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Assessing Mercury-Induced Stress on two Commonly Cultivated Mung Bean (*Vigna radiata*) Varieties: Evaluating its Effect on the Seed Germination and Seedling Growth

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Abstract

Mung bean (*Vigna radiata L.*), also known as green gram, is a short-season summer legume widely grown in tropical and subtropical regions, particularly in countries like Pakistan, China, India, Thailand, Indonesia, and the Philippines. Despite its agricultural importance, little is known about its response to mercury (Hg) stress. This study evaluated the biochemical and physiological effects of varying Hg concentrations (0, 50, 100, 150, 250, and 350 mg/kg) on two mung bean varieties, NM-06 and AZRI-06. Key growth parameters such as shoot and root length, as well as biomass, were measured to assess the impact of Hg during germination and growth. Results showed a dose-dependent decline in plant growth and biomass. Nutrient content in leaves was also affected: levels of carbon, nitrogen, phosphorus, potassium, and magnesium decreased, while sodium increased. Photosynthetic rate, chlorophyll, protein, and proline levels were significantly reduced under Hg stress. Yield components were adversely impacted, with the greatest effects observed in pod number and seed weight. A maximum harvest index of 8% was recorded. AZRI-06 showed greater tolerance to Hg than NM-06. Higher Hg doses (250–350 mg/kg) caused more severe damage compared to lower doses. The findings indicate that Hg stress negatively affects mung bean morphology, physiology, and yield. Further research is needed to understand the underlying stress-response mechanisms in germinating seeds.

KEYWORDS

Mercury, Mung bean; Seed germination, Toxicity; Plant growth; Biomass production

1.0 INTRODUCTION

Heavy metals have significant role in ecological pollution due to anthropogenic activities i.e. mining, electro plating, energy and fuel production, agricultural practices, use of sludge and industrial effluent etc [1-3]. Mercury, lead, cadmium, and chromium are non- essential heavy metals and causes many phytotoxic impacts in plants. Mercury poisoning become a severe problem due to environmental pollution worldwide [4] as being used for agricultural lands along with sludge, fertilizers, manure etc. Mercuric chloride ($HgCl_2$) is commonly used as catalysts in the manufacturing process of plastics, acetaldehyde, Hg is also used in the production of batteries, street lamps, and causes toxicity into aquatic environment [5, 6]. Mercury enters in plants from sewage disposal as inorganic forms during methylation after being absorbed from the soil remains deposited mostly in the root tissues and its critical toxic level in plants is assumed up to 8 ppm [7, 8]. Toxicity of mercury at its lower dose is considered as injurious to plant growth [9].

Several researchers [10, 11] reported limited seed germination at higher concentration of Hg heavy metal due to ion toxicity associated with the alterations in cellular permeability, inhibition of protein activity or toxicity to the embryo and growing seedling [12]. Kalimuthu and Sivasubramanian (1990) studied percent seed germination, root and shoot length in maize seedlings and found noteworthy decrease with increasing dose of both lead and mercury [13]. Cadmium and mercury toxicity affected seed germination, growth parameters, photosynthetic pigments, and total protein level in *Pisum sativum* [14]. Leaf biochemistry and various developmental stages of tomato plant found adversely affected by Hg doses [15]. Root, stem elongation, leaf performance, and chlorophyll content negatively affected in groundnuts due to Hg treatment [16, 17]. In various *Vigna* spp. Hg affected germination process, root, shoot length and leaf coloration [18]. WHO-approved levels of heavy metals in plants are necessary for both humans and animals, as concentrations above critical thresholds have a negative impact on development, mental and general health, and social behavior in people (WHO, trace elements in human nutrition and health, Geneva -1996) [19]. Pakistan's pre-urban areas are contaminated with heavy metals due to the discharge of untreated sewage water and garbage from various industries into water bodies [20, 21]. Heavy metal pollution in Pakistan is caused by a variety of industries, including paint, batteries, textiles, agriculture, and pharmaceuticals, as well as numerous kinds of home wastewater. Mung bean plants are the major source of pulses which are protein enriched and a part of our daily diet. It is playing a significant role in export economy of Pakistan. Looking towards possible health risks from use of contaminated crop yield in the area, present study was conducted to understand hazards of heavy metal pollution caused by mercury.

Mung bean (*Vigna radiata* L.) (Fabaceae) has been growing extensively throughout the tropics and subtropics. It is a highly significant short-season summer-growing legume that adapts well to a variety of cropping systems. Considering the nutritional advantages and nutraceutical qualities of mung bean, it is essential to analyze the hazardous effects which impact on its seed germination and on different growth

factors. Although there are many mung bean cultivars in Pakistan, M-1, NM-6, AZRI-6, NM-92, and NM-98 are more frequently grown because of their superior yield, shorter growth times, and resistance to various challenges (such as water and temperature). In Pakistan, they are typically consumed as one of the most popular pulses. The information provided here is likely to benefit food crop growers and consequently optimize production economically under stressed soils. In present research two mung bean varieties were grown in slightly alkaline sandy loam soil in Bio-Park of Bahauddin Zakariya University, Multan.

2.0 EXPERIMENTAL

2.1 Selection of plant variety

From a local seed supplier, certified and healthy mung bean (*Vigna radiate* L. Wilczek) varieties NM-06 & AZRI-06 were collected. To prevent fungal infection, a diluted solution of sodium hypochlorite was applied to the seeds' surface and left for a minute. The seeds were transplanted to 90 mm diameter Petri dishes with filter paper at room temperature after being cleaned with distilled water.

2.2 Seed germination test

In the Bio-Park of Bahauddin Zakariya University (BZU) in Multan, a pot experiment was carried out. A ten-day room-temperature seed germination test was conducted in the botany department of BZU. In accordance with Akinci & Akinci (2010) [22], the experiment was planned systematically and in an ideal environment. For experiment, earthen clay pots of 12-inch diameter were taken, washed with water and dried for 24 hours. The selected pots were filled with the soil prepared for experiment. Furthermore, 500 kg of sieved soil were prepared, and after weighing and combining HgCl; Hg mg/kg of soil, a 3:1 ratio of fine canal sand and clay was combined with humus and poured in labelled pots. A white colored HgCl crystalline salt (Merck-Germany) was employed as a source of mercury heavy metal. Different Hg doses i.e. 50, 100, 150, 250, 350 mg/kg of pot soil were thoroughly mixed within the pots.

2.3 Seed sowing process

Each variety's healthy, uniformly sized mung bean seeds were selected and they were planted 2 cm deep in the soil bed in against to each of the six treatments i.e., 0, 50, 100, 150, 250 and 350 mg/kg Hg doses, including control. Six repetitions of each treatment were then added, and a total of 72 pots of both types were set up in a randomized block pattern. Physio-chemical characteristics of oven dried soil were evaluated by using method according to standard protocol [23, 24] from the quality control laboratory of D.G. Khan Cement Company. Soil mineral composition, electrical conductivity (EC), organic carbon (%) were determined by loss on ignition (LOI %) technique by following Konare et al. (2010) and Abella et al. (2007) [25, 26]. Organic matter (%) and organic Nitrogen was estimated by Kjeldahl method. After necessary preparations and seed sowing process, the pots were left until growth of seedlings. Thinning was performed when seedlings attained an approximate height of six inches after twenty-five days. Four healthy plants pot^{-1} were sustained as harvest till maturity and various parameters were studied to explore the effects of Hg heavy metal on plants. Physiological Analysis of Plant was carried out by following Ahmad et al., 2011 and Vernay et al.,

2008 [27, 28].

2.4 Morphological analysis

Morphological and plant biomass parameters, such as; root length (cm), total plant height, shoot length, leaf area per plant (cm^2), number of leaves, number of flowers $plant^{-1}$, Dry weights (DW g $plant^{-1}$) and Fresh weights (FW g/plant) were recorded [27, 29]. Fluctuations in leaf color were noted for necrotic and chlorosis studies. Along the gradient of mercury content, a change in leaf color was observed.

2.5 Biochemical analysis

Biochemical Analysis of Plant such as; total chlorophyll contents, protein and proline levels, organic carbon and nitrogen, leaf K^+, Na^+, Mg^{2+} and P^{3+} were recorded through standard methods [27, 30-32]. Ultimately, the Perkin-Elmer atomic absorption spectrometer was used to quantify Cr at 357.9 nm [29, 33, 34]. Yield parameters of plant such as; number of pods per plant was calculated by following method described by Nanja et al., 2003 and Auda et al., 2010 [35].

2.6 Analysis of data

One-way ANOVA, linear regression graphs and Duncan multiple range tests were used to evaluate the data using SPSS-17.0 statistical software and the MS-Excel 2010 program.

3.0 RESULTS AND DISCUSSION

3.1 Effects of mercury on seed germination

Almost all tested seeds from both varieties NM-06 & AZRI-06, were germinated 100% at day 8, up to 50 mg/kg of Hg dose. Reduction in seed germination was observed at 100-350 mg/kg dose (Fig. 1). Regression graphs, Duncan multiple range tests, and analysis of variance demonstrate a strong impact of mercury dosages on the percentage of germination in two mung bean cultivars. The sandy loam soil used in the experiment had a slightly alkaline pH of 67.6 % sand and 19.0 % clay. Soil organic carbon was 5.9 % and organic nitrogen was 1.15 %, while soil electrical conductivity and organic matter were 1.75 % and 7.1 %, respectively.

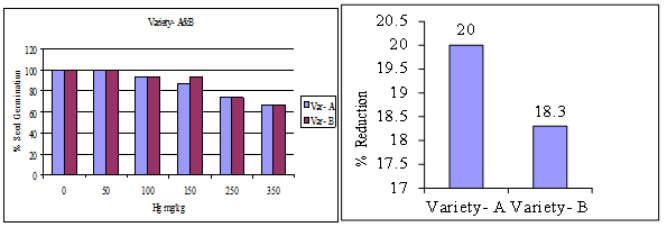

Fig. 1: Seed germination (a), Comparison of mean reduction in seed germination for mung bean Variety-A (NM-06) & Variety-B (AZRI-06) under mercury stress (b).

3.2 Effects of mercury on physiological parameters

On mung bean plants, mercury was found to have significant effects as shown in Figure 2. Reducing internal carbon use (Ci), stomatal conductance (Gs), and transpiration rate (E) resulted in a drop in photosynthetic rate (A). Hg had an impact on the transpiration rate, internal carbon usage, photosynthetic rate, and stomatal conductance of mung bean variety A (NM-06). A rapid decline was shown at higher Hg doses (150-350 mg/kg) by 9.10-14.50 %, 12.5-17.1-28.6 %. Results in Variety-B (AZRI-06), for same parameters were 6.2-12.2 % to 18.1-25.3 %, respectively. However, water use efficiency (WUE) of plants increased with increasing Hg doses (Fig. 2).

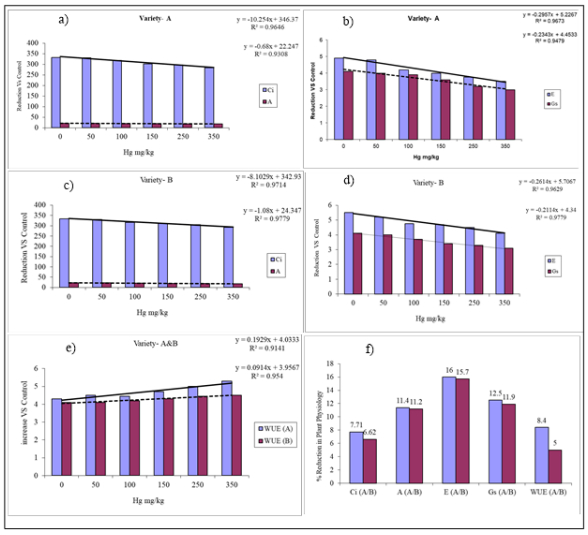

Fig. 2: Reduction in internal carbon use (Ci) and rate of photosynthesis (A) in Variety-A (a), transpiration rate (E) & stomatal conductance (Gs) in Variety-A (b), % internal carbon use and rate of photosynthesis in Variety-B (c), transpiration rate & stomatal conductance in Variety-B (d), Increase in water use efficiency (WUE) in plant (e), Comparison of mean reduction in plant physiology for mung bean variety-A/B under Hg stress (f).

3.3 Effect of Hg on morphological and growth parameters

From Table-1, it is determined that mercury has a significant effect on mung bean plants. Different growth parameters like total plant height (TPH), root length (RL), shoot length (Sh.L), number of leaves plant^{-1} (Lf. P) and leaf area per plant (LA) were affected. For mung bean test variety- A (NM-06); total plant height, root length, shoot length, number of leaves plant^{-1} and leaf area stressed by various Hg doses (mg/kg) as compared to control. A gradual decrease at Hg doses 50-150 mg/kg was 6.5 - 12.8 %, 0.21 – 9 %, 8.2 - 13.9 %, 2.9 - 13.5 %, 2.9 - 8.5 %, respectively. A rapid decline was noted at Hg dose 250-350 mg/kg i.e. 16.9 - 20.6%, 12.8 - 17.7 %, 17.9 - 21.5 %, 19 - 22.5 %, 8.5 – 13 %, respectively.

For mung bean test variety- B (AZRI-06), the available results at Hg dose 50-150 mg/kg were 3.9 – 11.01 %, 1.2 – 11 %, 8.1 - 13.81 %, 2.5 – 13.01 %, 1.9 – 8.1 %, respectively while at higher mercury doses i.e. 250-350 mg/kg these were 16 - 20.42 %, 15.51 - 18.92 %, 17.7 - 21.33 %, 19.8 – 22 %, 9.6 – 13.1 %, respectively. Analysis of variance was compared with Duncan multiple tests (Table-1.1) and linear regression was also performed that shows significant effect of Hg on plants. Mean reduction in plant morphological & growth parameters was calculated for both varieties (Fig. 3).

Table-1. Analysis of variance for total plant height (TPH), root length(RL), shoot length (SL), No. of leaves/plant (Lf. P) and leaf area (LA) in mung bean varieties A&B.

		DF	MS		F
			Var- A	Var- B	Var- A
TPH	Between Groups	5	50.65	54.3	24.7
	Within Groups	30	2.052	1.487	
	Total	35			
RL	Between Groups	5	1.8	2.3	6.7
	Within Groups	30	.263	.284	
	Total	35			
Sh. L	Between Groups	5	34.4	35.04	34.3
	Within Groups	30	1.002	1.069	
	Total	35			
Lf. P	Between Groups	5	6.03	8.1	10.15
	Within Groups	30	.594	.523	
	Total	35			
LA	Between Groups	5	12.53	14.70	24.45
	Within Groups	30	.513	.612	
	Total	35			

, significant, * Highly significant values at 0.05 significant level.

Table-1.1. Duncan tests for morphological analysis of plants in mung bean variety A&B.

Hg mg/kg	0	50	100	150	250	350
Variety-A						
N	6					
TPH.	39.38	36.80	34.46	34.33	32.73	31.25
Sig.	1.000	1.000	.055	.055	.083	.083
Subset	4	3	2	2	1	1
R.L	7.92	7.90	7.37	7.20	6.90	6.55
Sig.	.088	.088	.147	.147	.247	.247
Subset	3	3	2	2	1	1
Sh.L	31.48	28.90	27.13	27.10	25.83	24.70
Sig.	1.000	1.000	.954	.954	.059	.059
Subset	3	3	2	2	1	1
Lf. Pl	11.33	11.05	10.25	9.83	9.22	8.78
Sig.	.529	.082	.357	.176	.338	.338
Subset	5	4	3	2	1	1
L.A	30.58	29.60	28.78	27.98	27.60	26.57
Sig.	1.000	.057	.062	.361	.361	1.000
Subset	5	4	3	2	2	1
Variety-B						
TPH.	39.97	38.40	35.62	35.53	33.55	31.80
Sig.	1.000	1.000	.907	.907	1.000	1.000
Subset	5	4	3	3	2	1
R.L	8.17	8.07	7.43	7.30	6.90	6.62
Sig.	.747	.747	.111	.111	.364	.364
Subset	3	3	2	2	1	1
Sh.L	31.92	29.32	27.54	27.48	26.22	25.10
Sig.	1.000	1.000	.912	.912	.067	.067
Subset	3	3	2	2	1	1
Lf.Pl	11.92	11.62	10.80	10.35	9.55	9.33
Sig.	.346	.346	.387	.387	.937	.937
Subset	3	3	2	2	1	1
L.A	31.22	30.60	29.61	28.75	28.19	27.04
Sig.	1.000	1.000	.051	.345	.345	1.000
Subset						

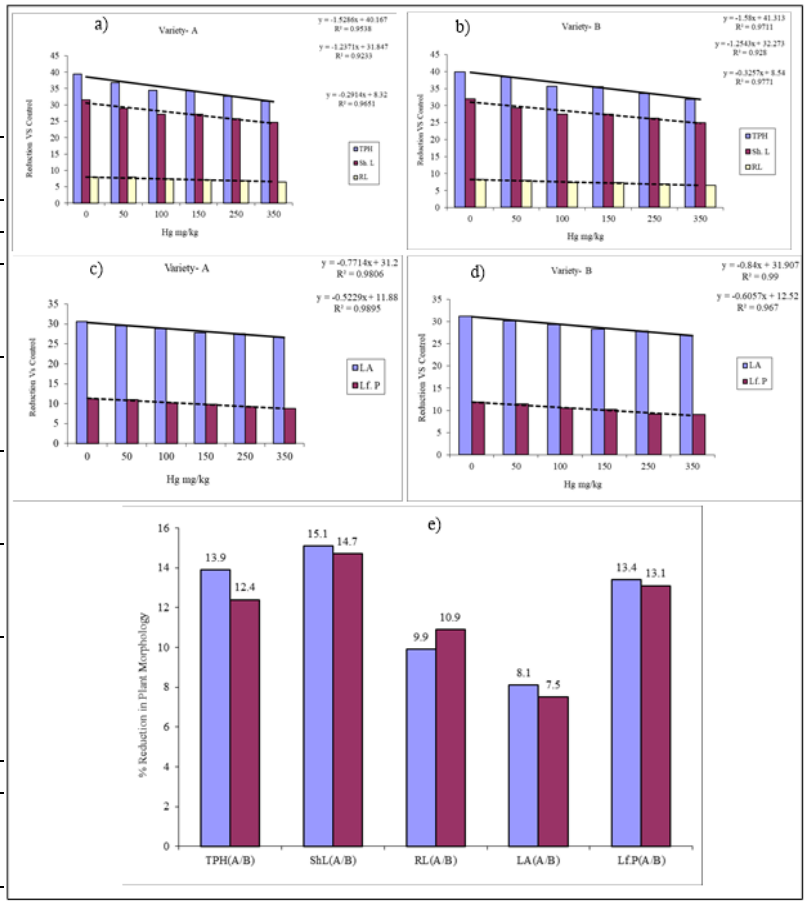

Fig. 3: % Reduction in total plant height (TPH), shoot length (Sh. L) and root length (RL) in Variety-A (a), % Reduction in total plant height, shoot & root length Variety-B (b), % Reduction in leaf area (LA) and number of leaf plant^{-1} (Lf. P) in Variety-A (c), % Reduction in leaf area and number of leaf plant^{-1} in Variety-B under Hg stress (d), Comparison of mung bean variety-A&B for % mean reduction in plant growth & morphological characters (e).

3.4 Effect on plant biomass parameters

Table-2 indicates mercury has an adverse impact on mung bean plants. Biomass parameters like root fresh weight (RFW), root dry weight (RDW), shoot fresh weight (SFW), shoot dry weight (SDW), leaf dry &

fresh weight (LDW, LFW), total plant fresh weight (Pt FW), total plant dry weight (Pt DW), and plant dry to fresh weight ratio (DW/FW) reduced, remarkably. In mung bean variety- A (NM-06) root fresh & dry weight, shoot fresh & dry weight, leaf fresh and dry weight, plant fresh & dry weight and plant dry weight & fresh weight ratio (DW/FW) adversely affected by Hg stress than control. A consistent decrease at Hg dose 50-150 mg/kg found was 6.0-16.0 %, 5.40-16.2 %, 2.5-18.81 %, 6.8-10.5 %, 7.2-11.4 %, 12.3-33.9 %, 6.2-13.7 %, 8.9-24.1 %, 2.8-11.9 %, respectively. A rapid decline was at Hg dose 250-350 mg/kg by 19.5-19.9 %, 19.8-30.6 %, 28.2-32.9 %, 12.3-18.5 %, 13.1–15 %, 41.4-47.9 %, 17.3-19.4 %, 29.7-36.9 %, 14.9–22 % respectively.

In mung bean variety- B (AZRI-06), plant changes than control for same parameters at Hg dose 50-150 mg/kg was 7.9–15 %, 5.2-15.5 %, 2.8-18.8 %, 7-11.2 %, 7.3–11 %, 11.8-35.1 %, 6.5–13 %, 8-24.6 %, 1.6-13.25 % respectively while at Hg dose 250-350 mg/kg 20.4-21.7 %, 19.8-30.1 %, 27.7-33 %, 12.9-21.2 %, 13-15.2 %, 41.9-47.6 %, 17.1-19.8 %, 29.9-37.4 %, 15.3-21.9% respectively.

Analysis of variance, DMRT (Table-2, table-2.1 & table-2.2) and linear regression graphs (Fig. 4) showed a visible effect of Hg doses on various plant biomass parameters. Mean reduction (%) in plant biomass for both test Varieties (Fig. 4) also revealed a remarkable impact of Hg on plants.

Table-2. Analysis of variance for biomass parameters in two mung bean Varieties A&B.

		DF	M S		F		Sig.	
			Var-A	Var-B	Var-A	Var-B	Var-A	Var-B
R.F.W	Between Groups	5	.541	.651	15.05	16.01	.000***	.000***
	Within Groups	30	.037	.041				
	Total	35						
R.D.W	Between Groups	5	.251	.296	14.15	15.91	.000***	.000***
	Within Groups	30	.018	.019				
	Total	35						
S.F.W	Between Groups	5	3.10	3.18	75.52	63.63	.000***	.000***
	Within Groups	30	.041	.050				
	Total	35						
S.D.W	Between Groups	5	.164	.240	4.10	6.30	.005**	.006**
	Within Groups	30	.040	.038				
	Total	35						
L.F.W	Between Groups	5	5.01	5.05	25.72	26.87	.000***	.000***
	Within Groups	30	.195	.187				
	Total	35						
L.D.W	Between Groups	5	8.75	9.22	91.11	85.54	.000***	.000***
	Within Groups	30	.096	.108				
	Total	35						
Pt.F.W	Between Groups	5	21.62	22.36	41.74	46.19	.000***	.000***
	Within Groups	30	.518	.482				
	Total	35						
Pt.D.W	Between Groups	5	13.86	15.32	68.71	67.82	.000***	.000***
	Within Groups	30	.205	.230				
	Total	35						
DW/FW	Between Groups	5	.008	.008	59.90	51.26	.000***	.000***
	Within Groups	30	.000	.000				
	Total	35						

Table-2.1. Duncan test for biomass parameters in mung bean variety A (NM-06)

Hg mg/kg	**0**	**50**	**100**	**150**	**250**	**350**
N	6					
RFW.	3.85	3.62	3.43	3.23	3.10	3.08
Sig.	1.000	.110	.083	.214	.214	.214
Subset	4	3	2	1	1	1
RDW.	1.85	1.75	1.68	1.55	1.48	1.28
Sig.	.202	.392	.093	.392	.392	1.000
Subset	5	4	3	2	2	1
SFW.	5.32	5.18	4.73	4.32	3.82	3.57
Sig.	.261	.261	1.000	1.000	1.000	1.000
Subset	6	5	4	3	2	1
SDW.	2.70	2.52	2.45	2.42	2.37	2.20
Sig.	.124	.247	.056	.056	.056	.056
Subset	3	2	1	1	1	1

LFW.	17.05	15.82	15.30	15.10	14.82	14.48
Sig.	1.000	.051	.082	.082	.201	.201
Subset	4	3	2	2	1	1
LDW.	6.63	5.82	5.12	4.38	3.88	3.46
Sig.	1.000	1.000	1.000	1.000	1.000	1.000
Subset	6	5	4	3	2	1
PtFW.	26.25	24.62	23.47	22.65	21.72	21.15
Sig.	1.000	1.000	.059	.059	.183	.183
Subset						
PtDW.	11.00	10.02	9.50	8.35	7.73	6.93
Sig.	1.000	1.000	1.000	.055	.055	1.000
Subset	5	4	3	2	2	1
DW/FW	41.88	40.68	40.50	36.86	35.61	32.76
Sig.	.052	.052	.052	.063	.063	1.000
Subset	4	4	4	3	2	1

Table-2.2. Duncan test for mung bean variety- B (AZRI-06)

Hg mg/kg	**0**	**50**	**100**	**150**	**250**	**350**
N	6					
RFW.	4.00	3.68	3.62	3.40	3.2	3.13
Sig.	1.000	.571	.072	.072	.670	.670
Subset	4	3	2	2	1	1
RDW.	1.93	1.83	1.77	1.63	1.55	1.32
Sig.	.053	.053	.100	.298	.298	1.000
Subset	4	4	3	2	2	1
SFW.	5.42	5.27	4.82	4.40	3.92	3.62
Sig.	.252	.252	1.000	1.000	1.000	1.000
Subset	5	5	4	3	2	1
SDW.	2.83	2.63	2.62	2.52	2.47	2.23
Sig.	.079	.188	.188	.188	.188	1.000
Subset	3	2	2	2	2	1
LFW.	17.12	15.87	15.43	15.22	14.88	14.52
Sig.	1.000	.093	.393	.192	.153	.153
Subset	5	4	3	2	1	1
LDW.	6.76	5.94	5.20	4.40	3.92	3.53
Sig.	1.000	1.000	1.000	1.000	.052	.052
Subset	5	4	3	2	1	1
PtFW.	26.53	24.82	23.87	23.20	21.98	21.30
Sig.	1.000	1.000	1.000	1.000	.084	.084
Subset	5	4	3	2	1	1
PtDW.	11.32	10.40	9.77	8.53	7.93	7.10
Sig.	1.000	1.000	1.000	1.000	1.000	1.000
Subset						
DW/FW	42.63	41.88	40.92	37.10	36.11	33.30
Sig.	.313	.203	.203	.198	.198	1.000
Subset	4	3	3	2	2	1

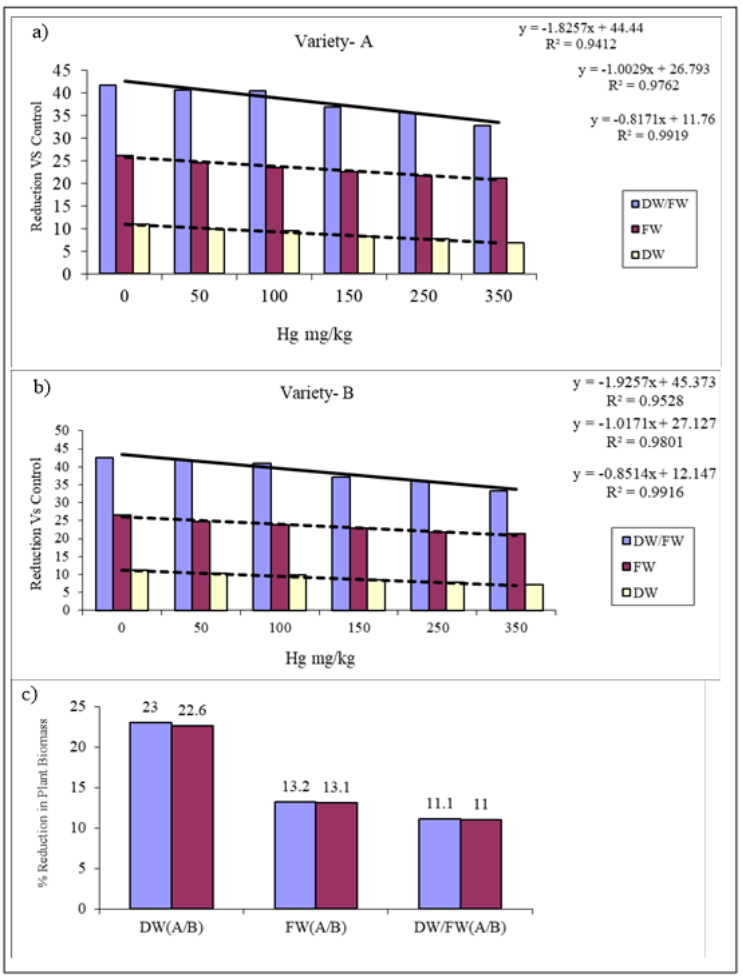

Fig. 4: % Reduction in plant biomass in Variety-A (a), % Reduction in plant biomass in Variety-B (b), Comparison of mean % reduction in plant biomass of mung bean variety A/B under Hg stress. DW (dry weight g/plant), FW (fresh weight g/plant) (c).

3.5 Effect of mercury on leaf contents in both varieties

Total leaf chlorophyll contents, protein, proline and leaf accumulated Hg were highly affected under Hg stress (Fig. 5). In mung bean variety-A (NM-06), total leaf chlorophyll (Lchl), protein, proline and leaf mercury contents were affected by Hg treatment. There was a less decrease at Hg dose 50-150 mg/kg by 3.2-12.2 %, 7.1-25.2 % and proline increased by 2.3-36.5 %, respectively. A fast decline occurred at Hg

dose 250-350 mg/kg which was 14.6-18.2 %, 30.7-32.3 % while proline increased 42.2-47.9 %, respectively. In mung bean variety- B (AZRI-06), the results for these parameters at Hg dose 50-150 mg/kg were 3.5-11.3 % to 0.55-37 %, respectively and at Hg dose 250-350 mg/kg by 14.4-18.1 % to 42-48 %, respectively (Fig. 5).

Results revealed that Hg has adverse impacts on mung bean plants and there is a decrease in leaf nutrient contents regarding carbon (C), phosphorus (P), nitrogen (N), magnesium (Mg) and potassium (K), but sodium (Na) content of leaf increased with increase in Hg doses (Fig. 6). In mung bean variety-A (NM-06), all leaf nutrient contents were affected under Hg treatment. A gradual decrease at Hg dose 50-150 mg/kg was 0.5-10.3 % to 2.5-34.2 %. A rapid decline was found at Hg dose 250-350 mg/kg by 19.5-29.5 % to 37.5-42.8 %. In mung bean variety- B (AZRI-06), at Hg dose (50-150 mg/kg) rate of reduction in leaf nutrients was 0.96-12.3 % to 3.8-32.3 % and at Hg dose 250-350 mg/kg it was 18.4-29.4 % to 36.9-42.3 %. Statistical analysis revealed significant effects of Hg on mung bean plants from two test varieties.

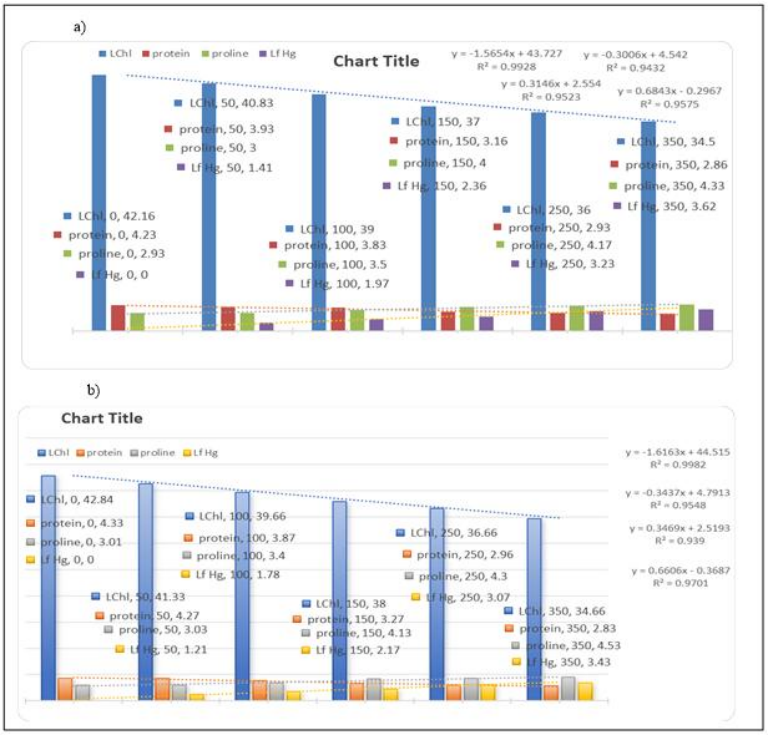

Fig. 5: Leaf chlorophyll, protein, proline and leaf Hg level in mug been Variety-A (a), leaf chlorophyll, protein, proline and leaf Hg level in mug been Variety-B (b).

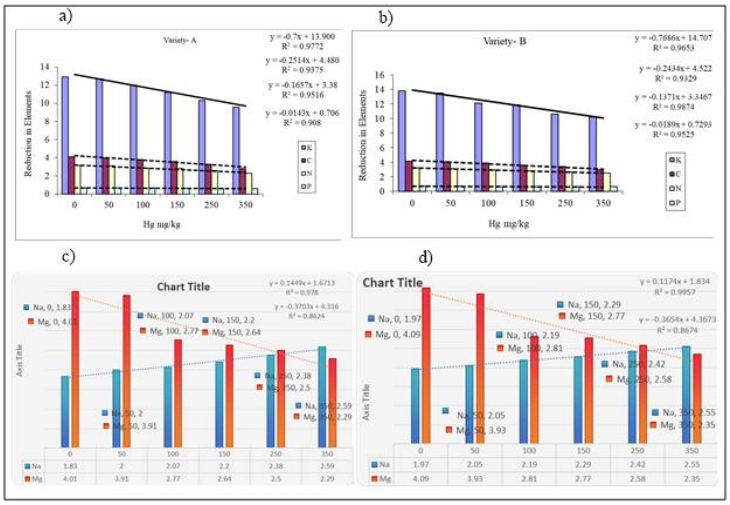

Fig. 6: Leaf carbon, potassium, nitrogen and phosphorus in mug been Variety-A (a), leaf carbon, potassium, nitrogen and phosphorus in mug been Variety-B (b), Leaf sodium (Na) and magnesium (Mg) in mung bean variety-A (c), Leaf sodium (Na) and

magnesium (Mg) in mung bean Variety-B (d).

3.6 Multivariate analysis

Results showed Hg heavy metal has a significant adverse impact on mung bean plants. Multivariate yield parameters in both test varieties were found affected at 50-350 mg/kg of Hg. Mercury affected pods plant^{-1} (9.1-43 %), number of seeds pod^{-1} (7-50 %), seed weight plant^{-1}(8.5-42 %), 10 seeds weight (2.6-16 %) and harvest index (0.5-8 %). At lower Hg doses (50-150 mg/kg), % reduction was less than at higher Hg doses (Table-3). Mean reduction for different yield parameters in both test varieties showed AZRI-06 more Hg tolerant than NM-06. Analysis of variance, graphs of regression analysis and Duncan multiple range tests showed a significant effect of Hg on both mung bean varieties A&B (Fig. 7).

Table-3. Duncan test for yield parameters in mung bean variety A (NM-06)

Hg mg/kg	**0**	**50**	**100**	**150**	**250**	**350**
Variety- A (NM-06)						
N	6	6	6	6	6	6
Pod plant^{-1}	10.00	9.00	8.67	7.50	6.50	5.66
sig.	1.000	1.000	.511	.511	.766	.766
subset	3	3	2	2	1	1
Sd/Pod	11.70	10.83	9.20	7.83	6.83	5.83
sig.	.099	.061	.061	.061	1.000	1.000
subset	4	3	3	3	2	1
Sd.WtP^{-1}	4.75	4.31	4.10	3.50	3.10	2.73
sig.	1.000	.075	.075	.253	.253	1.000
subset	4	3	3	2	2	1
10 seed wt	3.85	3.77	3.63	3.43	3.30	3.21
sig.	.164	.164	.174	.134	.134	.134
subset	3	3	2	1	1	1
H.I	43.20	43.10	42.70	42.01	40.24	39.75
sig.	.148	.148	.148	.152	.152	.175
subset	3	3	3	2	2	1
Variety- B (AZRI-06)						
Pod plant^{-1}	11.00	10.00	9.83	8.50	7.67	6.50
sig.	1.000	.499	.499	.811	.811	.811
subset	4	3	3	2	1	1
Sd/Pod	11.81	10.51	9.90	8.36	7.45	5.93
sig.	.781	.781	.236	.236	.550	1.000
subset	4	4	3	3	2	1
Sd.WtP^{-1}	4.82	4.46	4.11	3.53	3.22	2.80
sig.	1.000	.275	.275	.275	.275	1.000
subset	4	3	3	2	2	1
10 seed wt	3.80	3.67	3.61	3.47	3.34	3.27
sig.	.219	.219	.211	.176	.176	.176
subset	3	3	2	1	1	1
H.I	42.62	42.40	42.24	41.53	40.51	40.05
sig.	.163	.163	.190	.190	.190	.200
subset	3	3	2	2	2	1

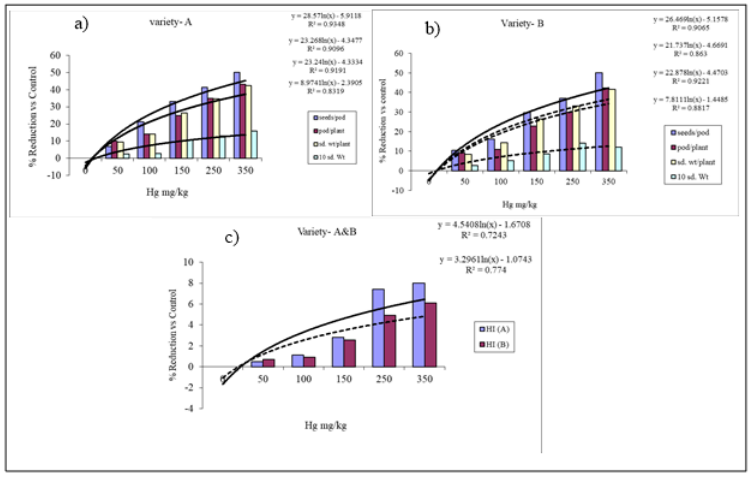

Fig. 7: Reduction in yield parameters in mug been Variety A (a), reduction in yield parameters in mug been variety B (b), reduction in harvest index (HI) for two mug been Varieties A & B (c).

4.0 DISCUSSION

On account of environmental degradation on a global scale, mercury poisoning has gained attention these days. Two-thirds of the intake comes from natural mercury emissions, with the remaining one-third coming from human releases. Lumps, fertilizers, manures and sludge may all contribute significant levels of mercury to agricultural soil. In present research two mung bean varieties were investigated. For Hg treatments, regarding various physiological and morphological parameters of plant growth rate observed less at lower Hg doses than higher doses i.e. 250-350 mg/kg [13, 14, 36]. In different physiological parameters, inhibitions were recorded i.e. rate of photosynthesis, internal carbon use, transpiration rate, stomatal conductance and water use efficiency under Hg doses (Fig. 2). As the role of heavy metals in inhibition of photosynthesis was revealed by Murthy et al., 1993 [37]. According to Boening (2000), reduction in photosynthesis, transpiration rate, water use efficiency of plants and chlorophyll synthesis found associated with increasing level of Hg, resent study also revealed same results [23]. Various morphological and growth parameters found stressed under different Hg treatments reflected mitotic inactivity in different Vigna spp. [38]. Plant biomass parameters are affected due to Hg treatments (Fig. 3). Ratio of DW/FW proved to be important criteria for accumulation of different metabolites and its decrease indicated abnormal accumulation of these metabolites in plants under Hg stress. A 50% reduction in root/shoot biomass in rice seedlings was recorded at 2.5 mg/kg Hg^{2+} dose was reported in a similar study [39]. By using same dose of Hg, a reduced transverse and longitudinal planes of *Cucumis* plants were observed in a research work performed by Chaudhary et al., 2007 [40]. Results from present study also well agreed with these referred citations. Leaf biochemical analysis showed decline phase regarding chlorophyll contents, protein and proline contents increased up to 48% [14]. Both varieties showed a decrease in the amount of plant biomolecules that were available, and this decline was also expected to result in a reduction in the biosynthesis of carbohydrates during photosynthesis. However, elevated sodium levels may be associated with decreased leaf performance. Gupta et al. (1998) and Patra et al. (2004) found a significant drop in chlorophyll and biomolecules when Hg concentrations increased from 0.5 to 20 μM [41, 42]. Plant yield characteristics have been changed by each dosage of Hg. Under Hg treatment, there was a decrease in the number and weight of seeds, which impacted pod production per plant. These findings were supported by previous studies, which showed that the harvest index is the best criterion to attain more production [36, 43]. This type of exception is linked to

dry biomass and irregular plant physiology, both of which reduce harvest index, or net plant yield.

5.0 CONCLUSION

This investigation has revealed that mercury (Hg) stress poses a considerable effect on a range of physiological and growth parameters of mung bean plants. At higher Hg doses (250-350 mg/kg), which produced more severe effects than lower ones (50-150 mg/kg) the two varieties, NM-06 and AZRI-06, were characterized by strong reductions in seed germination, photosynthetic rate and metrics of plant growth. Higher levels of Hg results in lower chlorophyll and protein levels in leaves and high levels of proline (a stress response). There was significant nutrient absorption as shown by the depletion in vital elements like nitrogen, phosphorus, potassium, and magnesium. There was also a negative impact on yield parameters, such as pod and seed measures, where AZRI-06 was rather more tolerant to Hg stress than NM-06. It is suggested that the negative impacts of Hg pollution on the growth of mung bean and underline the importance of mitigation measures to protect the crop production of the soils contaminated with Hg.

Authors Declarations

Ethical approval

The present study does not involve human or animal subjects and is therefore not applicable in this context. Mung bean seeds were collected in compliance with institutional, national, and international regulations, with all necessary permissions obtained. Voucher specimens (BOT-156) have been deposited in the Herbarium of the Department of Botany, The Government Sadiq College Women University, Bahawalpur, Pakistan.

Competing interests

The authors declare no relevant financial or non-financial interests.

Author's contributions

Tanveer Raza is responsible for Writing, review and editing. Saman Zulfiqar is responsible for review, editing, and Writing of original draft. Amjad Hussain is responsible for Visualization, Methodology, and Investigation. Muhammad Sajid Hamid Akash is responsible for Formal analysis, and Conceptualization. Muhammad Sanwal is responsible for Writing, review and editing Khayala Mammadova is responsible for Formal analysis and Conceptualization. Muhammad Imran is responsible for Formal analysis and Conceptualization. Meher Ali is responsible for review, editing, Writing the original draft. Muhammad Adnan Ayub is responsible for Supervision and Methodology. Shoaib Khan is responsible for Investigation, and Conceptualization. Sajjad Azam is responsible for Writing, review and editing of the manuscript. All the authors have read and approved this version of the manuscript.

Data availability statement

All generated or experimental data during this study are included in this manuscript file.

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