Effect of Heavy Metal Cadmium on Growth and Yield of Pigeonpea

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Abstract--- This study deals about the effect of heavy metal cadmium on growth and yield of Pigeonpea (Cajanus cajan L.). Cadmium is often readily taken up and accumulated by plants. The uptake of cadmium is affected by numerous plant and soil factors like cadmium concentration in the rooting medium, cadmium availability, plant species and plant age..Cadmium accumulated in plants causes different morphological changes like yellowing of leaves and their subsequent abscission, browning and bending of stem, swelling at the base of stem, increase in the secondary branches, early flowering, more and smaller leaves per plant, fewer pods, fewer seeds per pod and smaller seeds. Cadmium (3mM and 6mM) reduced leaf area, dry weight, fresh weight and growth and yield at all growth stages. Cadmium treated plants after showing a slow rate of dry matter accumulation during 'vegetative stage', picked up in the rate of deposition at the later stages. Dry matter harvest index was reduced at higher cadmium concentration (6mM Cd+2), however plants treated with 3mM Cd+2 exhibited a higher HI than the control.

Keywords: Cajanus cajan L., Plant height, Leaf area, Dry weight, Fresh weight, Growth, Yield, Harvest index (HI), Cadmium, 3mM Cd+2, 6mM Cd+2, Day after sowing (DAS).

I. INTRODUCTION

Pigeonpea (Cajanus cajan L.) is an important legume crop (Family-Fabaceae) of rainfed agriculture in the semiarid tropics. The Indian subcontinent, eastern Africa and Central America are the world's three main pigeonpea producing regions. Pigeonpea is cultivated in more than 25 tropical and subtropical countries. It originated in India and spread to Southeast Asia in the early centuries. It can grow in a wide range of soils with varying physical and chemical characteristics. Pigeonpea is a short-lived perennial shrub, usually grown as an annual, 0.5-4 m high, with thin roots up to 2 m deep, stems up to 15 cm in diameter, many slender branches, 1-2 cm long leaf rachis, half as long or less petiole, reticulate venation. Inflorescence is axillary arising from a single peduncle, usually slightly shorter than the leaves, mostly with 2-6 flowers. The flowers are cleistogamous, a condition favoring self-pollination, but bees visit the flowers to cause cross-pollination. Fruit is a pod, linear-oblong, apex obtuse or acute.

For the last few decades, there has been an increasing concern over the unabated and rapid pollution of the environment, largely owing to the relentless exploitation of the surroundings by mankind. In the process of pollution, enormous quantities of the potentially hazardous chemicals which cause diseases or abnormal conditions in humans, animals and vegetation's, are being discharged in the biosphere. The uncontrolled disposal of the industrial effluents and the solid wastes has become a matter of great concern as there are known to contain heavy metals such as Cd2+, Pb2+, Ni2+ etc. The problem of environment pollution with injurious gases and heavy metals is likely to be further accentuated by the anticipated proliferation of the industrial activities in the country.

Amongst the heavy metals, cadmium is a major pollutant. It enters the soil by various means such as vehicular exhaust, mining and smelting operations, coal and oil fired power units and paint industry. It has been reported that Cd is phytotoxic (Page et al., 1981) and when taken up in excess by animals and human beings, it causes toxicity in them. It also causes erythrocyte destruction, renal degradation, hypertension, various heart diseases, bronchitis and the well-known itai-itai disease (Nath, 1986).

Although cadmium is not essential for plant growth, it is readily taken up by many plant species and gets accumulated in different plant parts. This eventually causes a reduced seed germination, plant growth, and impaired and poor dry matter production. In higher plants, cadmium inhibits nitrogen metabolism, photosynthesis with functioning of PS II, photophosphorylation, chlorophyll synthesis and stomatal conductance. It also cause disorganization of the chloroplast structure, affects various enzymes of the carbon reduction cycle and interferes with respiration. It is also known that the various microorganisms and higher plants produce a specific type of protein known as phytochelatin which acts as a detoxification system to cope with poisonous effects of cadmium. As the heavy metals are readily taken up by plants and get accumulated in the various plant parts, they enter the food chain. The foods contaminated with heavy metals cause various diseases in human beings and animals. Besides endangering the human health, the heavy metals are also likely to further jeopardize the welfare of mankind by their impact on crop productivity. The problem is becoming more vicious around the industrial towns of India, where vegetables and other crops are grown using municipal wastes in various forms.

A. Cadmium uptake by plants

Although cadmium is not essential for plant growth, it is often readily taken up and accumulated by plants. Cadmium reaches plants or the soil they grow by a variety of means via water, air, pesticides, fertilizers and solid wastes. A few studies have shown that some cadmium may be taken up through plant leaves. However, the predominant mode of cadmium uptake is through plant roots. The uptake of cadmium is affected by numerous plant and soil factors like cadmium concentration in the rooting medium, cadmium availability, plant species and plant age.

B. *Distribution of cadmium in plants*

Cadmium uptake by plants is distributed among various plant organs and sub-cellular structures. Cadmium generally accumulates in roots and restricted from being translocated to the shoots. This may suggest that the root is more tolerant plant part. Based on the study of Ernst (1972) on Tilia platyphyllous and Aesculus hippocastanum trees, it was found that more than 70% of the total Cadmium was associated with cell wall and remaining was distributed in the cytosol, the vacuole sap and the cell organelles. Wagner (1979) found that cytosol of leaf protoplasts contained cadmium but none was found in the chloroplast or vacuole. Khan et al. detected cadmium only in the walls of sieve elements and middle lamella separating the endodermis from the pericycle. No cadmium was detected in any other cells within the mature root tissue. Plants are able to live and grow on soils with varying heavy metal contents, indicating that plants have the capacity to develop a specific detoxification system to cope with poisonous heavy metals. It has been shown recently that the most abundant heavy metal binding complexes in a number of higher plants comprises a family of sulphur rich peptides called phytochelatin that are structurally related to glutathione (Steffens et al., 1986). The structural similarity between phytochelatin and glutathione suggest that glutathione is involved in the synthesis of these heavy metal binding peptides (Scheller et al., 1997).

C. *Effect of cadmium on plants*

Virtually all studies where cadmium was applied have shown that this element cause a reduction in growth. However, at relatively low concentration, cadmium had a stimulatory effect on radish (John, 1972), lettuce (Turner, 1973), carrot (Wichmann et al., 1983) and pea (Wong et al., 1988). In many plants, the symptoms induced by cadmium are the chlorosis of leaves, resembling iron deficiency and their subsequent abscission (Koshino, 1972; Haghiri, 1973; Root et al., 1975; Lee et al., 1976). Boggess et al., (1978) observed that cadmium toxicity symptoms increased with the increasing cadmium rates. The symptoms include red coloration at the leaflet base or bases which spread along the veins, chlorosis and severe downward curvature, distortion and embrittlement of leaflets of soybeans.

1) Cadmium inhibits seed germination and the degree of inhibition normally increases with an increase in the cadmium concentration in the culture medium (Wong et al., 1988).
2) The growth of the embryo axis is reduced by cadmium (Imai and Siegel, 1973).
3) Cadmium inhibits growth of different organs (plumule/coleoptile, radicle). The reduction in growth is more pronounced in radicle than in plumule/coleoptile (Aggarwal et al., 1990).
4) The grain/seed yield is reduced by cadmium (Bingham et al., 1976).
5) The dry matter accumulation is drastically reduced by cadmium (Haghiri, 1973; Smith et al., 1985).
6) Leaf area of the plants grown in cadmium containing medium is reduced (Aggarwal et al., 1990).
7) Plant height is also adversely affected by cadmium (Chaney et al., 1977).
8) In view of above introduction, the present work is undertaken to see the effect of cadmium on the growth and yield of pigeonpea.

II. MATERIALS AND METHODS

A. *Selection of the variety and growing of the Crop:*

The seeds of UPAS-120 variety of pigeonpea were raised in earthen pots in a naturally lit net house. The pots were lined with polyethylene bags and filled each with washed river sand. Four seeds of Pigeonpea were sown per pot at a uniform depth and distance approximately. Before sowing, the seeds were surface sterilized and inoculated with suitable rhizobium culture. Thirty days after sowing (DAS), the plants were thinned to two per pot. The pots were supplied with tap water as and when required. The nitrogen free solution was supplied to each pot at weekly intervals.

B. *Sampling:*

Sampling was done at 7-8 days intervals starting from 30 days after sowing (DAS) of the crop till its maturity. Eight plants from each treatment were used at each sampling. Two plants constituted one replicate.

C. *Growth observations:*

The plants were uprooted and separated into different parts, i.e. stem, leaves, roots, nodules, flowers, buds, pod walls and seeds. Following growth parameters were recorded -

1) The fresh and dry weight.
2) The dry weight of abscised leaves.
3) Plant height.
4) Leaf area.

III. RESULTS AND DISCUSSION

In comparison with control treatment, the major morphological changes that occurred in cadmium treatment plants were:

1) Yellowing of leaves and their subsequent abscission.
2) Browning and bending of stem.
3) Swelling at the base of stem.
4) Increase in the secondary branches.
5) Early flowering.
6) More and smaller leaves per plant.
7) Fewer pods, fewer seeds per pod and smaller seeds.

A. *Plant Height*

The plant height was reduced with both the cadmium levels i.e. 3mM and 6mM (Table 1), but the reduction was significant only with 6mM Cd^{2+}. With 3mM Cd^{2+}, there was no significant reduction up to 53 days after sowing (DAS). In control and 6mM Cd^{2+} treatments, the maximum height was attained at 97 DAS. Thereafter, there was no significant change. With 3mM Cd^{2+}, the increase in height continued even up to 120 DAS. The differences in plant height were clearly visible at flowering stage.

B. *Leaf Area*

With cadmium, the total leaf area was reduced at all the stages of plant growth (Table 2). There was maximum reduction with 6mM Cd^{2+}. In control, there was maximum leaf area at 97 DAS, whereas in Cd^{2+} treated plants it was maximum at 111 DAS. Thereafter, there was a drastic reduction in leaf area due to leaf senescence and abscission.

C. Fresh Weight

Cadmium drastically reduced the fresh weight of all plant organs at all the stages of plant growth (Table 3). The fresh weight of leaves and stem increased up to 97 DAS in control and decreased thereafter. However the peak was reached at 111 DAS in plants treated with both the levels of cadmium. The nodule fresh weight of the control and 3mM cadmium treated plants increased to a maximum at 120 DAS and decreased thereafter. But nodules of plants treated with 6mM Cd2+ showed an increase in fresh weight even up to the harvest i.e. 129 DAS. The fresh weight of roots increased to reach a maximum at 111 DAS at both the cadmium levels, whereas the fresh weight of roots in control plants showed an increase up to maturity. The fresh weight of flowers, pod walls and seeds was also reduced by both the levels of cadmium, reduction being more at the higher concentration. The flowering in cadmium treated plants was observed at 75 DAS whereas in control, at four days later i.e. at 79 DAS. In control as well as in cadmium treated plants, the pod formation occurred at 90 DAS. The grain filling occurred at 97 DAS in control and with 3mM Cd2+ and at 111 DAS with 6mM Cd2+. The fresh weight of flowers in cadmium treated plants increased up to 97 DAS and it declined thereafter. In control also, the maximum fresh weight was observed at 111 DAS followed by a decrease. The fresh weight of pod wall and seeds showed a continuous increase up to maturity in both the control and the cadmium treated plants. Though there was an increase in the number of secondary branches under cadmium treatment, it was not accompanied by an increase in grain yield.

Treatment	Days After Sowing (DAS)											
	33	39	46	53	60	68	75	90	97	111	120	129
Control	34.1±3.8	42.1±6.2	51.9±6.2	56.8±4.2	62.3±6.9	79.3±6.1	112.5±9.8	129.6±10.2	136.2±11.6	136.8±11.1	136.7±10.6	135.9±11.3
3 mM Cd2+		38.7±3.8	48.7±4.1	50.2±4.9	52.6±5.5	56.1±5.3	62.3±5.8	73.6±6.2	83.2±6.9	89.9±7.1	95.8±7.8	95.6±7.6
6 mM Cd2+		36.8±3.9	38.5±3.8	41.9±4.2	46.3±4.9	50.8±4.8	58.9±5.2	68.2±5.8	73.6±6.1	73.8±6.8	74.6±7.0	74.5±7.1

Table 1: Effect of cadmium application on plant height (cm) at different stages of growth in Pigeonpea

Treatment	Days After Sowing (DAS)											
	33	39	46	53	60	68	75	90	97	111	120	129
Control	135±26	303±60	554±91	705±75	927±102	1175±171	1361±107	1584±123	1826±232	1089±218	1071±152	715±108
3 mM Cd^{2+}	135±26	196±18	447±85	451±90	458±96	482±98	508±96	710±97	717±103	798±101	715±161	527±105
6 mM Cd^{2+}	135±26	154±25	271±54	304±62	298±68	339±88	446±92	559±90	563±96	747±107	537±107	492±98

Table 2: Leaf area at different stages of growth in control and cadmium treated Pigeonpea plants

DAS	Plant organ											
	Leaves			Stem			Roots			Nodules		
	Control	3 mM Cd2+	6 mM Cd2+	Control	3 mM Cd2+	6 mM Cd2+	Control	3 mM Cd2+	6 mM Cd2+	Control	3 mM Cd2+	6 mM Cd2+
33	0.867±0.088			0.731±0.091			0.608±0.023			0.115±0.050		
39	1.159±0.242	1.208±0.211	0.991±0.162	1.161±0.153	0.931±0.142	0.740±0.104	0.795±0.080	0.826±0.134	0.808±0.106	0.266±0.057	0.236±0.071	0.198±0.055
46	3.1	2.2	1.0	2.0	1.0	1.3	2.0	1.7	1.0	0.6	0.4	0.3

	69±0.730	21±0.559	86±0.487	79±0.510	82±0.428	21±0.333	55±0.229	21±0.133	74±0.098	93±0.092	11±0.097	00±0.080
53	4.031±0.600	2.286±0.453	1.098±0.399	2.789±0.517	2.214±0.422	1.521±0.420	2.700±0.461	1.774±0.262	1.191±0.229	0.762±0.126	0.420±0.088	0.315±0.072
60	5.875±0.924	2.556±0.584	1.354±0.404	4.394±0.783	2.998±0.519	1.693±0.406	6.405±1.058	1.911±0.294	1.305±0.520	0.959±0.205	0.432±0.096	0.339±0.093
68	7.391±1.049	3.084±0.763	2.031±0.501	5.933±1.039	3.921±0.955	3.135±0.612	7.900±1.171	2.800±0.678	2.513±0.612	1.250±0.301	0.595±0.102	0.449±0.098
75	11.186±1.133	3.514±0.623	2.556±0.635	10.857±1.421	5.050±0.904	4.536±0.955	8.000±1.212	3.693±0.946	2.593±0.634	1.446±0.300	0.769±0.126	0.642±0.101
90	11.268±1.198	4.708±0.989	3.787±0.718	13.442±1.964	8.800±1.090	6.367±0.996	8.283±1.414	4.580±1.102	3.050±0.368	1.719±0.401	0.983±0.163	0.727±0.110
97	15.330±1.658	5.017±0.904	4.560±0.967	17.546±2.016	10.560±1.170	10.408±1.159	8.925±1.068	6.535±1.212	6.433±1.108	1.883±0.380	1.029±0.202	0.767±0.146
111	7.024±1.222	6.090±1.007	5.625±0.953	17.330±2.102	14.725±1.200	13.200±2.061	9.220±1.662	9.150±1.963	8.112±0.806	1.918±0.384	1.412±0.346	1.060±0.198
120	6.833±0.986	4.238±0.708	3.762±0.792	15.050±1.083	11.800±1.217	11.525±1.906	11.682±1.785	9.013±1.998	7.750±1.090	2.277±0.522	1.772±0.358	1.314±0.306
129	5.408±0.781	3.889±0.663	3.566±0.676	13.565±1.100	10.510±1.142	8.874±1.192	11.887±1.062	8.450±1.008	6.900±1.012	1.850±0.469	1.703±0.350	1.658±0.318

DAS	Plant organ								
	Flowers			Pod wall			Seeds		
	Control	3mM Cd^{2+}	6mM Cd^{2+}	Control	3mM Cd^{2+}	6mM Cd^{2+}	Control	3mM Cd^{2+}	6mM Cd^{2+}
75		0.109±0.012	0.086±0.008						
90	0.306±0.041	0.384±0.052	0.272±0.048	0.953±0.361	1.286±0.850	0.689±0.309			
97	0.335±0.052	0.605±0.078	0.521±0.070	1.862±0.984	2.703±0.990	0.886±0.165	0.255±0.076	0.416±0.099	

111	0.663 ±0.060	0.365 ±0.049	0.422 ±0.055	2.909 ±1.012	2.955 ±1.001	0.896 ±0.198	0.760 ±0.126	0.719 ±0.110	0.998±0.121
120	0.632 ±0.075	0.356 ±0.058	0.432 ±0.061	3.832 ±1.092	4.066 ±1.020	2.846 ±0.785	2.219 ±0.986	2.508 ±0.990	2.033±0.865
129	0.484 ±0.061	0.362 ±0.058	0.320 ±0.048	4.102 ±1.202	3.574 ±1.130	3.120 ±0.986	7.268 ±2.106	5.093 ±1.198	3.129±1.065

Table 3: Fresh weight (g plant-1) at different stages of growth in control and cadmium treated pigeonpea plant organs

D. *Dry Weight*

The dry weight of all plant parts was reduced by both the levels of cadmium (Table 4). In control as well as in cadmium treated plants, the dry weight of stem reached its maximum at 111 DAS; thereafter there was a slight reduction in the dry weight. The dry weight of leaves reached its maximum at 97 DAS in control as well as in cadmium treated plants followed by a decrease which was mainly due to a heavy leaf fall. The dry weight of abscised leaves in cadmium treated plants was greater at the initial growth stages, but during the later stages, it was less than or equal to that of control plants.

The root dry weight in control reached its maximum at 111 DAS, whereas in cadmium treated plants, it was at 120 DAS, thereafter there was reduction in dry weight in both control and cadmium treated plants. Nodule dry weight increased up to 111 DAS in both the control and the cadmium treated plants, thereafter there was reduction in the control plants but a slight increase up to 129 DAS in the cadmium treated plants.

The dry weight of flowers, pod walls and seeds were also reduced in cadmium treated plants. The maximum dry weight of flowers in control was observed at 111 DAS; thereafter there was a slow decrease. In cadmium treated plants, the maximum dry weight of flowers was attained a little earlier, i.e. at 97 DAS; thereafter there was a decrease in the dry weight. The dry weight of seeds and pod walls increased in both the control and the cadmium treated plants, but at every stage, the dry weight of seeds of the cadmium treated plants was less than that of the control.

DAS	Plant organ											
	Leaves			Stem			Roots			Nodules		
	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}
33	0.260±0.045	0.260±0.045	0.260±0.045	0.220±0.040	0.220±0.040	0.220±0.040	0.143±0.021	0.143±0.021	0.143±0.021	0.030±0.009	0.030±0.009	0.030±0.009
39	0.500±0.080	0.400±0.068	0.357±0.062	0.335±0.057	0.305±0.084	0.265±0.061	0.160±0.048	0.155±0.039	0.145±0.032	0.045±0.011	0.042±0.010	0.034±0.008
46	0.880±0.105	0.170±0.096	0.395±0.066	0.590±0.095	0.565±0.089	0.450±0.050	0.300±0.092	0.240±0.062	0.175±0.038	0.070±0.020	0.079±0.020	0.050±0.012
53	1.235±0.135	0.775±0.099	0.421±0.071	0.875±0.105	0.745±0.092	0.490±0.076	0.470±0.163	0.333±0.073	0.230±0.059	0.131±0.032	0.101±0.028	0.062±0.016
60	1.700±0.240	0.820±0.102	0.535±0.079	1.565±0.260	0.945±0.168	0.504±0.082	1.010±0.234	0.365±0.098	0.245±0.068	0.210±0.046	0.112±0.032	0.069±0.018
6	2.	1.	0.	2.	1.	0.	1.	0.	0.	0.	0.	0.

8	185±0.306	105±0.156	655±0.110	450±0.420	320±0.361	945±0.149	575±0.380	700±0.231	355±0.082	298±0.058	141±0.039	086±0.021
75	3.765±0.315	1.435±0.268	0.980±0.221	3.825±0.425	2.000±0.405	1.130±0.352	2.050±0.405	0.856±0.312	0.460±0.131	0.388±0.079	0.158±0.042	0.138±0.031
90	4.485±0.417	1.845±0.281	1.390±0.232	5.625±0.638	3.070±0.460	2.380±0.410	2.575±0.515	1.195±0.386	0.600±0.213	0.479±0.097	0.226±0.049	0.154±0.043
97	4.915±0.439	2.125±0.292	1.820±0.316	7.295±0.790	4.940±0.592	3.420±0.431	2.660±0.490	1.745±0.452	1.115±0.298	0.557±0.116	0.253±0.050	0.172±0.052
111	4.520±0.408	2.255±0.312	1.830±0.320	7.420±0.805	5.550±0.608	4.660±0.439	2.715±0.468	2.215±0.469	1.320±0.316	0.588±0.127	0.360±0.082	0.262±0.056
120	3.850±0.381	1.900±0.376	1.395±0.238	7.500±0.815	5.525±0.686	4.145±0.403	2.690±0.441	2.325±0.498	1.525±0.376	0.572±0.106	0.400±0.087	0.277±0.063
129	3.405±0.32	1.460±0.27	1.250±0.16	7.200±0.78	5.250±0.67	3.995±0.38	2.145±0.40	2.115±0.46	1.490±0.32	0.540±0.10	0.395±0.08	0.302±0.06

	3	2	9	9	2	6	8	2	6	1	4	2

DAS	Plant organ											
	Abscised Leaves			Flowers			Pod wall			Seeds		
	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}	Control	3 mM Cd^{2+}	6 mM Cd^{2+}
46		0.068±0.017	0.089±0.018									
53	0.063±0.016	0.079±0.018	0.090±0.019									
60	0.089±0.018	0.099±0.020	0.124±0.022									
68	0.095±0.034	0.135±0.045	0.145±0.052									
75	0.180±0.052	0.334±0.056	0.345±0.076									
90	0.280±	0.618±	0.534±	0.065±	0.150±	0.140±	0.100±	0.160±	0.090±			

	0.085	0.098	0.092	0.025	0.065	0.060	0.030	0.050	0.032			
97	0.420 ± 0.099	0.847 ± 0.106	0.815 ± 0.112	0.085 ± 0.036	0.210 ± 0.085	0.170 ± 0.052	0.410 ± 0.075	0.605 ± 0.092	0.150 ± 0.042	0.600 ± 0.020	0.100 ± 0.036	
111	0.985 ± 0.195	0.919 ± 0.162	0.840 ± 0.129	0.180 ± 0.064	0.075 ± 0.016	0.080 ± 0.031	0.900 ± 0.110	1.070 ± 0.125	0.226 ± 0.095	0.280 ± 0.055	0.435 ± 0.068	0.220 ± 0.050
120	1.301 ± 0.210	1.273 ± 0.215	0.999 ± 0.156	0.170 ± 0.060	0.055 ± 0.014	0.060 ± 0.024	0.965 ± 0.254	1.165 ± 0.032	0.810 ± 0.210	0.995 ± 0.190	0.841 ± 0.295	0.815 ± 0.186
129	1.489 ± 0.315	1.501 ± 0.369	1.290 ± 0.222	0.110 ± 0.051	0.054 ± 0.021	0.050 ± 0.011	1.186 ± 0.195	1.052 ± 0.270	1.050 ± 0.265	2.650 ± 0.465	2.105 ± 0.405	1.040 ± 0.320

Table 4: Dry weight (g plant-1) at different stages of growth in control and cadmium treated pigeonpea plant organs

E. Growth and Yield

Application of Cd2+ caused drastic reduction in seed yield. Deleterious effect of this heavy metal on seed or grain yield has also been reported in dwarf bean, pea and in wheat.. In the present investigation, the various parameters responsible for diminished seed yield in Cd2+ treated plants are decreased number of pods per plant, lesser number of seeds per pod, higher proportion of empty pods and reduced seed weight (Table 5). The reduction in plant growth as observed in the present study could be due to the adverse effect of the heavy metal cadmium on the various physiological and metabolic processes such as photosynthesis, nitrogen fixation and partitioning of carbon and nitrogen.

Item	Control	3mM Cd^{2+}	6mM Cd^{2+}
Seed weight $plant^{-1}$	2.98 ± 0.51	1.88 ± 0.53	0.98 ± 0.22
Seed weight (100)	5.25 ± 0.64	4.76 ± 0.32	3.93 ± 0.46
Number of seed pod^{-1}	3.13	2.95	2.43
Number of pod $plant^{-1}$	22.06	15.16	10.72

Table 5: Yield characteristics of pigeonpea as influenced by cadmium

F. Dry Matter Accumulation

Dry matter accumulation was severely affected by cadmium. In this study, dry matter accumulation was severely affected by Cd^{2+}. Control plants accumulated 19.1 gm dry matter through its life span, whereas 3mM and 6mM Cd^{2+} treated plants accumulated only 13.8 gm and 10.4 gm dry matter, respectively (Table 6). The percent accumulation (%age of total dry matter accumulated throughout life span) of dry matter at different stages of growth differed between the control and cadmium treated plants. Control plants accumulated dry matter at much faster rate. Control plants during 'vegetative phage' accumulated 53.2%. The corresponding values for cadmium treatments were much less, i.e. 34.6% and 29.5% for 3mM Cd^{2+} and 6mM Cd^{2+} respectively. But this trend was reversed during 'flowering and pod setting' and 'seed filling' stages.

The data clearly indicates that cadmium treatment enhanced the leaf abscission. Thus Cadmium affected both the rate of dry matter accumulation and dry matter loss from the plant.

Stage	Dry Matter increment at different stages of growth		
	Control	3mM Cd^{2+}	6mM Cd^{2+}
	19.13 (100)	13.84 (100)	10.40 (100)
Vegetative (0-75 DAS)	10.20 (53.2)	4.80 (34.6)	3.10 (29.5)
Flowering and pod setting (75-97 DAS)	6.20 (32.4)	6.03 (43.6)	4.61 (44.3)
Seed filling (97-129 DAS)	2.73 (14.3)	3.11 (22.5)	2.81 (27.0)

*Value in parenthesis denotes percentage

Table 6: Proportion of dry matter increment at different stages of growth

G. Harvest Index for Dry Matter

Harvest indices for dry matter have been calculated with and without considering the below ground mass and abscised leaves. Dry matter Harvest Index (HI) were reduced at higher cadmium concentration (6mM Cd2+), however plants treated with 3mM Cd2+ exhibited a higher HI than the control (Table 7). Higher HI under 3mM Cd2+ was mainly due to greater decrease in biological yield compared to grain yield as the treatment was given at vegetative stage.

Values of HI obtained were higher than those obtained by

Rao et al., (1984) for the same crop. During 'seed filling' phage, unlike other legumes, the shoot did not exhibit any appreciable decrease in either dry weight, the underground parts showed an even lesser decrease in dry weight. The cadmium treated plants showed a higher mobilization of carbon from the stem than the control plants.

Criteria for calculation	Dry Matter		
	Control	3mM Cd^{2+}	6mM Cd^{2+}
1. Proportion of aerial phytomass			
a) Excluding abscised leaves	25	31	20
b) Including abscised leaves	22	26	16
2. Proportion of total phytomass			
a) Excluding abscised leaves	19	23	15
b) Including abscised leaves	17	20	13

Table 7: Dry matter harvest indices of pigeonpea under control and cadmium treatment

The major morphological changes that occurred in cadmium treated plants were the yellowing of leaves and their subsequent abscission, browning and bending of stem, swelling at the base of stem, increase in the secondary branches, early flowering, more leaves per plant, smaller leaves, fewer pods, fewer seeds per pod and smaller seeds. The height was reduced with both the cadmium levels but the reduction was significant only with 6mM Cd2+. With cadmium, the total leaf area was reduced at all the stages of the plant growth however the reduction was maximum with 6mM Cd2+.Cadmium drastically reduced the fresh weight of all plant organs at all stages of plant growth. Similarly the dry weight of all plant parts was reduced by both levels of cadmium. Application of cadmium caused drastic reduction in seed yield. In the present investigation, the various parameters responsible for diminished seed yield in cadmium-treated plants included decreased number of pods per plant, lesser number of seeds per pod, higher proportion of empty pods and reduced seed weight. Dry matter HI were reduced at higher cadmium concentration (6mM Cd+2), however plants treated with 3mM Cd+2 exhibited a higher HI than the control. Higher HI under 3mM Cd+2 was mainly due to greater decrease in biological yield compared to grain yield as the treatment was given at vegetative stage.

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