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Variation in Growth, Photosynthesis and Yield of Five Wheat Cultivars Exposed to Cadmium Stress

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Abstract: Cadmium is a highly toxic metallic pollutant which adversely affects the plant growth. A greenhouse experiment was conducted to study the variation in growth, photosynthesis and yield characteristics of five wheat (*Triticum aestivum* L.) cultivars, namely PBW343, HT2329, PBW373, UP2338 and WH542 at three plant growth stages, treated with 0, 25, 50 and 100 mg Cd kg^{-1} soil. Maximal significant reductions in the growth characteristics were observed with 100 mg Cd kg^{-1} soil in all the cultivars at all the sampling times. Among cultivars, PBW343 proved tolerant and showed lesser decrease in the characteristics, whereas, WH542 emerged as non-tolerant and suffered maximum decrease.

Key words: Cadmium · photosynthesis · tolerance index · wheat

INTRODUCTION

Cadmium (Cd) is a highly toxic metallic pollutant that does not have any metabolic use, enters in the natural and agricultural environment mainly from the industrial and municipal wastes, combustion of fossil fuels and use of agro-chemicals [1]. The toxic effect of Cd on plants has been extensively studied [2]. High Cd concentrations in the soil lead to reduction in metabolic processes like, photosynthesis, respiration and nitrogen metabolism resulting in poor growth and low biomass accumulation [1]. The ability of plant genotypes to detoxify Cd can differ between and within the plant species, which plays a significant role in the expression of high tolerance in plants to Cd toxicity [3]. Therefore, the selection of plant genotypes with high ability to tolerate Cd toxicity is a reasonable approach to counteract the adverse effects of Cd in crop plants. In the present investigation, five cultivars of wheat (*Triticum aestivum* L.) were treated with Cd concentrations to evaluate their relative tolerance to Cd toxicity on the basis of growth, photosynthesis and yield attributes.

MATERIALS AND METHODS

Seeds of five wheat (*Triticum aestivum* L.) cultivars namely, PBW343, HT2329, PBW373, UP2338 and WH542 were sown in 23 cm diameter clay pots filled with a mixture of soil and compost (3:1) with neutral in reaction. Soil was mixed with the appropriate amount of Cd $(NO_3)_2$ for 0, 25, 50 and 100 mg Cd kg^{-1} soil. Nitrate content in the Cd treatments was balanced with the application of urea. The treatments were arranged in randomized block design and each treatment was replicated three times. After germination, five plants per pot were maintained and watered with deionized water as and when required. The pots were kept in naturally illuminated green house of the Department of Botany, Aligarh Muslim University, Aligarh, India. Growth in terms of shoot length, shoot dry weight and leaf area and net photosynthetic rate were determined at 30, 60 and 90 days after sowing corresponding to tillering, heading and milky grain stages, respectively. Among yield characteristics, spikelet number per ears, ear number per plant, 1000 grain weight and grain yield were recorded at harvest. Shoot length was measured on meter scale. Leaf area was measured by a leaf area meter (LA-211, Systronics, India). Net photosynthetic rate was measured on fully expanded leaves of plants using Infra Red Gas Analyzer (Li6200, LiCor, Nebraska) at 11:00 - 12:00 h at light saturating intensity. Dry weight was recorded by drying the plants in an oven at 80°C till constant weight. Tolerance index was calculated using the data on grain yield obtained in 100 mg Cd kg^{-1} soil treatment and control, and expressed in percentage.

$$\text{Tolerance index} = \frac{\text{Grain yield of treated plants}}{\text{Grain yield of control plants}} \times 100$$

Data were analyzed statistically using analysis of variance (SPSS ver. 10 Inc.). F-value was calculated at

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Table 1: Shoot length (cm plant^{-1}) and shoot dry weight (mg plant^{-1}) of five wheat (*Triticum aestivum* L.) cultivars exposed to Cd concentrations at 30, 60 and 90 days after sowing (DAS)

		Cd treatments (mg Cd kg^{-1} soil)							
		Shoot length				Shoot dry weight			
DAS	Cultivars	0	25	50	100	0	25	50	100
30	PBW343	22.7^{a}	22.9^{a}	19.3^{a*}	17.8^{a*}	98.0^{a}	101.0^{a}	80.0^{a*}	76.0^{a*}
	HT2329	21.2^{a}	21.4^{a}	17.8^{a*}	15.8^{ab*}	91.0^{ab}	95.0^{ab}	72.0^{ab*}	68.0^{ab*}
	PBW373	19.5^{ab}	19.5^{ab}	15.6^{a*}	13.4^{b*}	81.0^{b}	83.0^{b}	62.0^{b*}	56.0^{b*}
	UP2338	16.1^{bc}	16.2^{bc}	10.7^{b*}	8.8^{c*}	54.0^{c}	57.0^{c}	36.0^{c*}	30.0^{c*}
	WH542	15.7^{c}	15.8^{c}	9.5^{b*}	7.5^{c*}	51.0^{c}	53.0^{c}	32.0^{c*}	24.0^{c*}
	Mean	19.0	19.1	14.6	12.7	75.0	78.0	56.0	51.0
60	PBW343	47.1^{a}	47.3^{a}	37.9^{a*}	34.3^{a*}	287.0^{a}	293.0^{a}	229.0^{a*}	218.0^{a*}
	HT2329	45.9^{a}	46.0^{a}	36.0^{ab*}	32.5^{ab*}	280.0^{a}	282.0^{a}	214.0^{a*}	200.0^{a*}
	PBW373	44.3^{a}	44.4^{a}	33.4^{b*}	28.7^{b*}	217.0^{b}	219.0^{b}	158.0^{b*}	141.0^{b*}
	UP2338	36.0^{b}	36.1^{b}	21.5^{c*}	17.2^{c*}	153.0^{c}	158.0^{c}	93.0^{c*}	75.0^{c*}
	WH542	33.5^{b}	33.6^{b}	18.0^{c*}	13.7^{c*}	141.0^{c}	143.0^{c}	76.0^{c*}	53.0^{c*}
	Mean	41.3	41.5	29.4	25.3	216.0	219.0	154.0	137.0
90	PBW343	59.0^{a}	59.1^{a}	48.5^{a*}	44.7^{a}	677.0^{a}	682.0^{a}	547.0^{a*}	535.0^{a*}
	HT2329	56.3^{ab}	56.5^{b}	43.3^{b*}	38.8^{b*}	653.0^{ab}	658.0^{ab}	487.0^{a*}	443.0^{b*}
	PBW373	55.0^{b}	55.2^{b}	40.5^{c*}	34.2^{c*}	584.0^{b}	590.0^{b}	385.0^{b*}	338.0^{b*}
	UP2338	42.1^{c}	42.2^{c}	23.5^{d*}	18.0^{d*}	318.0^{c}	321.0^{c}	165.0^{c*}	130.0^{c*}
	WH542	40.3^{c}	40.4^{c}	20.8^{c*}	14.4^{c*}	303.0^{c}	305.0^{c}	142.0^{c*}	90.0^{c*}
	Mean	50.5	50.7	35.3	30.3	507.0	511.0	345.0	307.0

Different letters within a column at each sampling time indicate significant differences ($p<0.05$) between genotypes in each external cadmium level

* indicates significant differences at $p<0.05$, between 25, 50 and 100 mg Cd kg^{-1} soil and control, and refer to each subset of data within each treatment and can be compared only transversely

Table 2: Leaf area (cm^2 plant^{-1}) and net photosynthetic rate (μmol m^{-2} s^{-1}) of five wheat (*Triticum aestivum* L.) cultivars exposed to Cd concentrations at 30, 60 and 90 days after sowing (DAS)

		Cd treatments (mg Cd kg^{-1} soil)							
		Leaf area				Net photosynthetic rate			
DAS	Cultivars	0	25	50	100	0	25	50	100
30	PBW343	32.2^{a}	33.2^{a}	24.7^{a*}	22.1^{a*}	19.3^{a}	17.6^{a*}	15.2^{a*}	13.5^{a*}
	HT2329	31.5^{a}	31.8^{a}	22.9^{a*}	19.5^{a*}	18.2^{ab}	16.1^{a*}	13.6^{ab*}	11.6^{ab*}
	PBW373	27.6^{b}	27.8^{b}	19.5^{b*}	16.3^{b*}	18.0^{ab}	15.9^{ab*}	13.0^{bc*}	11.0^{b*}
	UP2338	23.3^{c}	23.9^{c}	14.4^{c*}	10.9^{c*}	16.4^{bc}	14.0^{bc*}	10.3^{cd*}	8.5^{c*}
	WH542	21.5^{c}	21.9^{c}	11.6^{d*}	7.7^{d*}	15.9^{c}	13.1^{c*}	8.8^{d*}	7.0^{c*}
	Mean	27.2	27.7	18.6	11.6	17.6	15.3	12.2	10.3
60	PBW343	66.8^{a}	67.6^{a}	49.3^{a*}	43.3^{a*}	21.3^{a}	18.9^{a*}	15.4^{a*}	13.7^{a*}
	HT2329	56.5^{b}	57.0^{b}	38.4^{b*}	32.1^{b*}	$20.^{2ab}$	$17.^{5ab*}$	13.8^{b*}	11.8^{b*}
	PBW373	51.4^{c}	52.1^{c}	32.3^{c*}	26.2^{c*}	19.5^{b}	16.5^{b*}	13.1^{b*}	11.8^{b*}
	UP2338	43.2^{d}	43.5^{d}	24.5^{d*}	16.7^{d*}	17.8^{c}	14.6^{c*}	10.5^{c*}	8.6^{c*}
	WH542	40.5^{d}	40.9^{d}	19.4^{c*}	9.6^{c*}	16.4^{c}	13.1^{c*}	9.0^{d*}	7.1^{d*}
	Mean	51.7	52.2	32.8	25.6	19.1	16.1	12.3	10.5
90	PBW343	43.3^{a}	43.9^{a}	32.9^{a*}	29.0^{a*}	15.8^{a}	13.9^{a*}	12.0^{a*}	10.6^{a*}
	HT2329	40.7^{ab}	41.0^{ab}	26.8^{ab*}	21.9^{b*}	14.7^{ab}	12.6^{ab*}	9.8^{b*}	8.2^{b*}
	PBW373	36.5^{b}	36.9^{b}	21.4^{bc*}	17.6^{b*}	13.7^{b}	11.5^{b*}	8.5^{b*}	6.7^{b*}
	UP2338	27.7^{c}	28.1^{c}	15.3^{cd*}	11.2^{c*}	12.0^{c}	9.7^{c*}	6.3^{c*}	5.0^{c*}
	WH542	24.2^{c}	26.7^{c}	12.0^{d*}	8.5^{c*}	11.6^{c}	9.0^{c*}	5.3^{c*}	3.6^{c*}
	Mean	34.5	34.9	21.1	17.6	13.6	11.3	8.4	6.8

Different letters within a column at each sampling time indicate significant differences ($p<0.05$) between genotypes in each external cadmium level

* indicates significant differences at $p<0.05$, between 25, 50 and 100 mg Cd kg^{-1} soil and control, and refer to each subset of data within each treatment and can be compared only transversely

Table 3: Spikelet number per plant, ear number per plant, 1000 grain weight (g) and grain yield (g plant^{-1}) of five wheat (*Triticum aestivum* L.) cultivars exposed to Cd concentrations at 110 days after sowing (DAS)

		Cd treatments (mg Cd kg^{-1} soil)							
		Spikelet number per plant				Ear number per plant			
DAS	Cultivars	0	25	50	100	0	25	50	100
110	PBW343	23.4^{a}	23.2^{a}	19.0^{a*}	17.8^{a*}	2.9^{a}	2.7^{a}	2.4^{a*}	2.2^{a*}
	HT2329	21.5^{ab}	21.1^{ab}	16.5^{b*}	15.4^{b*}	2.2^{b}	2.1^{ab}	1.7^{b*}	1.6^{ab*}
	PBW373	19.8^{b}	19.4^{b}	14.8^{b*}	13.6^{b*}	2.1^{bc}	2.0^{bc}	1.5^{bc*}	1.4^{bc*}
	UP2338	17.5^{c}	17.0^{c}	11.9^{c*}	10.6^{c*}	1.6^{cd}	1.4^{cd*}	1.0^{cd*}	0.9^{cd*}
	WH542	16.9^{c}	16.1^{c}	10.1^{c*}	9.1^{c*}	1.4^{d}	1.3^{d}	0.8^{d*}	0.5^{d*}
	Mean	19.8	19.4	14.5	13.3	2.1	1.9	1.5	1.3
		1000 grain weight				Grain yield			
110	PBW343	45.2^{a}	44.9^{a}	35.7^{a*}	32.5^{a*}	3.3^{a}	3.2^{a}	2.7^{a*}	2.6^{a*}
	HT2329	41.4^{a}	40.6^{a*}	31.0^{b*}	28.1^{b*}	2.9^{ab}	2.8^{ab}	2.3^{ab*}	2.2^{ab*}
	PBW373	36.3^{b}	35.7^{b}	26.5^{c*}	24.3^{b*}	2.7^{b}	2.6^{b}	2.1^{b*}	1.9^{b*}
	UP2338	31.2^{c}	30.5^{c}	19.9^{d*}	18.0^{c*}	1.8^{c}	1.6^{c*}	1.2^{c*}	1.1^{c*}
	WH542	28.3^{c}	27.6^{c}	16.1^{d*}	13.2^{d*}	1.6^{c}	1.4^{c*}	1.0^{c*}	0.9^{c*}
	Mean	36.5	35.9	25.8	23.2	2.5	2.3	1.9	1.7

Different letters within a column at each sampling time indicate significant differences ($p<0.05$) between genotypes in each external cadmium level

* indicates significant differences at $p<0.05$, between 25, 50 and 100 mg Cd kg^{-1}soil and control, and refer to each subset of data within each treatment and can be compared only transversely

$p<0.05$ to determine the significance. Significant data were identified by calculating least significant difference.

RESULTS AND DISCUSSION

Higher concentration of Cd significantly reduced growth, net photosynthetic rate and yield (Tables 1-3). Shoot length, shoot dry weight and leaf area of the five cultivars at 30, 60 and 90 days were maximally and significantly reduced with 100 mg Cd kg^{-1} soil (Tables 1 & 2). Cadmium at a concentration of 25 mg Cd kg^{-1} soil exerted no change on the observed characteristics in all the cultivars. The order of performance of cultivars in terms of percent reduction was PBW343 > HT2329 > PBW373 > UP2338 > WH542. Growth reductions of Cd-treated wheat plants have been described [4-6] due to the higher accumulation of Cd and reductions in the availability of other nutrients resulting in disturbed metabolism. The reduction in shoot dry weight by Cd toxicity in wheat cultivars could be the direct consequence of the inhibition of photosynthesis. The low Cd concentration (25 mg Cd kg^{-1} soil) did not show decrease in the characteristics indicating that low Cd concentration indirectly influence metabolic processes in association with other metal like zinc. This argument finds support from the results of Narwal *et al.* [7] showing slight increase in dry matter yield of corn shoots at low levels of Cd in the soil. Similarly, Gussarsson [8] also reported an initial increase in the relative growth rate of *Betula pendata* plants to low Cd treatments. Increasing concentration of Cd also reduced the net photosynthetic rate in all the cultivars, and significantly maximum reduction was observed with 100 mg Cd kg^{-1} soil. Cadmium toxicity inhibits chlorophyll biosynthesis [9] and photosynthesis [10-12]. It has been reported that light and dark reactions of photosynthesis were inhibited under Cd stress [13]. It was also noticed that 100 mg Cd kg^{-1} soil proved toxic for all yield attributes because it gave maximum percent decrease than any other Cd treatment (Table 3). The application of Cd to soil has been found to decrease the yield of crop plants [14, 15].

Regarding cultivars, PBW343 showed lesser decreases in growth and yield characteristics than the other cultivars; whereas, WH542 suffered maximum decrease by the application of 100 mg Cd kg^{-1} soil (Table 3). The tolerance index of the cultivars PBW343, HT2329, PBW373, UP2328 and WH542 was 79.8, 75.6, 71.0, 68.3 and 52.7%, respectively. The tolerance index data emphasize PBW343 and WH542 are tolerant and non-tolerant cultivars and have maximum and minimum potential for Cd tolerance (Fig. 1). It may be assumed that the cultivar PBW343 possess inherent sequestration mechanisms to avoid effects of Cd toxicity. Plant species

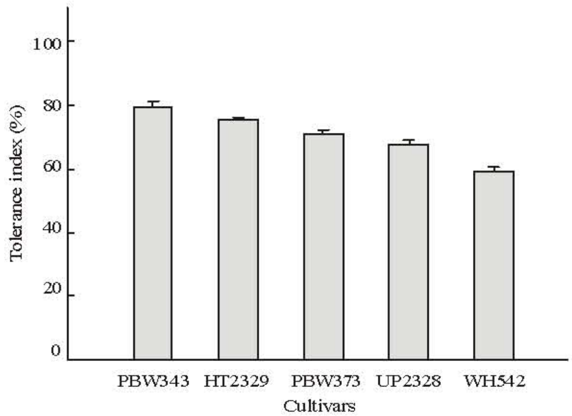

Fig. 1: Tolerance index of five wheat (*Triticum aestivum* L.) cultivars exposed to 100 mg Cd kg^{-1} soil. Tolerance index was calculated as percentage of grain yield obtained in 100 mg Cd kg^{-1} soil and control. Data shown are mean ± S.E

and even genotypes differ greatly in their ability to take up, transport, accumulate and sequester Cd within the plant.

In conclusion it may be said that 100 mg Cd kg^{-1} soil exerted significant reductions in growth, photosynthesis and yield of wheat cultivars. The cultivar PBW343 appeared to be the Cd tolerant with lesser reduction in the characteristics while WH542 emerged as non-tolerant cultivar showing maximum reductions.

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