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Phytotoxic Effect of Cadmium Induced Stress on LAI, CGR and Yield of Rice Plant (*Oryza sativa* L.)

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ABSTRACT

Background: Cadmium is a noxious heavy metal that is commonly found in the soil while its concentration is increasing in soil because of industrialization at the global level. It does not only reduce the yield of crops but also adulterates food and underground drinkable water. The availability of Cd beyond the threshold level may cause many problems in human beings. Exposure to Cd for a short period causes inhalation, muscle pain and lung damage while for a longer time, it may cause bone and kidney-related issues. The present study aimed to study the phytotoxic effect of Cadmium-induced stress on morphological changes and their impact on the yield of rice plants.

Methods: Present piece of research work was carried out on the Research Farm of Lovely Professional University, Department of Agronomy, School of Agriculture, in 2019-20. A range of five different concentrations of $CdCl_2$ was comprised with statistical design CRD. The range of 100 to 300 ppm $CdCl_2$ was considered to induce Cd-based stress. The standard procedures were followed to measure the growth parameters at regular intervals while the SPSS software was used to analyze the significance of the data.

Result: Cadmium-induced stress was created artificially in an experiment to analyze the detrimental effect on the growth and yield of rice plants. As the externally imposed cadmium stress increased from the control set (T_0), all the growth parameters along with grain yield, Biological yield hill^{-1} (g) and harvest index (%) started to decline till the maximum concentrations of $CdCl_2$, *i.e.* 300 ppm. As per the DAT is concerned, % reduction of each parameter was also calculated to the known intensity of toxicity where the maximum % reduction was recorded at 50 DAT in the leaf area and LAI (38.47% and 38.38%) while the maximum % reduction of CGR was recorded at 50-75 DAT (35%). However, the % reduction in grain yield, biological yield hill^{-1} (g) and harvest index % were recorded at the highest concentration of $CdCl_2$ (31.87, 28.70 g and 11.1%).

Key words: $CdCl_2$, CGR, Harvest index, Heavy metal, LAI.

INTRODUCTION

Cadmium is a heavy metal that occurs naturally in the soil as well as in the atmosphere in the least concentrations. As per the degree of toxicity is concerned, it ranks 7th most toxic HMs in the universe (Jaishanker *et al.* 2014). It is assumed that the artificial source of cadmium accumulation in the soil and water is fertilizers and agrochemicals which are consistently used on the crop to boost the harvest. Due to the increase in industrialization and urbanization, the deposition of cadmium (Cd) along with other harmful salts increases in soils while its translocation within plant organs leads to threats to food safety (Anjum *et al.* 2016; Siddique *et al.* 2018; Rizwan *et al.* 2012 and Satpathy *et al.* 2014).

As per the area under rice cultivation is concerned, it was 321.79 lakh ha in which West Bengal, UP, Punjab, Haryana, Telangana and Tamil Nadu are the main states of rice production while as per the report published (TOI, 2018) out of all the district of India, 24 districts are severely affected with cadmium toxicity. Rice is known for easily uptake and translocation of Cd in roots and shoots of rice plant hence is considered one of the sensitive plants among the monocot species because it is a probability of chance that cadmium can enter to food chain easily (Guo *et al.* 2018 and Song *et al.* 2015 and Aziz *et al.* 2015).

The adverse effect of Cadmium toxicity started from seed germination and seedling growth stages while carrying forward up to the crop's yield. During the growing period of the rice plant, various morpho-physiological and biochemical changes appear due to cadmium toxicity that often results in the degradation of chlorophyll, protein, fat and carbohydrate synthesis, consequently leading to the death of the plant (Siddique and Dubey, 2017; Siddique *et al.* 2018; Guo *et al.* 2018; Dong *et al.* 2019 and Srivastava *et al.* 2014). Although several studies about Cd toxicity to the rice plant have been done, further studies are required to make it clear about overcoming cadmium stress.

MATERIALS AND METHODS

A pot experiment was carried out on the Research Farm of Lovely Professional University, Department of Agronomy,

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School of Agriculture in *Kharif* season 2019-20. The healthy and bold seeds of rice variety Pusa Basmati -1121 were procured from the Punjab Agriculture University Ludhiana. Statistical design CRD was considered to conduct the trial comprised of five concentrations of CdCl2 ranging from 100 to 300 ppm and five replications to reduce the experimental errors. The treatments of $CdCl_2$ were placed in experimental pots before the transplanting of rice seedlings. As per the recommendation, 120, 60 and 60 kg ha^{-1} of N, P and K were used to raise the rice crop. However, the nitrogen was applied in two equal doses while Phosphorus and potash were applied at the sowing. The observation regarding the leaf area was measured by the use of a leaf area meter (Model no. 211) $hill^{-1}$ basis. However, leaf area index (LAI) and crop growth rate (CGR) were calculated at regular intervals of 25 DAT up to 100 DAT by the use of the following formula given by Watson (1947 and 1952).

$$\text{Leaf area index} = \frac{\text{Total leaf area (cm}^2)}{\text{Total ground area (cm}^2)}$$

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{A} \text{ mg cm}^{-2} \text{ day}^{-1}$$

Whereas:

W_2 = Dry weight of sample at second intervals.

W_1= Dry weight of sample at the first interval.

T_2 = Second time of intervals.

T_1 = First time of interval.

A = Ground area of plant sample

The observation regarding the grain yield and biological $hill^{-1}$, mature plants were harvested from each plot and recorded their biological yield while the grain yield was recorded after threshing. However, HI% was calculated as per the formula (Donald and Hamblin, 1976).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (seed yield)}}{\text{Biological yield}} \times 100$$

Statistical analysis

The significance test for the mean differences among the concentrations of $CdCl_2$ for the respective parameters was evaluated by using one-way ANOVA and CD (p<0.05) using SPSS software (Model 21). It is also subjected to the DMRT where the different alphabets indicate the significance among the treatments while in contrast, the same alphabets indicate nonsignificant differences among the treatments.

RESULTS AND DISCUSSION

Leaf area, LAI and CGR

Morphological changes were observed under the influence of externally imposed heavy metal stress via cadmium chloride on leaf area, leaf area index (LAI), crop growth rate (CGR), grain yield, biological yield and harvest index (HI%) in rice plants. It was observed from data as the intensity of stress increased from least to higher concentrations of $CdCl_2$, the leaf area and leaf area index (LAI) $hill^{-1}$ gradually decreased as compared to control. However, as the days after transplanting (DAT) is a concern, the maximum leaf area and LAI was recorded at 75 DAT during an entire set of treatment which was 855.8, 821.2, 787.6, 721.6, 678.4 660 cm^2 $hill^{-1}$ and 5.71, 5.47, 5.25, 4.81, 4.52, 4.40 $hill^{-1}$ (Table 1 and Fig 1). Similarly, % reduction of leaf area and LAI was calculated for each parameter corresponding to the HLCT and control and found that out of all DAT, a maximum% reduction was recorded at 50 DAT 38.47% and 38.38% (Table 1, Fig 1 and 4). The statistical analysis of the morphological parameters like leaf area and LAI were found highly significant at each DAT While the comparison of the mean value of each treatment indicated about the leaf area had no significant difference among the T4 and T5 at 25, 50 and 75 DAT. However, to check whether the treatments were significant or nonsignificant at a particular DAT for LAI, five subsets were received as per the DMRT test (p>0.05) which ranged from a to e in which similar alphabets had nonsignificant differences while dissimilar had significant

Table 1: Effect of different concentrations of Cadmium Chloride ($CdCl_2$) treatment on leaf area (cm^2) $hill^{-1}$.

Treatments \ Days after transplanting	25 DAT	50 DAT	75 DAT	100 DAT
T_0	156.2^c (±3.99)	446.0^d (±5.79)	855.8^e (±4.51)	783.8^d (±4.25)
T_1	148.6^c (±3.30)	378.4^c (±4.34)	821.20^d (±7.50)	765.00^d (±4.35)
T_2	140.2^b (±2.85)	358.4^{cb} (±4.43)	787.60^c (±8.26)	691.60^c (±10.50)
T_3	136.2^{ab} (±1.69)	337.4^b (±6.33)	721.60^b (±17.09)	601.00^b (±8.04)
T_4	133.0^{ab} (±1.90)	300.8^a (±21.01)	678.40^a (±6.27)	594.20^b (±23.82)
T_5	130.6^a (±1.69)	274.4^a (±7.16)	660.00^a (±6.72)	548.00^a (±3.45)
% Reduction of leaf area between control to *HLCT	16.38	38.47	22.87	30.08
CD.	7.97	29.48	27.37	33.72
SE (m±)	2.72	10.04	9.32	11.48
SE (d)	3.84	14.20	13.18	16.24

*HLCT= Highest level of cadmium toxicity, Data is significant at p<0.05%.

Note: T_0= Control, T_1=100 ppm $CdCl_2$, T_2= 150 ppm $CdCl_2$, T_3= 200 ppm $CdCl_2$, T_4 = 250 ppm $CdCl_2$ and T_5= 300 ppm $CdCl_2$.

among them (Fig 1). Crop growth rate (CGR) was also influenced by externally imposed $CdCl_2$ treatments as other parameters. The intensity of stress due to $CdCl_2$ also poses the reverse impact as the concentrations increased from least to higher concentrations. Statistical analysis carried out through SPSS also indicated the status of CGR. The scrutiny of ANOVA indicated that the parameter CGR had a significant difference. As per the days after transplanting (DAT) is a concern, the maximum crop growth rate was recorded between 50-75 DAT in each set of treatments, i.e. 1.717, 1.712, 1.646, 1.615, 1.476 and 1.254 mg cm^2 day^{-1} as compared to 75-100 DAT and 25-50 DAT Similarly, % reduction of crop growth rate was calculated and found that out of all the intervals, the maximum % reduction was recorded 35.0 mg cm^2 day^{-1} at 75-100 DAT followed by 26.79 and 20.89 mg cm^2 day^{-1} at 50-75 and 25-50 DAT. The scrutiny of the mean data among the treatments corresponding with CD found that CGR had nonsignificant differences among the T_0, T_1, T_2 and T_3 at 50-75 DAT while T_3, T_4 and T_5 had nonsignificant at 75-100 DAT (Fig 2).

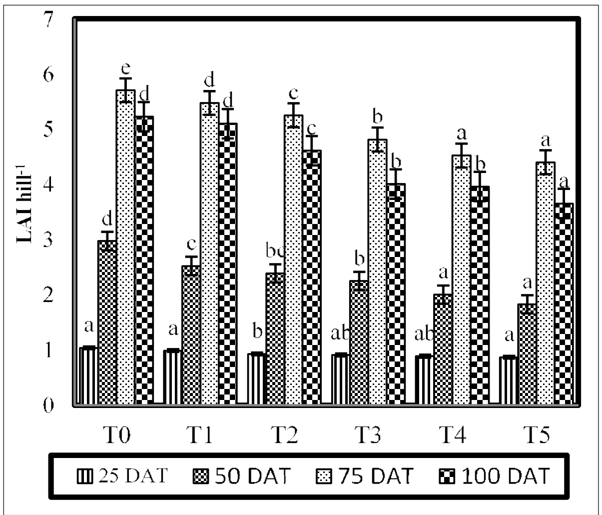

Fig 1: Effect of different concentrations of cadmium chloride ($CdCl_2$) treatment on Leaf Area Index $hill^{-1}$.

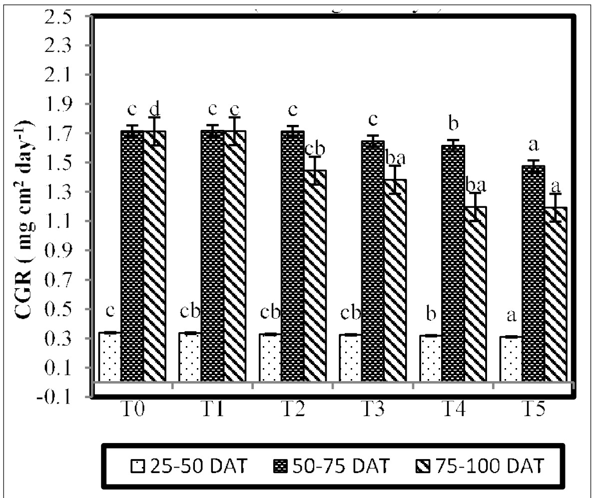

Fig 2: Effect of different concentrations of Cadmium Chloride ($CdCl_2$) treatment on Crop Growth Rate (CGR mg cm^2 day^{-1}) $hill^{-1}$.

Grain yield, biological yield and harvest index

Data pertaining in (Fig 3) shows that as the concentrations of $CdCl_2$ increased from least to higher concentrations, gradually declined in the grain yield $hill^{-1}$, biological yield $hill^{-1}$ (g) and harvest index (%) were noticed compared to control. Among the treatments of $CdCl_2$, the maximum amount of grain yield and biological yield was recorded in (T_1) 12.88 and 28.83 g $hill^{-1}$, while the minimum was recorded in (T_5) 8.87 and 22.31 g $hill^{-1}$. Similarly, the maximum HI % was also recorded (T_1) at 44.68% and the minimum was recorded (T_5) at 39.79%. However, % reduction was also calculated to know the severity of externally imposed stress on grain yield biological yield and harvest index which was 31.87, 28.7 and 11.10 % respectively (Fig 4). The presented in (Fig 3) were also analyzed through ANOVA and found that the parameters grain yield, biological yield and HI% had highly significant differences at (p>0.05) while the close analysis of mean data of each parameter indicated that grain yield yields and biological yield had significant differences among the treatments of $CdCl_2$. However, in the case of HI%, only T_4 and T_5 had significant differences while from T_0 to T_3 recorded nonsignificant differences among them. Leaves area $plant^{-1}$ and LAI both are positively linked together because the cumulative efforts of both the parameters laid the healthy foundation for the better growth and development of subsequent stages of the plant while the crop growth rate reveals the impact of growth within a certain period. Reduction in morphological growth in terms of leaf area, leaf area index (LAI) and CGR were observed throughout the study due to externally imposed $CdCl_2$ stress. The bounded growth of leaf area due to the interference of $CdCl_2$ reflected in LAI depends on cell division and cell enlargement. Our results are positively correlated with the finding of (Hatamian *et al.* 2020 and Fellet and Marchiol, 2011), who reported that cadmium stress had a detrimental effect on leaf morphology due to the restricted growth of cells and their expansion (Nagajyoti and Sreekanth, 2010). CGR is an output of dry matter accumulation of plant which was also affected adversely due to the uptake and translocation of $CdCl_2$ in the plant (Xue *et al.* 2013 and Siddique and Dubey, 2017). Harvest index is an efficient indicator of partitioning of photosynthate from source to sink consequently reflected in grain yield. Cadmium had a negative impact on the functioning of chlorophyll and its related enzyme activity while under the severe conditions it destroy the chloroplast consequently it suppress the portioning efficiency of photosynthate which in turn reduced grain yield (Lemoine *et al.* 2013). Enough evidence is available that indicates the negative relationship between Cd^{2+} and chlorophyll content because Cd^{2+} had a detrimental effect on chloroplast (Song *et al.* 2019; Siddique *et al.* 2018 and Latif, 2008). Enough shreds of evidence are available in favor of cadmium-induced stress suppressing the process

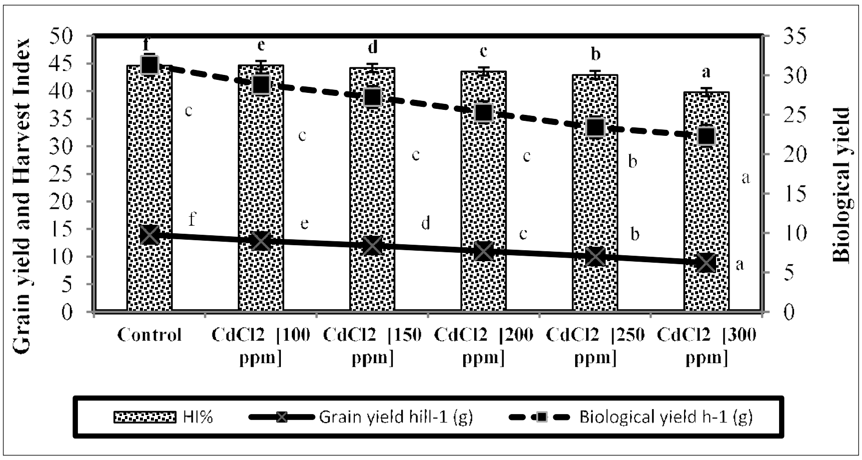

Fig 3: Effect of different concentrations of Cadmium Chloride ($CdCl_2$) treatment on grain yield, biological yield hill^{-1} (g) and harvest index (%).

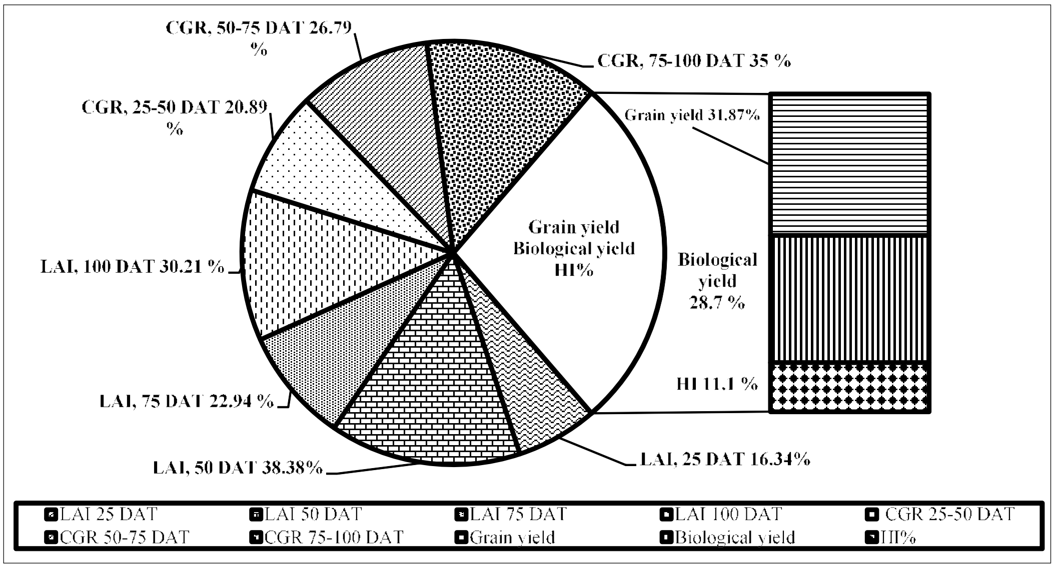

Fig 4: % reduction of morphological growth and yield over control under the influence of cadmium toxicity.

of photosynthesis by destroying chlorophyll structure, damaging the pigment system and reducing Rubisco activity, while the negative response of root growth and biomass production is also affected (Kupper *et al.* 2010; Santos *et al.* 2018; Rascio *et al.* 2008; Siddique *et al.* 2017; Song *et al.* 2019 and Sun *et al.* 2016).

CONCLUSION

As per the findings of our results, it is concluded that externally imposed cadmium stress shows a deleterious effect on the leaf area, LAI and CGR, biological yield, grain yield and HI%. The detrimental effect was calculated in terms of % reduction over the control and found a certain time (DAT) during the life cycle at which % reduction was recorded maximum. As a consequence of $CdCl_2$ toxicity, leaf area, growth analysis parameters, grain yield and other attributes like biological yield and HI % were adversely affected because the plant's reproductive growth depends on vegetative growth in which the number of leaves, leaf area and LAI is one of the important parameters that help in stabilizing plant for further growth.

Conflict of interest: None.

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