						
NM 2006	5.45	5.31	5.07	5.06	4.94	4.54	5.07
AZRI 2006	5.30	4.83	4.80	5.26	4.67	4.30	4.86
Mean	5.38	5.09	4.94	5.16	4.81	4.42	
% Decrease		-5.35	-8.23	-4.07	-10.64	-17.81	
	No. of seeds/pod						
NM 2006	10.40	10.40	9.80	9.60	8.80	6.20	9.20
AZRI 2006	11.80	10.40	10.40	9.00	8.00	6.40	9.33
Mean	11.10	10.40	10.10	9.30	8.40	6.30	
% Decrease		-6.30	-9.01	-16.22	-24.32	-43.24	
	Seed yield/plant (g)						
NM 2006	5.47	3.65	3.23	2.84	1.84	1.04	3.01
AZRI 2006	7.41	5.61	3.48	2.21	1.31	0.74	3.46
Mean	6.44	4.63	3.35	2.53	1.58	0.89	
% Decrease		-28.07	-47.92	-60.77	-75.51	-86.17	

while non-significant for treatment × varieties interaction. Gradual reduction in shoot sodium contents was observed in all treatments with increasing concentration of Pb^{2+} and water stress. Minimum reduction was observed as compared to control in simple lead treatment T_2 (11.32%) and maximum in combined lead and water stress treatment T_6 (30.51%). Comparison of means showed that treatments T_4 and T_5 differed non-significantly from each other as well as other treatments except control. Treatment T_6 differed significantly from T_1 and T_2 and non-significantly from other treatments. A comparison between variety means showed greater accumulation of Na^+ in AZRI Mung 2006 as compared to NM 2006 and also differed significantly from each other. Kibria et al. (2009) also studied the effect of lead on growth and nutrient uptake of *Amaranthus ganeticus* and *Amaranthus oleracea* and observed the significant reduction in shoot sodium and phosphorus contents.

Analysis of variance revealed highly significant differences among treatments and treatment × variety interaction but non-significant among varieties for shoot Pb^{2+} contents. Increase in lead concentration was observed in all treatments except simple water stress T_4 which showed reduction in shoot lead content (11.56%). Highest increase in lead concentration was observed at single but higher concentration of lead treatment T_3 i.e. 92.75%. It was observed that water stress reduced the uptake/accumulation of lead in combined lead and water stress treatments as compared to simple lead treatments. Moreover, treatments T_2 and T_6 were found non-significant to each other but differed significantly to all other treatments including control. Treatments T_3, T_4 and T_5 were differed significantly from each other as well as control. Piechalak et al. (2002) studied the effect of lead in three legume species i.e. *Vicia faba, Pisum sativum* and *Phaseolus vulgaris* and observed that highest concentration of Pb^{2+} was accumulated in the roots of *Phaseolus vulgaris*.

Figure1: *Phenotypic response of mungbean varieties to different levels of soil mixed Pb^{2+} and water stress.*

Yield traits

Analysis of variance for yield related traits is presented in Table 3 and response of varieties to change in investigated traits in Table 6. For number of pods/plant, highly significant differences were observed among treatments and treatment × variety interaction while significant among varieties. Highest number of pods per plant was observed in control (10.85) while all stress treatments showed gradual reduction with water stress and increasing concentration of lead. Combined lead and water stress treatment (T_6) showed maximum reduction (71.43%) over control. Comparison between treatment means showed that treatments T_5 and T_6 differed significantly from all other treatments but non-significant to each other. T_2, T_3 and T_4 were differed significantly from each other as well as from control. Moreover, both varieties behaved differently towards various treatments applied and differed significantly from each other. For pod length, highly significant differences were observed among treatments but non-significant among varieties and treatment × variety interaction. Gradual reduction in pod length was observed with increasing concentration of lead and water stress over control. Maximum reduction was observed in combined lead and water stress treatment. Treatment means T_3, T_4 and T_5 were differed non-significantly from each other but significantly from all other treatments. Combined lead and water stress treatment T_6 was differed significantly from all other treatments while simple lead treatment T_2 was non-significant to control and T_3. Variety means showed that both varieties behaved in the same pattern towards various treatments applied and differed non-significantly from each other. These results are in accordance with the findings of Manjru et al. (2007) who observed that water stress at flowering stage significantly reduced seed weight, seeds per pod and grain yield in mungbean.

For 100-seed weight, highly significant differences were observed among treatments but non-significant among varieties and treatment × varieties interaction. Maximum 100-seed weight was observed in control (5.378) while minimum in treatment T_6 (4.420). Gradual reduction was observed in all treatments with increasing concentration of lead and water stress. Minimum reduction was observed in single water stress treatment T_4 (4.07%) while maximum in combined lead and water stress treatment T_6 (17.81%). Comparison between treatment means showed that the treatments T_2, T_3 and T_4 were differed non-significantly from each other as well as from control and T_5. Treatment T_6 differed significantly from all other treatments except T_5. Moreover, comparison of variety means indicated more 100-seed weight in NM 2006 as compared to AZRI 2006 but both varieties differed non-significantly from each other. Number of seeds per pod showed highly significant differences among treatments but non-significant among varieties and treatment × variety interaction. Gradual reduction in number of seeds per pod with increasing concentration of lead and water stress treatment was observed in all treatments. Single lead treatment (T_2) showed minimum reduction (6.30%) while maximum in combined lead and water stress treatment T_6 (43.24%). Treatment means T_1, T_2 and T_3 differed non-significantly from each other but significantly from T_5 and T_6. Comparison of variety means showed that both varieties behaved in the same pattern towards various treatments applied and differed non-significantly from each other.

Seed yield per plant showed highly significant differences among treatments and treatment × variety interaction but non-significant among varieties. Generally, it was observed that lead and water stress either individually or in combination showed adverse effects on seed yield/plant. Maximum reduction (86.17%) was observed at higher dose of lead and water stress (T_6). Comparison between treatment means showed that all treatments differed significantly from each other except T_5 and T_6 which differed non-significantly from each other. Comparison of variety means indicated more seed yield in AZRI Mung 2006 as compared to NM 2006 but both varieties differed non-significantly from each other. The results are in accordance with the findings of Sadeghipour (2008) who studied the response of three mungbean varieties in water stress and observed significant reduction in all yield related traits of mungbean. In this experiment, sudden decrease was also observed in pods per plant due to combined effect of lead and water stress treatment as compared to simple lead treatment which may cause decrease in yield per plant. This was happened due to flower shedding when water stress was applied. This result showed that water stress may cause more adverse effect on crop yield as compared to Pb^{2+} application.

Conclusions

In general, lead and water stress showed adverse effect on plant growth and development. All morpho-physiological and yield parameters showed gradual reduction with increasing concentration of lead and water stress and maximum reduction was observed in combined lead and water stress (80 mg Pb^{2+} Kg^{-1} soil + 50% FC). Among both varieties, AZRI Mung 2006 was observed to be better as compared to NM 2006.

Author's Contribution

MH and GA developed the basic idea. FA conducted the experiment and recorded data. MJA performed the statistical analysis. MR helped in the execution of experiment and prepared the draft manuscript.

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