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Differential responses on germination, seedling growth and localization pattern of mungbean genotypes under cadmium stress

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Abstract
The present experiment has been designed to study the effect of 100 µM cadmium stress on 14 genotypes of mungbean [*Vigna radiata* (L.) Wilczek] at seedling growth stage. The data revealed that 100 µM cadmium concentrations did not produce any significant change in seed germination as compared to control but the root showed more sensitivity to cadmium stress than shoot. Perusal of the data exhibited significant reduction of dry weight of root, shoot, leaf and whole seedling under cadmium stress in all fourteen genotypes studied. Among all the genotypes, the highest stress tolerance index (STI) was registered by Samrat (90.10%), PDM 54(88.90%), Pusa Baisakhi (85.98%), IPM 02-03(85.49%) and K 851 (82.87%) were considered to be tolerant and genotypes IPM 03-01, Meha, PDM 84-139, B1 and Bireswar with 65.30%, 69.54%, 69.67% 70.81% and 71.24% STI, respectively were considered as susceptible to cadmium treatment in the present study. In general, the root showed much higher accumulation of cadmium than shoot and leaf. Rate of uptake of cadmium in the root in tolerant genotypes was also found to be lower than the susceptible ones.

Keywords: cadmium stress, heavy metal, mungbean, stress tolerance index

1. Introduction
Cadmium is considered as a major toxic trace pollutant for humans, animals and plants. Largest quantity of cadmium enters the soil during the disposal of sewage sludge and waste materials, which contain more cadmium than all the other sources put together. Globally, cadmium content in soil is about 0.01-2 mg Kg^{-1}, with an average of 0.35 mg Kg^{-1} of soil (Kebata-Pendias and Pendias, 2001) [13]. In plants, cadmium is one of the most readily absorbed and most rapidly translocated heavy metal. This explains why it exerts such strong toxicity even at relatively low concentrations (Seregin and Ivanov, 1998) [23]. Accumulation of cadmium in plant tissues may cause a variety of toxicity symptoms ranging from chlorosis, wilting, and growth reduction, to cell death (Wahid *et al.*, 2007; Sreedevi *et al.*, 2008; Shaukat *et al.* 2010; Muneer *et al.*, 2011; Siddhu and Khan, 2012 and Tao *et al.*, 2015) [32, 24, 18, 25, 30].
Mungbean [*Vigna radiata* (L.) Wilczek] is an important leguminous species and is among the most important pulse crops in semi-arid tropics. So far, only limited research works have been conducted on the effect of cadmium toxicity on mungbean and the tolerance of this crop to this stress (Rout *et al.*, 2000; Bindhu and Bera, 2001; Reshu and Bhargava, 2007; Ghani, 2010; Muneer *et al.*, 2011 and Tao *et al.*, 2015) [20, 4, 19, 11, 18, 25]. Therefore, the present experiment has been designed to study the differential cadmium tolerance of some genotypes of mungbean and to understand cadmium accumulation and its subsequent distribution pattern to different plant parts which were important determiners of genotypic susceptibility to cadmium toxicity.

2. Materials and Methods
2.1. Plant Material
Seeds of 14 genotypes of mungbean [*Vigna radiata* (L.) Wilczek] were used in the experiment.

Table 1: List of genotypes used in the experiment:

Sl. No.	Genotypes	Sl. No.	Genotypes	Sl. No.	Genotypes
1	B 1	6	IPM 03-01	11	PDM 54
2	Bireswar	7	Samrat	12	K 851
3	Meha	8	Pusa Baisakhi	13	Pusa 105
4	IPM 02-03	9	Sunaina	14	PDM 11
5	Pant Mung 5	10	PDM 84-139		

2.2 Studies on germination and seedling growth

For germination studies, seeds of uniform size were surface sterilized with 0.1% (w/v) $HgCl_2$ for 3 minutes followed by thorough washing in distilled water. Twenty five seeds from each genotype were set to germinate in petridishes of 9 cm diameter lined with Whatman No.1 filter paper and moistened with 100 mM $CdCl_2$, H_2O solutions. Seeds were also germinated in glass distilled water (control) for comparison of performances. Three replicates were maintained at constant temperature of 28±1^{O}C. Final germination count was done at five days after germination.

Similarly, twelve seeds were arranged in a row over a glass plate (20×30 cm) lined with blotting paper separately. The whole set was then placed in a transparent polythene bag containing 50 ml of cadmium solution in each case. The seedlings were allowed to develop for 8 days under indoor laboratory conditions of bright diffused light, around 80% relative humidity (R.H.) and at a temperature of 28±1^{0}C. Surface sterilized seeds treated similarly with glass distilled water served as control. Three replicates were maintained in all cases including control. Eight days old seedlings were removed from the glass plate for studying different growth parameters.

Stress tolerance index was calculated for each genotype as per Garg and Singla (2004) [10]:

$$\text{STI \%} = \frac{\text{Dry weight of the genotype under stress}}{\text{Dry weight of the genotype under non-stress condition}} \times 100$$

2.3 Determination of cadmium content in plant samples

For determination of cadmium content in plant samples, the root, shoot and leaf of 8-day old seedlings grown in presence of 100 µM of cadmium were oven dried at 80±1°C. One gram of the dried samples were digested with di-acid mixture (HNO_3:$HClO_4$: 9:4) on a hot plate (APHA, 1995). The clear solutions were filtered through Whatman No. 42 filter paper and diluted to 50 ml for analysis by Atomic Absorption Spectrophotometer (GBC-902, Australia). For determination of cadmium content the following specifications were used:

Instrument Model	Metal	Lamp Current (mA)	Wave Length (nm)	Silt Width (nm)	Working Range (µg ml^{-1})
GBC-902, Australia	Cd	3.0	228.8	0.5	0.2-1.8

2.4 Histochemical localization of cadmium in cells and tissues

The histochemical localization of cadmium was done following the procedure of Seregin and Ivanov (1997) [22] with slight modification. Cross- and Transverse sections were made of the shoots and roots of seedlings raised in cadmium containing medium for 8 days. Cadmium was detected histochemically in these sections in cells and tissues using dithizone (diphenylthiocarbazone) dye. Thirty milligram of dithizone was dissolved in 60 ml acetone and 20 ml distilled water. Then the thin sections from root and shoot were stained in this solution for 1.5 hour. After staining, the sections were rinsed in water and analyzed by light and stereoscopic microscopy. The presence of cadmium in tissues was detected as dark red to black complexes of cadmium with dithizone (Szmal and Lipiec, 1996 and Seregin and Ivanov, 1997) [29, 22].

2.5 Statistical analysis

The mean data in all the cases were subjected to statistical analysis following two factor factorial design using Indostat version 7.1 software.

On the basis of stress response index (SRI) of root length, fresh weight and dry weight of root, fresh weight of whole seedling and stress tolerance index (STI), the 14 genotypes were analyzed for genetic similarity based on Euclidean distance using NTSYS-PC version 2.0 software. Dendrogram was constructed by Sequential Agglomerative Hierarical Nested (SAHN) clustering using the Un-weighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm.

3. Results and Discussion

3.1 Effect of cadmium stress on germination of mungbean genotypes

The data on percentage of germination under cadmium stress have been presented in Table 1. The analysis of variance indicated significant variation among genotypes for seed germination percentage. But the treatments as well as the interaction of genotype and treatment indicated non-significant differences. The data revealed that 100 µM cadmium concentration did not produce any significant change in seed germination as compared to control in the present study (Table 1). The findings were well consistent with the early reports of Tao *et al.* (2015) [25]. He *et al.* (2008) [12] reported inhibitory effect of cadmium on seed germination only at high concentration.

3.2 Effect of cadmium stress on seedling growth of mungbean genotypes

The effect of 100 µM cadmium on growth of 8-day old seedlings of fourteen mungbean genotypes was studied. The data on different growth parameters have been presented in Table 2-4. The analysis of variance indicated that the genotypes, treatments and the interaction between genotype and treatment showed highly significant variations for all the characters studied. Perusal of data revealed that cadmium treatment caused reduction in length of root, shoot and whole seedling in all the genotypes (Table 2). The genotypes differed in their responses to cadmium treatment in respect of these characters. The extent of decrease in root and shoot length ranged from 2.77-61.55% and from 0.74-30.29% over control, respectively. The root showed more sensitivity to cadmium stress than shoot. Greater sensitivity of root growth than shoot growth to cadmium accumulation was reported earlier by several workers (Al-Yemeni, 2001; Cheng *et al.*, 2008 and Subin and Steffy 2013). Taylor and Foy (1985) [2, 8, 28] and Tao *et al.* (2015) [25] concluded that the inhibition of root elongation was the first evident effect of metal toxicity in plants. In the present experiment, the genotypes PDM 54 and K 851 with 2.77% and 10.41% decrease in root length under cadmium treatment, respectively, exhibited the minimum detrimental effect of cadmium, while Bireswar (61.55% decrease over control) and IPM 03-01 (40.30% decrease over control) registered the most severe effect of cadmium on root length. Cadmium treatment caused minimum reduction in

shoot length in K 851 (0.74% decrease over control), Samrat (1.24% decrease over control) and IPM 02-03 (1.43% decrease over control). The two genotypes IPM 03-01 and Pusa 105 with 30.29% and 22.74% decrease over control, respectively, revealed the greatest adverse effects of cadmium on shoot length. The length of whole seedling under cadmium stress decreased to an extent of 2.46-38.09% over that of unstressed control in the fourteen genotypes. The two genotypes PDM 54 and K 851 with 2.46% and 5.31% decrease over control, respectively, indicated the minimum reduction in seedling length, while Bireswar (38.09% decrease over control) and IPM 03-01 (33.47% decrease over control) revealed the greatest inhibitory effect of cadmium treatment on seedling length.

Perusal of the data exhibited significant reduction of dry weight of root, shoot, leaf and whole seedling under cadmium stress in all the fourteen genotypes studied (Table 3 and 4). The extent of inhibition for dry weight of root, shoot, leaf and the whole seedling ranged from 7.77-37.85%, 7.01-39.41%, 3.24-52.14% and 9.90-34.70% over control, respectively. The two genotypes Samrat and K 851 with 7.77% and 10.91% reduction in dry weight of root over control, respectively, showed the least adverse effect of cadmium toxicity for this character. On the other hand, PDM 84-139 (36.47% decrease over control) and Pant Mung 5 (37.85% decrease over control) had the greatest inhibitory effect of cadmium for dry weight of root. Among all the genotypes, Samrat (7.01% decrease over control) and Pusa Baisakhi (10.04% decrease over control) revealed the lowest detrimental effect and IPM 03-01 (37.01% decrease over control) and PDM 84-139 (39.41% decrease over control) showed the greatest inhibitory effect of cadmium on dry weight of shoot. For dry weight of leaf, PDM 84-139 (3.24% decrease over control) and PDM 54 (7.38% decrease over control) registered the least adverse effect, while Meha (52.14% decrease over control) and IPM 03-01 (31.74% decrease over control) had the greatest adverse effect of cadmium treatment. In the present experiment, the two genotypes, Samrat and PDM 54 with 9.90% and 11.10% decrease, respectively, in dry weight of whole seedling under cadmium stress as compared to control, revealed the least detrimental effect of cadmium stress. On the contrary, cadmium treatment caused the greatest inhibition of dry weight of seedling in IPM 03-01 (34.70% decrease over control) and Meha (30.46% decrease over control).

Summarizing the data on growth parameters, it might be concluded that cadmium stress caused considerable reduction in length of root and shoot as well as biomass in the seedlings of mungbean genotypes in the present experiment. Negative effect of cadmium on root length, shoot length and seedling biomass was also reported earlier by Wang and Shen (2001) [33], Bora *et al.* (2003) [6], Kiran and Sahin (2006) [14], Wahid *et al.* (2007) [32], Sreedevi *et al.* (2008) [2], Liu *et al.* (2009) [15], Shaukat *et al.* (2010) [24], Muneer *et al.* (2011) [18], Siddhu and Khan (2012) [25] and Tao *et al.* (2015) [25]. The growth inhibition produced by cadmium stress could be mainly due to the effect of this heavy metal on photosynthetic rate (Sandalio *et al.,* 2001) [21]. This reduction could be in part due to decreases in chlorophyll content produced by cadmium treatment (Somashekaraiah *et al.,* 1992) [26].

On the basis of dry weight of whole seedling under cadmium stress and in unstressed control condition, the stress tolerance index (STI) was calculated separately for each genotype. The analysis of variance indicated highly significant differences among the genotypes for this character. The STI of fourteen genotypes ranged from 65.30% to 90.10% under 100 µM cadmium treatments in the present study (Table 5). The genotypes showing STI of 80% or above were generally considered to be tolerant in the present experiment. Among all the genotypes, the highest STI was registered by Samrat (90.10%). It was followed by PDM 54, Pusa Baisakhi, IPM 02-03, K 851 and PDM 11 with 88.90%, 85.98%, 85.49%, 82.87% and 81.73% STI, respectively. These genotypes were considered to be tolerant to cadmium stress. On the contrary, the genotypes IPM 03-01, PDM 84-139, Meha, B1 and Bireswar with 65.30%, 69.54%, 69.67% 70.81% and 71.24% STI, respectively, were found to have much lower STI and were considered to be susceptible to cadmium treatment in the present study (Table 6).

3.3 Clustering of genotypes

On the basis of stress response index (SRI) of root length, fresh weight and dry weight of root, fresh weight of whole seedling and STIs, the fourteen genotypes were grouped following Sequential Agglomerative Hierarical Nested (SAHN) clustering on the basis of Euclidean distance. The dendrogram showed that the 14 genotypes formed two big clusters A and B (Fig.1). The four susceptible genotypes IPM 03-01, Meha, PDM 84-139, B1 and Birswar belonged to cluster A forming different sub-clusters. On the contrary, cluster B was separated into two distinct sub-clusters B1 and B2. The B1 sub-cluster contained two tolerant genotypes IPM 02-03 and Samrat. The sub-cluster B2 could be further separated into two sub-clusters B2a and B2b. The B1a sub-cluster contained the tolerant genotype PDM 11, while the three tolerant genotypes K 851, PDM 54 and Pusa Baisakhi grouped themselves in sub-cluster B2b.

3.4 Cadmium accumulation in different plant parts

The accumulation of cadmium in root, shoot and leaf of four tolerant and four susceptible genotypes of mungbean was measured using an atomic absorption spectrophotometer. Cadmium was not detected in the plant samples collected from the seedlings grown under unstressed control. The data on cadmium content in different plant parts under cadmium stress revealed highly significant differences among the genotypes. In general, the root showed much higher accumulation of cadmium than shoot and leaf (Table 7). The finding corroborated well the early observations of Cataldo *et al.* (1983) [7] and Blum (1997) [5]. Cohen *et al.* (1998) [9] concluded that roots can accumulate and retain cadmium in the apoplast by ionic interactions with carboxyl and/or sulphydryl groups from components of cell wall and part of the metal can be complexed by phytochelatins and sequestered in the vacuole. In the present experiment, the genotypes showed considerable differences among them in respect of cadmium uptake in root. The four identified tolerant genotypes had a cadmium content in the root ranging from 20.700 to 25.240 µg g^{-1} dry weight, whereas, the four susceptible genotypes had a cadmium content ranging from 25.825 to 29.895 µg g^{-1} dry weight. Among all the genotypes, Bireswar showed the highest (29.895 µg g^{-1} dry weight) cadmium uptake in root and it was followed by Meha (29.561 µg g^{-1} dry weight). On the contrary, the lowest uptake was noted in PDM 54 (20.700 µg g^{-1} dry weight) and it was followed by K 851 (23.145 µg g^{-1} dry weight). The cadmium accumulation in the shoot ranged from 2.813 to 10.762 µg g^{-1} dry weight with the susceptible genotypes showing higher content of cadmium in their shoots than the tolerant ones. The highest accumulation of cadmium in shoot was noted in the susceptible genotype Bireswar (10.762 µg g^{-1} dry weight) and

it was closely followed by IPM 03-01 (9.279 µg g^{-1} dry weight). The tolerant genotypes PDM 54 and K 851 with 2.813 and 2.818 µg g^{-1} dry weight, respectively, were the lowest accumulator of cadmium in shoot. Like the root and shoot, the leaf cadmium content was also found to be lower in the tolerant genotypes than the susceptible ones. The lowest amount of cadmium in leaf was detected in two genotypes PDM 54 (1.391 µg g^{-1} dry weight) and K 851 (1.738 µg g^{-1} dry weight), while, the genotypes Bireswar and IPM 03-01 with 3.686 and 3.301 µg g^{-1} dry weight, respectively, had the highest accumulation of cadmium in leaf. Thus, the rate of uptake of cadmium in the root and its subsequent distribution to different plant parts were important determiners of genotypic susceptibility to cadmium toxicity in the present experiment. Akhtar and Macfie (2012) [1], Meng *et al.* (2012) [17] also concluded that the ability to check root uptake and aerial distribution of cadmium depends on its binding to extracellular matrix, root efflux, intracellular detoxification and its transport efficiency, and this ultimately determines the tolerance of genotypes to oxidative stress induced by cadmium.

3.5 Histochemical detection of cadmium

Cadmium was detected histochemically in the transverse sections of root using dithizone staining. The presence of cadmium in cells was detected as dark red to black complexes of cadmium with dithizone (Szmal and Lipiec, 1996 and Seregin and Ivanov, 1997) [29, 22]. Cadmium was detected in the epidermal layer, cortical cells as well as in vascular bundles of root and shoot. In the transverse sections (T.S.) of roots of two tolerant genotypes (PDM 54 and Samrat) the presence of cadmium could be detected as reddish brown complexes especially in the epidermis and vascular bundles. However, in the T.S. of roots of two susceptible genotypes (Meha and Bireswar), these complexes turned blackish especially in the vascular bundles. This indicated the quantitative difference between the tolerant and susceptible genotypes in respect of cadmium uptake and accumulation in root. Thus, the dithizone staining technique clearly revealed the quantitative differences between tolerant and susceptible genotypes of mungbean in respect of cadmium uptake in root and its translocation to shoot (Plate 1, 2).

4. Conclusion

On the basis of above finding it may be concluded that the characters like seedling length, dry weight was effectively affected by cadmium stress though tolerance to metal toxicity is mainly manifested by an interaction between genotype and its environment. Based on the histochemical study it was suggested that the tolerant genotypes identified in the present experiment, showed lesser accumulation of cadmium in than the susceptible genotypes. The present study might be a prerequisite for establishing a breeding programme for cadmium tolerance in mungbean.

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Table 1: Effect of 100 µM cadmium on seed germination in mungbean genotypes

Genotypes	Germination (%)		
	Control	Treatment	Mean
B 1	97.33 (81.36)	97.33(81.36)	97.33 (81.36)
Bireswar	98.67 (84.25)	98.67(84.25)	98.67(84.25)
Meha	100.00 (87.14)	100.00 (87.14)	100.00 (87.14)
IPM 02-03	100.00 (87.14)	98.67(84.25)	99.33 (85.70)
Pant Mung 5	96.00 (78.47)	96.00 (78.47)	96.00 (78.47)
IPM 03-01	98.67 (84.25)	98.67 (84.25)	98.67 (84.25)
Samrat	100.00 (87.14)	100.00 (87.14)	100.00 (87.14)
Pusa Baisakhi	98.67 (84.25)	96.00 (79.73)	97.33 (81.99)
Sunaina	97.33 (81.36)	94.67 (76.84)	96.00 (79.10)
PDM 84-139	98.67 (84.25)	97.33 (81.36)	98.00 (82.81)
PDM 54	97.33 (81.36)	96.00 (78.47)	96.67 (79.92)
K 851	94.67 (76.84)	93.33(75.20)	94.00 (76.02)
Pusa 105	98.67 (84.25)	97.33 (81.36)	98.00 (82.81)
PDM 11	98.67 (84.25)	98.67 (84.25)	98.67 (84.25)
Mean	98.19 (83.31)	97.33 (81.72)	
	S.E. m(±)	C.D. 5%	
Genotype(G)	2.371	4.749	
Treatment(T)	0.896	NS	
G×T	3.353	NS	

NS= Non- significant Data in parentheses indicate arcsine values

Table 2: Effect of 100 µM cadmium on length of 8 days old seedlings of 14 genotypes of mungbean

Genotype	Root length (cm)			Shoot length (cm)			Total length (cm)		
	Control	Treatment	Mean	Control	Treatment	Mean	Control	Treatment	Mean
B 1	11.167	7.933 (-28.96)	9.550	13.917	12.033 (-13.54)	12.975	25.084	19.966 (-20.40)	22.525
Bireswar	14.750	5.671 (-61.55)	10.211	14.900	12.686 (-14.86)	13.793	29.650	18.357 (-38.09)	24.004
Meha	9.257	5.838 (-36.93)	7.548	13.957	11.950 (-14.38)	12.954	23.214	17.788 (-23.37)	20.501
IPM 02-03	10.590	8.650 (-18.32)	9.620	21.650	21.340 (-1.43)	21.495	32.240	29.990 (-6.98)	31.115
Pant Mung 5	10.657	8.450 (-20.71)	9.554	13.143	12.300 (-6.41)	12.722	23.800	20.750 (-12.82)	22.275
IPM 03-01	6.940	4.143 (-40.30)	5.542	14.920	10.400 (-30.29)	12.660	21.860	14.543 (-33.47)	18.202
Samrat	9.513	8.000 (-15.90)	8.757	13.838	13.667 (-1.24)	13.753	23.351	21.667 (-7.21)	22.509
Pusa Baisakhi	11.967	8.189 (-31.57)	10.078	13.300	12.367 (-7.02)	12.834	25.267	20.556 (-18.64)	22.912
Sunaina	13.890	10.030 (-27.79)	11.960	14.856	13.890 (-6.50)	14.373	28.746	23.920 (-16.79)	26.333
PDM 84-139	8.800	6.940 (-21.14)	7.870	14.088	12.760 (-9.43)	13.424	22.888	19.700 (-13.93)	21.294
PDM 54	12.489	12.143 (-2.77)	12.316	14.370	14.056 (-2.19)	14.213	26.859	26.199 (-2.46)	26.529
K 851	10.860	9.730 (-10.41)	10.295	12.120	12.030 (-0.74)	12.075	22.980	21.760 (-5.31)	22.370
Pusa 105	14.588	11.611 (-20.41)	13.100	13.475	10.411 (-22.74)	11.943	28.063	22.022 (-21.53)	25.043
PDM 11	13.025	9.100 (-30.13)	11.063	18.488	17.050 (-7.78)	17.769	31.513	26.150 (-17.02)	28.832
Mean	11.321	8.316		14.787	13.353		26.108	21.669	
	S.E. m(±)	C.D. 5%		S.E. m(±)	C.D. 5%		S.E. m(±)	C.D. 5%	
Genotype(G)	0.041	0.116		0.041	0.116		0.041	0.116	
Treatment(T)	0.016	0.044		0.016	0.044		0.016	0.044	
G×T	0.058	0.165		0.058	0.165		0.058	0.165	

Data in parentheses indicate percentage increase (+) or decrease (-) over control

Table 3: Effect of 100 µM cadmium on root and shoot dry weight of 8 days old seedlings of 14 genotypes of mungbean

Genotype	Root dry weight (mg)			Shoot dry weight (mg)		
	Control	Treatment	Mean	Control	Treatment	Mean
B 1	1.750	1.411 (-19.37)	1.581	5.833	3.711 (-36.38)	4.772
Bireswar	2.986	1.967 (-34.13)	2.477	11.667	8.443 (-27.63)	10.055
Meha	2.013	1.600 (-20.52)	1.807	9.114	7.038 (-22.78)	8.076
IPM 02-03	2.330	2.060 (-11.59)	2.195	12.220	10.490 (-14.16)	11.355
Pant Mung 5	4.586	2.850 (-37.85)	3.718	25.457	21.725 (-14.66)	23.591
IPM 03-01	3.380	2.457 (-27.31)	2.919	14.371	9.040 (-37.10)	11.706
Samrat	2.033	1.875 (-7.77)	1.954	7.700	7.160 (-7.01)	7.430
Pusa Baisakhi	2.500	2.100 (-16.00)	2.300	10.178	9.156 (-10.04)	9.667
Sunaina	3.370	2.420 (-28.19)	2.895	12.680	10.160 (-19.87)	11.420
PDM 84-139	3.400	2.160 (-36.47)	2.780	11.950	7.240 (-39.41)	9.595
PDM 54	3.622	3.000 (-17.17)	3.311	11.000	9.800 (-10.91)	10.400
K 851	2.750	2.450 (-10.91)	2.600	18.180	14.810 (-18.54)	16.495
Pusa 105	3.113	2.467 (-20.75)	2.790	8.138	6.189 (-23.95)	7.164
PDM 11	2.800	2.000 (-28.57)	2.400	12.588	11.000 (-12.62)	11.794
Mean	2.902	2.201		12.220	9.712	
	S.E. m(±)	C.D. 5%		S.E. m(±)	C.D. 5%	
Genotype(G)	0.041	0.116		0.041	0.116	
Treatment(T)	0.016	0.044		0.016	0.044	
G×T	0.058	0.165		0.058	0.165	

Data in parentheses indicate percentage increase (+) or decrease (-) over control

Table 4: Effect of 100 µM cadmium on leaf and total dry weight of 8 days old seedlings of 14 genotypes of mungbean

Genotype	Leaf dry weight			Total dry weight		
	Control	Treatment	Mean	Control	Treatment	Mean
B 1	3.700	2.867 (-22.51)	3.284	11.283	7.989 (-29.19)	9.636
Bireswar	4.429	3.183 (-28.13)	3.806	19.081	13.593 (-28.76)	16.337
Meha	4.150	1.986 (-52.14)	3.068	15.277	10.623 (-30.46)	12.950
IPM 02-03	5.500	4.590 (-16.55)	5.045	20.050	17.140 (-14.51)	18.595
Pant Mung 5	5.771	4.050 (-29.82)	4.911	35.814	28.625 (-20.07)	32.220
IPM 03-01	3.160	2.157 (-31.74)	2.659	20.911	13.65 (-34.70)	17.283
Samrat	3.167	2.588 (-18.28)	2.878	12.900	11.623 (-9.90)	12.262
Pusa Baisakhi	4.444	3.467 (-21.98)	3.956	17.122	14.722 (-14.02)	15.922
Sunaina	5.000	3.670 (-26.60)	4.335	21.050	16.250 (-22.80)	18.650
PDM 84-139	4.780	4.625 (-3.24)	4.703	20.130	14.025 (-30.33)	17.078
PDM 54	5.367	4.971 (-7.38)	5.169	19.989	17.771 (-11.10)	18.880
K 851	6.390	5.380 (-15.81)	5.885	27.320	22.640 (-17.13)	24.980
Pusa 105	4.644	3.325 (-28.40)	3.985	15.894	11.980 (-24.63)	13.937
PDM 11	5.000	3.663 (-26.74)	4.332	20.388	16.660 (-18.28)	18.526
Mean	4.679	3.609		19.801	15.521	
	S.E. m(±)	C.D. 5%		S.E. m(±)	C.D. 5%	
Genotype(G)	0.041	0.116		0.041	0.116	
Treatment(T)	0.016	0.044		0.016	0.044	
G×T	0.058	0.165		0.058	0.165	

Data in parentheses indicate percentage increase (+) or decrease (-) over control

Table 5: Stress tolerance index (STI) of 14 mungbean genotypes

Genotypes	STI (%)	Genotypes	STI (%)
B 1	70.81	Pusa Baisakhi	85.98
Bireswar	71.24	Sunaina	77.20
Meha	69.54	PDM 84-139	69.67
IPM 02-03	85.49	PDM 54	88.90
Pant Mung 5	79.93	K 851	82.87
IPM 03-01	65.30	Pusa 105	75.37
Samrat	90.10	PDM 11	81.73

Table 6: List of most tolerant and susceptible genotypes under cadmium stress

Tolerant group		Susceptible group	
Genotypes	STI (%)	Genotypes	STI (%)
Samrat	90.10	IPM 03-01	65.30
PDM 54	88.90	Meha	69.54
Pusa Baisakhi	85.98	PDM84-139	69.67
IPM 02-03	85.49	B1	70.81
K 851	82.87	Bireswar	71.24

Table 7: Cadmium content in different plant parts of mungbean genotypes grown in 100 µM cadmium (Data expressed as µg g^{-1} dry weight)

Genotypes	Root	Shoot	Leaf
PDM 54	20.700	2.813	1.391
K 851	23.145	2.818	1.738
Samrat	24.668	3.262	1.854
IPM 02-03	25.240	3.584	2.143
B1	25.825	4.284	2.683
Meha	29.561	7.968	3.146
IPM 03-01	27.118	9.279	3.301
Bireswar	29.895	10.762	3.686
Mean	25.769	5.596	2.493
S.E. m(±)	0.481	0.051	0.119
C.D. 5%	1.020	0.108	0.252

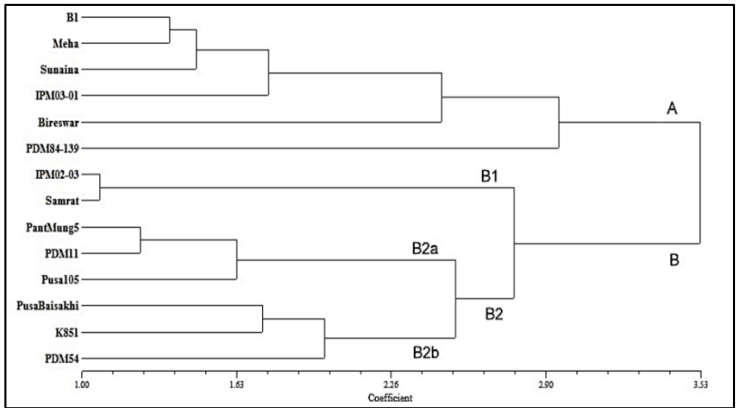

Fig 1: Dendogram showing the clustering of 14 mungbean genotypes on the basis of cadmium tolerance

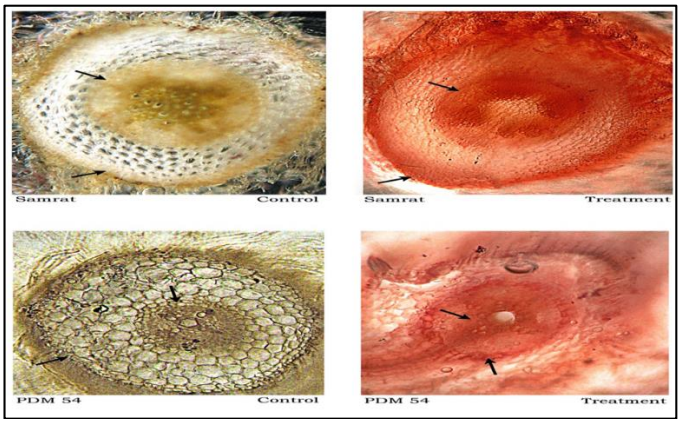

Plate 1: Localization of cadmium by dithizone staining in transverse section of root of two tolerant genotypes (Samrat and PDM-54) grown at 100 µmol Cd

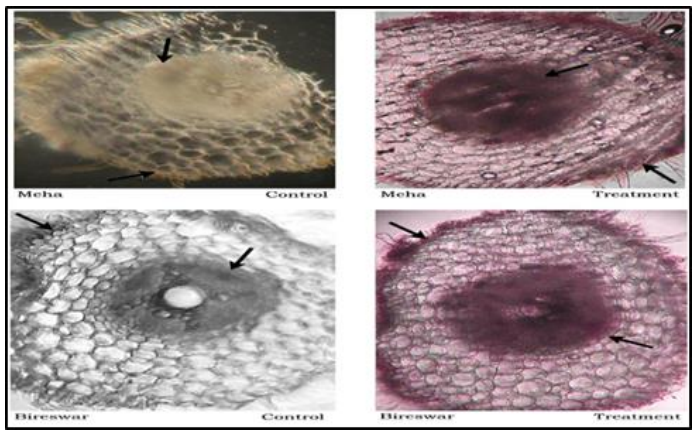

Plate 2: Localization of cadmium by dithizone staining in transverse section of root of two susceptible genotypes (Meha and bireswar) grown at 100 µmol Cd.

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