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EFFICACY OF PHYTOREMEDIATION POTENTIAL OF MUSTARD (*BRASSICA JUNCEA*) AS CADMIUM ABSORBENT

Agriculture

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ABSTRACT

Mustard (Brassica junccea) is an oilseed crop in Bangladesh. Its oil content varies from 42 - 45% based on genotypes and growing conditions. This crop may be useful in soil reclamation as phytoremediation and phytoextraction of toxic heavy metals such as cadmium (Cd) from soil. Therefore, identification of phytoremediation potential B. juncea genotypes that accumulate heavy metal in their vegetative parts with less transportation to seedss would be of great importance for reclaiming the heavy metal contaminated soil. Eleven commonly grown B. juncea genotypes in Bangladesh were investigated to determine the phytoremediation potential against Cd stress. Among 11, genotype Sambal and Daulat showed maximum reduction in plant height (42%), leaves number (45%), leaves greenness (63%), root length (25%), shoot dry weight (34%) and root dry weight (34%), siliquae number (40%) and yield (34%) compared to their control. Sambal and Daulat accumulated maximum amount of Cd in vegetative parts. In contrast, the genotype BJDH17 showed maximum reduction of different phenotypic traits and minimum Cd accumulation in vegetative parts. We found minimum Cd translocation from root to shoot and shoot to seeds in the genotypes BJDH17 and BJDH20. Sambal and Daulat had the highest bioaccumulation coefficient (BC), whereas BJDH17 had the lowest in under Cd stress. Present findings help us in selecting genotypes suitable for phytoremediation to reclaim the soil against Cd stress and safe for cultivating as commercial varieties in heavy metal contaminant soil, like in industrial areas.

KEYWORDS

B. juncea; Phytoremediation; Cadmium; Hydroponic

INTRODUCTION

High concentrations of heavy metals, such as cadmium (Cd), lead (Pb), mercurry (Hg), aluminium (Al), chromium (Cr) etc. are contaminated in soil and water may cause long-term risks to ecosystems (Shaheen et al., 2014). Bangladesh is a large delta and composed of wetland soils, which are frequently contaminated with heavy metals (Frohne et al., 2014), which might be released and mobilized into soil and groundwater and could be entered into food chain (Licina et al., 2010). Thus, remediation of soils contaminated with heavy metals is a natural, environmental friendly and a cost effective technology. Selection and use of suitable vegetation which has capability to accumulate the elements in their body from soils and waters termed as phytoremediation (Prasad et al., 2015). Recently, oil-producing crops are recommended in phytoremediation because of these plants are not used directly as food for consumption, instead their processed products are consumed (Lavu et al., 2013).

Soil and water are frequently contaminated by highly mobile toxic heavy metal, like cadmium (Cd) by industrial effluents, fertilizers, sewage and mining activities (Shen et al., 2017). This heavy metal brings toxicity to human food and animal feed through entering into food chain by the crops grown in the contaminated soil. A high concentration of Cd inhibits seed germination, root elongation, leaf chlorosis and plant death (Rai et al., 2005). Vegetables are reported to be a major source of Cd phytoextraction, therefore the ancient *Brassica* species Indian mustard (*Brassica juncea*) has gained as an interesting candidate species of phytoremediation.

Phytoremediation is the process that helps plants to remove pollutants from the environment or to render them harmless (Salt et al., 1998). It is a renewable, green and sustainable process. Indian mustard has been widely used to extract toxic metals from contaminated soils worldwide. Indian mustard seems to be effective in accumulating high concentrated heavy metal in their body tissues when grown onto heavy metal contaminated soil. Heavy metals accumulator crop species take-up and stored heavy metals in their tissues at high concentration. Usually, heavy metals possess threat to plant survival, induce toxicity and raise food adulteration in crop plants (Hernandez et al., 1996).

Indian mustard is an amphidiploid species (AABB genome, 2n = 36) that originated through interspecific hybridization of *Brassica rapa* (AA genome, 2n = 20) and *Brassica nigra* (BB genome, 2n = 16). Oilseed *B. juncea* is grown as a spice crop in north America, but it is used as a source of cooking oil in Asia (Hemingway, 2013). It stands 1^{st} position in respect of area and production among the oilseed crops grown in Bangladesh.

Indian mustard is a traditional major oil crop and also potential in phytoremediation of soils polluted with heavy metals (Rathore et al., 2019; Suthar et al., 2013). Phytoextraction is a long-term process, therefore, fields undergo this process need to keep productive with the same crop by selecting suitable genotypes which could be worked as high-accumulator of heavy metals in body but less transportation from body to seeds. Moreover, the use of energy and/or biodiesel crops in phytoextraction is somewhat luxuriant for developing countries, like Bangladesh which has limited cultivable land. It is practical to use the dual purpose genotypes which are potential in phytoremediation and give commercial harvest with less contaminants. No such attempts have been made to select the Indian mustard genotypes for using as dual purpose in phytoremediation and oil extraction as well. Therefore, we screened some Indian mustard genotypes as accumulators of heavy metals in the vegetative parts from soil but restricted in transport to seeds. The objectives of our study were (i) to examine the efficiency of Indian mustard genotypes in phytoextraction of Cd, (ii) to screen mustard genotypes having high Cd content in shoot and root tissues and (iii) to assess amount of Cd transportation from medium to vegetative parts to seeds in Indian mustard.

MATERIALS AND METHODS

i. Plant Materials And Experimental Design

Eleven Indian mustard germplasm including varieties and advanced lines were collected from Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh. The selected germplasms were named as Sambal, BJDH05, BJDH12, BJDH17, BJDH20, BJ1111536, RAI5, BARI Sarisha10, BARI Sarisha11, BARI Sarisha16 and Daulat. The experiment was conducted in growth chamber with 24/20°C temperature, 16/8 h light at day/night and 75% RH following Complete Randomized Design (CRD) with two factors

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(genotype and heavy metal stress) with three replicates.

ii. Experimental Procedure

Seeds of the genotypes were pre-soaked in soap and 1% Dettol for 15 minutes and thoroughly washed at least 5 times in running tap water for removing soap and Dettol solution completely. Seeds were dried on tissue paper and placed in plastic pots filled with acid washed sand. Seeds germinated on sand and grown up seedlings prior to transplant into hydroponic system contained Hoagland solution (Hoagland and Arnon, 1950). Twenty days old seedlings with two true leaves were transplanted into hydroponic system, where we were supported seedlings with Styrofoam platform placed on 15 L size bowl. Each bowl was filled with 10 L Hoagland solution (pH 6.5) and circulated with automated air-bubbler for ensuring adequate dissolved oxygen. Each seedling had support of foam at the base of the seedling, so that the seedlings did not bend-down. Seedlings placed into Hoagland solution carefully by submerging the roots, whereas foam did not touch the solution. The pH of Hoagland solution was kept 6.5 by adding 1% NaOH solution at every three days interval. One thousand (mg) Cadmium nitrate ($Cd(NO_3)_2$) was dissolved in 1 L water for making 1000 ppm cadmium stock solution. Seventy five ml cadmium stock solution was added to each bowl contained 15 L Hoagland solution for ensuring 5 ppm heavy metal stress. After 20 days of heavy metal contamination, data on plant height, leaf number, leaf greenness and root length were recorded for observing the effect of heavy metal on morphology. Pods per plant, yield, dried shoots and roots were also measured. Cadmium residue in plant samples was estimated by atomic absorption spectrometry (AAS). AAS was performed by AA-6300 using air acetylene flame described by (Chakrobarty et al., 2019). The total experimental process is presented schematically in Fig. 1.

Figure 1. Schematic Presentation Of The Whole Experimental Procedure For Screening And Selection Of The Brassica Juncea Against Cadmium Stress Using Hydroponic System.

The amount of Cd content (ppm) = AAS conc. reading x Dilution factor

Here, Dilution factor = $\frac{workingsample\ (ml)}{weight\ (g)}$

iii. Statistical analysis

Analysis of variance (ANOVA) for all the collected data and mean comparison were performed following Tukey test using statistical package Minitab18 (State College, PA, USA). Translocation of heavy metals from plant root to shoot to grain was calculated as translocation factor TF (Mattina et al., 2003). The phyto-extraction rate or bioaccumulation coefficient (BC) described as the heavy metal concentration in plant divided by heavy metal concentration in the solution (Kumar et al., 1995). Cd translocation from root to shoot to grain was measured by TF as follows:

Translocation factor root to shoot (TF) = $\frac{Concentration\ of\ metals\ on\ shoot}{Concentration\ of\ metals\ on\ root}$

If, TF > 1 represents translocation of heavy metal effectively from root to shoot to grain (Baker and Brooks, 1989; Fayiga and Ma, 2006; Zhang et al., 2002).

Bioaccumulation Coefficient (BC) = $\frac{\text{Cd or Pb content per gram dry plant tissue}}{\text{Cd or Pb content in per ml nutrient solution}}$

RESULTS

Effect cadmium on morphological traits

A significant variation among the varieties, treatment and their interaction was observed for plant height, leaf number, leaf greenness, root length, pod number and yield (Table 1). Cadmium stress made significant differences for plant height, leaf number and leaf greenness after 20 days of Cd treatment (Table 2) indicates that vegetative growth was hampered due to heavy metal stress. Similarly, significant effects of Cd stress observed at reproductive stages confirmed by the significant reduction of siliquae number and yield/plant after 60 days of Cd stress compared to the control (Table 2). Roots are the main part of plant to escape any abiotic stress like heavy metal stress by elongating them, however we recorded retarded root growth from the beginning of the Cd stress and found reduced root growth after 60 days of Cd stress,

Table 1. Mean Squares Of Different Traits Of B. Juncea Genotypes Are Grown Under Control And Cadmium (CD) Stress

Sources of variation	df	Mean square					
		Plant height	Leaf number	Leaf greenness	Root length	Pod number	Yield/ plant
Treatment (T)	1	2485.23**	345.47**	52.74**	474.68**	808.5**	0.98**
Genotype (G)	10	359.67**	121.52**	0.92**	170.1**	30.4**	0.06**
T × G	10	20.29**	7.30**	0.58	1.65**	3.6**	0.007**
Error	44	0.52	0.33	0.28	0.38	0.58	0.001

$^{**}p \leq 0.01$

Table 2. Effect Of Cd On Different Vegetative And Reproductive Traits Of B. Juncea Genotypes On 20 And 60 days Against Cd Stress

	20 days on Cd stress			60 days on Cd stress		
Treatment	Plant height	Leaf number	Leaf greenness	Root length	Pod number	Yield/ plant
Control	42.51a	23.75a	3.69a	27.63a	23.21a	1.06a
Cd stress	31.42b	19.60b	1.93b	23.27b	16.66b	0.78b
Reduction (%)	26.09	17.47	47.54	15.79	28.20	26.64

Response Of The Genotypes Against Cd Stress

Genotypes showed significant variations for different vegetative and reproductive traits (Table 1). Among 11 genotypes, BJDHJ17 had maximum values for all of the traits and scored as top rank considering 6 vegetative and reproductive traits against Cd stress (Table 3). BARI Sarisha11 ranked in 2nd position considering all 6 traits, this genotype had maximum values for 5 traits without plant height. Genotype BJDH12 ranked 3rd and produced on an average values for all of the traits. Among the genotypes, Daulat affected severely due to Cd stress for most of the traits and produced least plant height, number of leaves, low leaf greenness, less number of roots, minimum siliquae and yield/plant, which was followed by the genotype Sambal and rest of the other genotypes (Table 3).

Table 3. Performance of 11 Brassica Juncea Genotypes Harvest On 60 Days After 5 ppm Cadmium Stress In Hydroponic System

Genotypes	Plant height	Leaf number	Leaf greenness	Root length	Siliquae number	Yield/ plant	Genotypes appeared in top	Ranking of genotypes
BJDH5	33.8f	20.6f	2.8bc	23.6e	19.1e	0.88d	0	4
BJDH12	41.3c	24.6c	3.0ab	26.8c	21.1c	0.97c	1	3
BJDH17	49.3a	27.3a	3.3a	34.0a	23.5a	1.04a	6	1
BJDH20	44.8b	25.6b	3.3a	30.8b	22.2b	1.00b	1	3
BJ1111536	36.0e	22.2e	2.7bcd	23.8e	20.3d	0.94c	0	4
RAI5	33.0g	20.7f	2.3d	21.7f	18.8e	0.88d	0	4
BARI Sarisha10	30.3h	17.7g	2.3d	21.7f	18.7e	0.86d	0	4

BARI Sarisha11	45.5b	26.8a	3.3a	33.6a	23.3a	1.07a	5	2
BARI Sarisha16	37.8d	23.0d	2.8bc	25.3d	19.2e	0.88d	0	4
Sambal	26.5j	16.2h	2.5bcd	18.7h	16.2f	0.76f	0	4
Daulat	28.2i	13.7i	2.5bcd	19.8g	16.8f	0.80e	0	4
SE (±)	0.30	0.24	0.19	0.25	0.29	0.01		
Minimum	26.5	13.66	2.33	18.66	16.16	0.75		
Maximum	49.33	27.33	3.33	34.0	23.5	1.1		

Interaction effect of the genotypes against cadmium (Cd)

Genotypes were responded differently for mitigating Cd stress due to their inherent genetical potentialities, therefore Cd stress differentially effected the vegetative and reproductive traits of *B. juncea*. Analysis of variance indicated that most of the traits except leaf greenness exhibited highly significant variation ($p < 0.01$, Table 1) due to Cd × genotype interaction. Maximum plant height, leaf number, root length, siliquae and yield/plant was recorded in the genotype BJDHJ17 and identified as the most suitable one, which showed minimum effect of Cd stress on different vegetative and reproductive traits. Sambal found as poor-performing genotype because most of the traits were effected by Cd stress and produced short plant stature, less number of leaf, short root, minimum siliquae and least yield/plant. Most of the traits were reduced drastically due to Cd stress compared with their non-stressed control. However, the genotypes showed different trend of reducing response of different traits due to their genetic constituents (Fig. 2). Among the genotypes, Daulat showed the highest percentage of reduction for most of the traits except siliquae number and yield/plant on harvest, in which he highest reduction percentage were 42% for plant height, 45% for leaf number, 63% for leaf greenness and 25% for root length. Similar reduction trend for all of the traits observed in the genotype Sambal against Cd stress. BJDH17 showed minimum reduction trend for all of traits against Cd stress, 12% plant height, 4% leaf number, 18% leaf greenness, 7% root length, 14% siliquae number and 11% yield/plant reduction due to Cd stress were recorded. BJDH20 had reduction of all the traits except yield like BJDH17. These results indicated that BJDH17 and BJDH20 could be selected as suitable genotypes for cultivation as phyto-remediation sources as well as commercial cultivation without minimum sacrifice of the vegetative and reproductive traits.

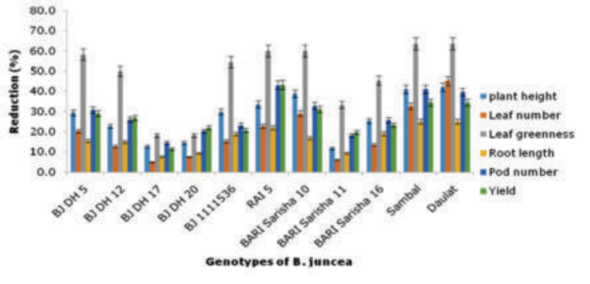

Figure 2. Relative reduction of different morphological and yield related traits of 11 Brassica juncea genotypes under cadmium stress compared to their respective control.

Cadmium Concentration In Roots, Shoots And Seeds

There were significant variations among the accessions of *B. juncea* in respect of cadmium concentration in dry biomass of roots, shoots and grains. Sambal showed high performance in cadmium accumulation in root (1835.67 µg/g) followed by Daulat, BARI Sarisha10, RAI5, BJDH05, BJ1111536, BARI Sarisha16, BJDH12, BJDH20, BARI Sarisha11 and BJDH17. Whereas, BJDH17 showed poor performance in Cd accumulation (1520.67 µg/g) followed by BARI Sarisha11, BJDH20, BJDH12, BARI Sarisha16 (Table 4). We identified Sambal as superior genotype (334.66 µg/g) in accumulating Cd also in the shoots followed by Daulat, BARI Sarisha10, RAI5, BJDH05, BJ1111536, BARI Sarisha16, BJDH12, BJDH20, BARI Sarisha11 and BJDH17. Whereas, BJDH17 showed poor performance in Cd accumulation (121.33 µg/g) in the shoots followed by BARI Sarisha11, BJDH20, BJDH12 and BARI Sarisha16. Sambal also showed higher amount of Cd accumulation (14 µg/g) in seeds compared to rest of the genotypes, which was followed by Daulat, BARI Sarisha10, RAI5, BJDH05, BJ1111536, BJDH12, BJDH20, BARI Sarisha11 and BJDH17. Whereas, BJDH17 accumulated least amount of Cd in the grains (3.42 µg/g) followed by BARI Sarisha11, BJDH20, BJDH12 and BJ1111536 (Table 4). It could be concluded that the genotype Sambal could be a good source in using phyto-remediation and reclamation of heavy metal (Cd) contaminated soil, whereas BJDH17 could be recommended for cultivation in heavy metal contaminated soil.

Table 4. Cadmium concentration in roots, shoots, grains and TFroot to shoot, TFshoot to seeds, BC (bioaccumulation coefficient) of 11 Brassica juncea genotypes harvest at 60 days after 5 ppm cadmium stress in hydroponic system

Genotype	Cadmium concentration (µg/g) in			$Tf_{root\ to\ shoot}$	$Tf_{shoot\ to\ seeds}$	BC
	root	shoot	seed			
BJDH05	1744.3e	244.6e	7.2e	0.14e	0.03cd	399.24e
BJDH12	1691.33h	194.66h	4.86g	0.11h	0.02d-f	378.17h
BJDH17	1520.66k	121.33k	3.42i	0.07j	0.022c-e	329.08k
BJDH20	1650.0i	188.66i	4.23gh	0.11h	0.03f	368.58i
BJ1111536	1725.33f	223.33f	6.5f	0.12f	0.02cd	391.03f
RAI5	1755.66d	265d	8.4d	0.16d	0.04bc	405.81d
BARI Sarisha10	1789.33c	303.66c	9.1c	0.17c	0.03cd	420.42c
BARI Sarisha11	1583.66j	165.66j	3.86hi	0.11i	0.03ef	350.64j
BARI Sarisha16	1710.66g	205.33g	6f	0.12g	0.02cd	384.4g
Sambal	1835.66a	334.66a	14a	0.18a	0.05a	436.86a
Daulat	1807.33b	322.33b	11.6b	0.17b	0.04b	428.25b
$LSD_{(0.05)}$	2.13	2.13	0.69	0.002	0.005	0.71
$LSD_{(0.01)}$	2.88	2.88	0.94	0.01	0.003	0.98
CV	0.07	0.534	5.72	0.53	4.97	0.11

***CV** = Coefficient of variation; **LSD**= Least significant difference*

Translocation Efficacy Of Cadmium From Root To Shoot To Seed

Translocation factor (TF) is one of the main components to make decision for selecting genotypes, whether the genotypes could be used in cultivation or phyto-remediation without having chance of entering toxic heavy metals in our food chain. TF of Cd from root to shoot to seed was calculated and and found significant variations among the genotypes. Sambal had higher TF values; 0.18 and 0.05 from root to shoot and shoot to seed, respectively with high bioaccumulation coefficient (436.87), which was followed by Daulat, BARI Sarisha10, RAI5, BJDH05, BJ1111536, BARI Sarisha16, BJDH12, BJDH20, BARI Sarisha11 and BJDH17. Whereas, BJDH17 had low TF value (0.07) from root to shoot translocation with low bioaccumulation coefficient (329.08) and BJDH12 showed minimum TF from shoot to seed translocation (Table 4). Thus, these two genotypes could be selected as safe genotypes which will not bring Cd in our food chain if they are cultivated in the Cd contaminated soil.

Relationship and effect of different traits on yield

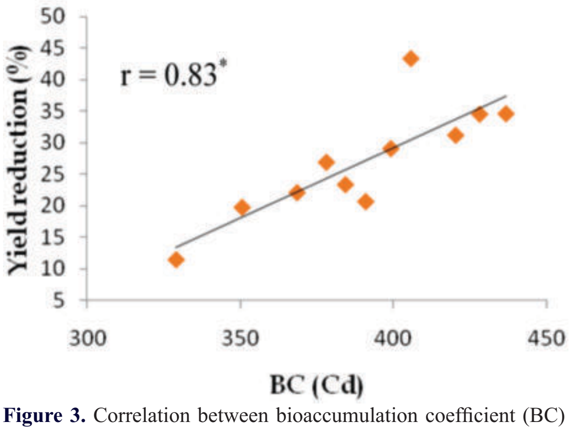

Figure 3. Correlation between bioaccumulation coefficient (BC) of cadmium and percent reduction of yield/plant of Brassica juncea genotypes due to cadmium stress.

Correlation and path coefficients were estimated to know the relationship among different traits and their direct and indirect effects on yield. Most of the traits had highly significant positive correlations with yield, of them correlation coefficient was varied from 0.82 to 0.99 (Table 4). We found positive correlation between bioaccumulation coefficient and reduction of yield/plant ($r = 0.83^*$; Fig. 3), indicating that heavy metal stress susceptible genotypes produced lower seeds or most of the case no seeds in the siliquae and drastically reduced yield. Path analysis was performed to know influences of independent variables to the dependent variable yield/plant directly and via independent variables themself indirectly. Plant height (PH), root length (RL) and siliquae/plant (S/P) exhibited positive direct effect on yield/plant (0.10, 0.52 and 0.99 respectively), whereas leaf number (LN) and leaf greenness (LG) had negative direct effect on yield/plant. The highest indirect effects on yield/plant were observed with plant height (PH) via leaf greenness (0.91), leaf number (0.90) and root length (0.40) (Table 5). In addition very low residual effect was recorded (0.0063) indicating efficient selection of the independent variables which had effect on independent variables with minimum duplicate effects of them.

Table 5. Direct And Indirect Effect Estimated By Path Coefficient And Correlation Among The Dependent Variable (yield/plant) And The Independent Variables

Trait	Correlation coefficient	Direct effects	Indirect effects				
			PH	LN	LG	RL	S/P
PH	0.93**	0.10					
LN	0.84**	-0.15	0.90				
LG	0.92**	-0.10	0.91	0.10			
RL	0.82**	0.52	0.40	-0.13	-0.07		
S/P	0.99**	0.99	0.10	-0.02	-0.10	0.02	
Residual effect (R) = 0.0063							

Whereas, PH= plant height, LN= leaf number, LG= leaf greenness, S/P = siliquae/plant, RL= root length; ** indicates p ≤ 001

DISCUSSION

Cadmium (Cd) is a health hazardous heavy metal tends to contaminate agricultural land through phosphate fertilizers, industrial discharge and using urban drained effluents as organic manure. Agricultural products become contaminated with the heavy metals due to cultivation of the crops in the contaminated soils and those heavy metals enter into food chain and threaten human health. Even the productive soils could be turned into fellow due heavy contamination with heavy metals. Therefore, we need to periodically reclaim our soil near to the industrial regions by phyto-remediation techniques using suitable crop species and genotypes for keeping our agricultural soils as cultivable. In recent years, pollution of agricultural soils by Cd has become a serious concern around the world due to increasing anthropogenic activities (Horiguchi et al., 2013). Currently, plant species from Asteraceae, Brassicaceae, Voilaceae, Poaceae and Fabaceae family possess the ability to tolerate and accumulate heavy metal in their tissue from contaminated soil and water. Among them, Brassicaceae has nearly 80 species as metal accumulators. From them, Indian mustard (*Brassica juncea*) has the capacity to extract and detoxify the heavy metals from contaminated soils (Rathore et al., 2019).

The uptake and accumulation of different metals may vary in plant species, such discrepancies arise due to type of heavy metals, its concentration and plant species (Kim et al., 2003). Different metals are differently mobile within plant, cadmium is more mobile than lead and copper (Prasad, 2004). Cadmium is one the most dangerous heavy metals due to its high mobility and the small concentration at which its effects on the plants begin to show (Vázquez et al., 1992). There was an increase in root length up to 1 ppm, whereas shoot length increases up to 2 ppm concentrations. Thereby, significant decrease was reported in root at higher concentration as compared to shoot length (Sen et al., 2013). Decrease in growth rate, decrease dry weight and reduction in transpiration rate were observed in mustard plant due to accumulation of Cd, which causes structural changes in plant height, root length, stems and leaves and altered physiological and morphological characteristics (Bauddh and Singh, 2011; Chaturvedi, 2004; Heidari and Sarani, 2011; Sridhar et al., 2005).

Cadmium showed a significant reduction of leaf number and leaf greenness of *B. juncea* compared to its control. Sambal and Daulat produced minimum number of leaf in Cd stressed condition due to high accumulation of Cd in shoots. The reduction of leaf number of these two genotypes were ≈ 32% and ≈ 45%, respectively. Whereas, BJDH17 produced maximum number of leaf in both stressed and control conditions due to genetic potentiality of its tolerant and low cadmium accumulation (121.33 µg/g) in shoots. It also showed minimum reduction of leaf number (≈ 4%) in Cd stress. In Cd stress, BJDH17 and BJDH20 genotypes found as the best for retaining leaf greenness due to low Cd accumulation (121.3 and 188.6 µg/g, respectively) in shoots. Sambal, Daulat, BARI Sarisha10 and RAI5 genotypes had low leaf greenness in Cd stress compared to control due to high accumulation of Cd in the shoots. Previous study showed that Cd toxicity could have direct consequence in inhibition of chlorophyll synthesis (Padmaja et al., 1990) and declined the enzyme activities of chlorophyll biosynthesis and photosynthesis have been documented in response to Cd stress (Böddi et al., 1995; Fargašová, 1998; Sepehr and Ghorbanli, 2006).

Siliquae number/plant was adversely oppressed due to effect of Cd toxicity, BARI Sarisha11 produced maximum siliquae due to tolerance potentiality, whereas it was minimum in Sambal and Daulat because of susceptible towards Cd toxicity. In Cd toxicity, highest reduction of siliquae was recorded in Sambal (≈ 40%) might due to maximum BC (436.86), whereas least reduction of siliquae (≈ 14%) with minimum BC (329.083) found in BJDH17. Previous study showed that Cd toxicity could be the direct consequence of the inhibition of photosynthesis (Baszyński, 2014). Several studies have been reported a remarkable reduction in photosynthetic rate for different plant species when exposed to Cd stress (Satyakala and Jamil, 1997). Heavy metal uptake can be considered as an important parameter to predict mustard's capacity of Cd phyto-extraction. Among Indian mustard genotypes for heavy metal uptake along with physical and chemical properties of the soil. This was confirmed by positive correlation results between bioaccumulation coefficient and reduction of yield in our present study. Differences in uptake of Cd in aerial and below ground parts may be apparently related to translocation in the vascular system (Karak et al., 2013).

In this study, BJDH17 was ascertained as superior genotype in respect to yield/plant with low yield reduction (≈ 11%) and low BC (329.08) under Cd stress. Whereas, Sambal substantiated as poor-performing genotype regarding yield/plant with higher yield reduction (42%) compared to other genotypes and maximum BC (436.86) under Cd stress, similar yield reduction was reported by (Palizban et al., 2015). The uptake of higher root Cd than shoots in our study was in agreement with several studies (Aung et al., 2015; Jia et al., 2017; Sheetal et al., 2016). Significant differences in uptake and distribution of Cd in individual plant parts depends upon the entry and availability of the Cd into plant root through plasma membrane cation channels (Seregin and Kozhevnikova, 2008). In agreement to our results, former study regarding *B. juncea* reported that number of leaves/plant revealed negative direct effect on yield and total chlorophyll and positively influenced the yield. In addition, plant height, number of siliquae/plant had positive direct effect on yield (Rout et al., 2018).

CONCLUSIONS

The overall evaluation of phytoremediation efficacy of the genotypes depends on the total Cd accumulation in aboveground parts of the plants. After 60 days of cultivation, our results indicated that significant differences in shoot Cd content of eleven *Brassica juncea* genotypes grown on 5 ppm Cd supplemented Hoagland solution. Among the genotypes, Sambal and Daulat shoots accumulated more Cd, indicating that these varieties had good potential compared with other studied genotypes. Higher amount of Cd uptake and translocation in shoots confirms these are preferred genotypes suitable for Cd phyto-extraction from contaminated soils. By contrast, the smart selection of plant cultivars with great potential to tolerate Cd could be the best strategy to counteract the inhibitory effects of Cd in crop plants. We selected BJDH17 and BJDH20 as superior genotypes tolerance to heavy metal with less translocation in the shoots and could be used in cultivation for oil extraction having low heavy metal (Cd) contamination in the food chain. The genotypes are selected in this study could be good source in phyto-extraction and tolerant material could be cultivated in heavy metal contaminated industrial regions.

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Key Findings:

Sambal and Daulat could be selected as superior genotype for soil reclamation through phytoremediation. BJDH17 and BJDH20 found as promising for oil extraction without heavy metal contamination in food chain.

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