Phytoremediation of hexavalent chromium by mung bean through bio-accumulation and bio-stabilization in a short duration (2021)

Table 1: Regulatory concentrations of Cr in agricultural soils of different areas.

Area	Regulatory concentrations of Cr
China	≤250/150 mg·kg^{-1} (pH≤6.5) ≤300/200 mg· kg^{-1} (6.5<pH≤7.5) ≤350/250 mg· kg^{-1} (pH>7.5) in paddy/dryland soil
European Union	≤200 mg·kg^{-1}
Australia	≤50 mg·kg^{-1}
Canada	≤64 mg·kg^{-1}
US	≤11 mg·kg^{-1}

Table 2: The stress tolerance indices for different growth parameters of mung bean plants under Cr(VI) stress after 7 d of growth.

Treatment	RLSTI	SLSTI	RDSTI	SDSTI	RFSTI	SFSTI
3 mg·L^{-1}	44.17±0.66 a	83.14±2.84 a	70.32±8.88 a	98.06±1.32 b	59.80±2.73 b	75.57±2.71 ab
5 mg ·L^{-1}	38.52±7.38 a	74.54±0.80 b	67.98±1.15 a	103.29±4.20 b	80.26±10.73 a	83.33±6.50 a
10 mg ·L^{-1}	14.09±1.98 b	21.69±3.60 c	37.77±2.48 b	129.50±9.74 a	36.66±2.44 c	65.45±8.48 bc
30 mg ·L^{-1}	7.42±0.47 bc	9.98±1.43 d	16.55±2.49 c	126.59±4.70 a	18.98±2.96 d	61.82±0.57 bc
50 mg ·L^{-1}	6.59±0.67 bc	6.50±0.91 de	15.87±2.18 c	135.64±10.39 a	17.37±2.60 d	62.70±7.06 bc
70 mg ·L^{-1}	7.07±0.06 bc	4.45±0.92 de	17.87±1.14 c	132.51±3.63 a	19.19±0.50 d	63.97±0.68 bc
100 mg ·L^{-1}	5.85±0.46 c	3.25±0.29 de	11.49±0.91 c	138.21±8.76 a	11.97±0.11 d	61.61±4.27 bc
130 mg ·L^{-1}	5.18±0.40 c	1.81±0.5 4e	10.87±0.83 c	133.27±8.06 a	7.97±0.70 d	53.50±2.97 c
150 mg ·L^{-1}	5.47±0.07 c	1.32±0.08 e	9.73±0.05 c	128.34±7.30 a	8.04±0.06 d	60.60±0 bc

Diferent letters indicate statistically significant differences at $P<0.05$ by Tukey's multiple range tests.

Table 3: Phytoremediation potential for hexavalent chromium of different plant species.

Plat species	Initial Cr(VI) concentration	Grow condition	Growth period	Accumulation ($mg \cdot kg^{-1}$ DW)			BCF	TF	References
				Plants	Roots	Shoots			
Salvinia herzogii	$6\ mg \cdot L^{-1}$	Nutrient solution	21 d for treatment	NA	2570	880	NA	0.34	(Maine et al. 2016)
Pistia stratiotes	$6\ mg \cdot L^{-1}$	Nutrient solution	11 d for treatment	NA	1860	527	NA	0.28	(Maine et al. 2016)
Convolvulus arvensis	$10\ mg \cdot L^{-1}$	Nutrient solution	10 d for growth 10 d for treatment	NA	1500	150	NA	0.10	(Montes et al. 2013)
Medicago truncatula	$10\ mg \cdot L^{-1}$	Nutrient solution	10 d for growth 10 d for treatment	NA	1100	339	NA	0.31	(Montes et al. 2013)
Medicago sativa	$10\ mg \cdot L^{-1}$	Nutrient solution	2 d for germination 30 d for treatment	NA	1000	1000	NA	1	(Bonfranceschi et al. 2009)
Leersia hexandra	$30\ mg \cdot L^{-1}$	Nutrient solution	15 d for growth 45 d for treatment	2921	3299	2846	97	0.86	(Zhang et al. 2007)
Halimione portulacoides	$30\ mg \cdot L^{-1}$	Nutrient solution	15 d for growth 7 d for treatment	NA	964	20	NA	0.02	(Duarte et al. 2012)
Helianthus annuus	$70\ mg \cdot kg^{-1}$	Clay soil	90 d	NA	2730	242	NA	0.09	(Ranieri et al. 2013)
Phragmites australis	$70\ mg \cdot kg^{-1}$	Clay soil	90 d	NA	1800	602	NA	0.22	(Ranieri et al. 2013)
Sorghum bicolor	$80\ mg \cdot L^{-1}$	Nutrient solution	2 d for germination 30 d for treatment	NA	5800	3000	NA	0.52	(Bonfranceschi et al. 2009)
Amaranthus dubius	$100\ mg \cdot kg^{-1}$	Potting soil	49 d for growth 16 d for treatment	NA	308	150	4.6	0.5	(Mellem et al. 2012)
Cichorium spinosum	$100\ mg \cdot kg^{-1}$	Soil	60 d for treatment	248	NA	NA	2.48	NA	(Antoniadis et al. 2017)
Nopalea cochenillifera	$104\ mg \cdot L^{-1}$	MS medium	40 d for treatment	13,000	NA	NA	125	0.5	(Adki et al. 2013)
Pteris vittata	$130\ mg \cdot L^{-1}$	Nutrient solution	210 d for growth 1 d for treatment	NA	11,913	296	NA	0.02	(De Oliveira et al. 2016)
Prosopis laevigata	$177\ mg \cdot L^{-1}$	MS medium	10 d for germination 50 d for treatment	NA	8090	5461	24	0.67	(Buendia-Gonzalez et al. 2010)
Lactuca sativa	$200\ mg \cdot L^{-1}$	Soil	21 d for growth 28 d for treatment	NA	1900	225	NA	0.12	(Dias et al. 2016)
Mung bean	$3\ mg \cdot L^{-1}$	Agar medium	7 d	209	277	173	69	0.72	This work
	$30\ mg \cdot L^{-1}$			1868	1814	2013	62	1.11	
	$150\ mg \cdot L^{-1}$			5041	9328	5007	33	0.43	

Source: https://link.springer.com/article/10.1007/s13762-020-03001-7

Table 1: Minimum inhibitory concentrations (MIC) of Cr (VI) and plant growth-promoting (PGP) traits of the bacterial isolates. Data are the mean of replicates with SE±. Values with different letters are significantly different ($p < 0.05$)

Isolat	MIC (mg/L) Cr (VI)	PSI	IAA (μg/mL)	Sid	N_2	EPS	NH_3	HCN	Case	Pase	Chase
NT1	600	2.4 ± 0.2^{cde}	167 ± 1.42^{e}	+	–	–	+	–	+	+	+
NT2	400	1.33 ± 0.1^{fgh}	187.5 ± 1.5^{cd}	+	+	–	+	–	+	+	+
NT3	600	1.8 ± 0.1^{cdefgh}	125.75 ± 1.45^{h}	–	–	–	+	+	+	–	+
NT4	600	2.8 ± 0.2^{bc}	10 ± 0.42^{p}	+	–	–	+	+	+	+	+
NT5	600	2.33 ± 0.3^{cdef}	71.5 ± 1.1^{k}	+	–	–	+	–	+	+	+
NT6	600	1.14 ± 0.2^{h}	144.75 ± 1.37^{fg}	–	+	–	+	–	+	–	–
NT7	400	1.83 ± 0.3^{cdefgh}	161.75 ± 1.47^{e}	+	+	–	+	+	+	–	+
NT8	400	2 ± 0.1^{cdefgh}	63.25 ± 1.18^{lm}	–	–	–	+	+	–	+	+
NT9	600	1.25 ± 0.1^{gh}	61.5 ± 1.15^{lm}	+	+	+	+	+	–	+	+
NT10	300	2 ± 0.2^{cdefgh}	92.25 ± 1.21^{ij}	+	–	–	+	+	+	+	+
NT11	600	1.44 ± 0.3^{efgh}	144 ± 1.19^{g}	+	+	–	+	+	–	–	+
NT12	400	2 ± 0.2^{cdefgh}	143.75 ± 1.22^{g}	+	+	+	+	+	+	–	–
NT13	300	1.92 ± 0.4^{cdefgh}	189.5 ± 2.43^{c}	+	+	–	+	+	+	–	+
NT14	300	2 ± 0.1^{cdefgh}	45.5 ± 1.16^{o}	+	+	–	+	+	+	+	+
NT15	600	3.6 ± 0.5^{ab}	192.95 ± 2.5^{c}	+	+	–	+	+	–	–	+
NT16	400	1.71 ± 0.2^{defgh}	73 ± 1.25^{k}	+	+	+	+	+	–	+	+
NT17	600	1.68 ± 0.3^{defgh}	124.5 ± 1.68^{h}	+	–	–	+	–	–	+	+
NT18	400	2.06 ± 0.4^{cdefgh}	96.75 ± 1.23^{i}	+	–	–	+	–	–	+	+
NT19	600	2.55 ± 0.1^{cd}	88.63 ± 1.25^{j}	+	+	+	+	–	+	+	+
NT20	600	2.1 ± 0.1^{cdefgh}	572.27 ± 4.25^{a}	+	+	+	+	+	+	+	+
NT21	400	2.07 ± 0.4^{cdefgh}	181.5 ± 1.31^{d}	+	–	–	+	+	+	–	+
NT22	600	2.54 ± 0.2^{cd}	49 ± 1.14^{no}	+	+	–	+	+	–	–	–
NT23	300	2.57 ± 0.3^{cd}	152 ± 2.24^{f}	+	–	–	+	+	+	–	+
NT24	400	2.21 ± 0.1^{cdefg}	213.25 ± 3.44^{b}	+	–	–	+	+	–	+	+
NT25	300	3.91 ± 0.6^{a}	56.25 ± 1.16^{mn}	+	–	–	–	+	+	–	–
NT26	600	2.09 ± 0.2^{cdefgh}	46.75 ± 1.17^{o}	+	+	–	+	–	+	–	+
NT27	600	2.62 ± 0.3^{cd}	64.11 ± 1.13^{kl}	+	+	+	+	+	+	+	+

+ positive test, – negative test, *Sid siderophores, Chase chitinase, Case cellulase, Pecase pectinase, PSI* phosphate solubilization index

Table 2: Growth-promoting traits of the selected bacterial isolates (NT_{15}, NT_{19}, NT_{20}, and NT_{27}) in

the presence of Cr (VI) at 100, 150, and 200 mg/L. Data are the mean of replicates with SE±. Values with different letters are significantly different ($p < 0.05$)

Isolate	[Cr (VI)] (mg/L)	PGP traits							
		PSI	N_2	[IAA] (mg/L)	NH_3	HCN	Case	Chase	Pecase
NT15	Control	3.55 ± 0.5[a]	+	197.63 ± 2.43[a]	+	+	–	+	–
	100	3.04 ± 0.3[a]	+	164.74 ± 1.44[b]	+	–	–	–	–
	150	2.90 ± 0.3[a]	+	142.63 ± 1.42[c]	+	–	–	–	–
	200	–	–	47.11 ± 0.17[d]	+	–	–	–	–
NT19	Control	2.50 ± 0.2[a]	+	89.21 ± 1.16[a]	+	–	+	+	+
	100	2.00 ± 0.1[a]	–	71.58 ± 1.17[b]	+	–	+	–	–
	150	1.78 ± 0.0[a]	–	63.29 ± 0.41[c]	+	–	+	–	–
	200	–	–	31.71 ± 0.11[d]	+	–	+	–	–
NT20	Control	2.05 ± 0.4[a]	+	560 ± 5.65[a]	+	+	+	+	+
	100	1.58 ± 0.2[a]	+	353.50 ± 4.55[b]	+	–	+	–	+
	150	0.71 ± 0.1[a]	+	247.36 ± 2.51[c]	+	–	+	–	+
	200	–	+	115.44 ± 1.22[d]	+	–	+	–	–
NT27	Control	2.55 ± 0.3[a]	+	66.14 ± 1.17[a]	+	+	+	+	+
	100	1.44 ± 0.3[ab]	+	49.11 ± 1.12[b]	+	+	+	–	+
	150	1.12 ± 0.2[b]	+	35.26 ± 0.43[c]	+	–	+	–	+
	200	0.95 ± 0.1[b]	+	19.40 ± 0.03[d]	+	–	+	–	–

+ positive test, – negative test, *Chase chitinase*, *Case: cellulase*, *Pecase pectinase*, *PSI phosphate* solubilization index

Table 3: Effect of Pseudomonas sp. (NT_{27}) on Cr content (µg/g) and bioaccumulation factor (BAF) of the shoots and roots of alfalfa grown on contaminated soils with Cr (VI). Values with different letters are significantly different ($p < 0.05$)

Treatment	Chromium uptake (µg/g of dry weight)		BAF	
	Roots	Shoots	Roots	Shoots
Control	ND	ND	–	–
Cr (VI)	3.12 ± 0.3[a]	1.49 ± 0.2[a]	0.31 ± 0.1[a]	0.15 ± 0.11[a]
Cr (VI) + NT27	4.65 ± 0.33[b]	1.58 ± 0.1[a]	0.46 ± 0.1[b]	0.16 ± 0.02[a]

Source: https://link.springer.com/article/10.1186/s43141-021-00254-8

Table 1: List of chromium tolerant plant species, their habitats and tolerance mechanisms.

Family	Plant	Habitat	Tolerance Mechanism	References
Aizoaceae	*Mesembryanthemum crystallinum L.*	Large, mat-forming annual with sprawling stems	Phyto-extraction	[141]
Amaranthaceae	*Gomphrena celosoides* Mart.	Perennial herb	Increased proline and antioxidant enzyme activities	[137]
Amaryllidaceae	*Allium griffithianum Boiss*	Perennial herb	Hyper-accumulation	[118]
Apocynaceae	*Calotropis procera* (Aiton) W.T. Aiton	Large shrub or small tree	Increased activities of superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GR)	[138]
Araceae	*Colocasia esculenta (L.)* Schott	Fast growing, herbaceous	High accumulation of Cr(VI)	[116]
	Lemna minor L.	Free floating aquatic plants	Increased anti-oxidant activity, Phyto-extraction	[142]
	Lemna minuta Kunth	Small aquatic floating plant	Increased anti-oxidant activity	[133]
	Pistia stratiotes L	Aquatic plant	Anti-oxidant activity and accumulation	[136]
	Spirodela polyrrhiza (L.) Schleid	Aquatic weed	Hyper-accumulation	[119]
Araliaceae	*Hydrocotyle umbellata L.*	Creeping, aquatic herb	Hyper-accumulation	[120]
Asteraceae	*Cirsium vulgare (Savi)* Ten.	Annual or biennial, herbaceous plant	Hyper-accumulation	[130]
	Dicoma niccolifera Wild	Terrestrial	Hyper-accumulation	[13]
	Gynura pseudochina (L.) DC.		Cr VI reduction	[143]
	Helianthus annuus L.	Annual forb	Hyper-accumulation	[144]
	Parthenium hysterophorus L.	Annual, erect, herbaceous	Hyper-accumulation	[117]
	Vernonia cinerea (L.) Less.	Perennial herb		[127]
Brassicaceae	*Brassicanapus L.*	Annual or biennialherb	Gentle Remediation Options (GROs)	[139]
Callitraceae	*Callitriche cophocarpa* Sendtn	Aquatic macrophyte	Cr VI reduction	[145]
Cannabaceae	*Cannabis sativa L.*	Annual, herbaceous, flowering	Hyper-accumulation	[117,118]
Cannaceae	*Canna indica L.*	Long-lived, perennial herb	Hyper-accumulation	[120]
Commeliniaceae	*Tradescantia pallida* (Rose) D.R.Hunt	Succulent perennial herb	Increased anti-oxidant activity	[146]
Convolvulaceae	*Ipomoea aquatica Forssk.*	Semi-aquatic, tropical plant	Hyper-accumulation	[131]
Euphorbiaceae	*Euphorbia helioscopia L.*	Desert, herbaceous spurge	Hyper-accumulation	[117]
	Rumex dentatus L.			
Fabaceae	*Arachis hypogea L.*	Annual herb	Hyper-accumulation	[114]
	Cassia tora L.	Annual under shrub		[140]

	Medicago sativa L.	Perennial flowering plant	High proline and GST accumulation	[147]
	Medicago truncatula Gaertn.	Small annual legume	Regulating the sulphur transport and metabolism	[14]
	Sesbaniasesban (L.) Merr.	Fast-growing, perennial legume tree	Phyto-stabilizer	[125]
	Vigna unguiculata (L.) Walp.	Annual, herbaceous legume	Hyper-accumulation	[114]
Lamiaceae	*Origanum vulgare L.*	Mediterranean, perennial herb	Hyper-accumulation	[122]
	Salvia moorcroftiana Wall.ex Benth.	White-woolly perennial herb	Biosorptive detoxification	[135]
Plantaginaceae	*Callitriche cophocarpa* Sendtn	Water-submerged, macrophyte	Hyper-accumulation	[128]
	Arundo donax L.	Tall perennial cane	Hyper-accumulation	[126]
	Brachiaria mutica (Forssk.) Stapf	Evergreen, perennial grass	Phyto-stabilizer	[125]
	Chrysopogon zizanioides (L.) Roberty	Perennial, bunch-grass	Hyper-accumulation	[121]
	Diectomis fastigiata (Sw.) P. Beauv	Tropical grass		[127]
	Triploid hybrid Napier grass (diploid Pennisetum americanus *L. X tetraploid* elephant grass *Pennisetum purpureum* Schumach)	Waste lands, roadside, tropical grass	Iron-biochar nano-complex & hyperaccumulator	[123]
Poaceae	*Leersia hexandra* Sw.	Aquatic perennial grass	Iron-biochar nano-complex & hyperaccumulator	[134]
	Miscanthus sinensis Andersson (1855)	Herbaceous perennial plant	Hyper-accumulation	[97]
	Oryza sativa L.	Flooded, arable land	Hyper-accumulation	[18]
	Phragmites australis (Cav.)Trin. ex Steud.	Perennial grass	Cr III precipitation	[148]
			Cr VI reduction	[144]
	Phragmites communis (Trin.)	Wetland grass	Producing indole acetic acid, siderophores etc.	[15]
	Spartina argentinensis (Trin.) Merr.	Perennial grass	Hyper-accumulation	[66]
	Vetiveria zizanoides (L.) Roberty			[115]
Pontederiaceae	*Eichhornia crassipes* Mart.	Aquatic, flowering plant	Hyper-accumulation	[129]
		Aquatic plant	Anti-oxidant activity and accumulation	[136]
		Free floating, perennial aquatic plant	Increased anti-oxidant activity	[149]
Pteridaceae	*Pteris vittata L.*	Fern species	Hyper-accumulation	[150]
Rubiaceae	*Genipa americana L.*	Wood plant	Hyper-accumulation	[151]
Salviniaceae	*Salvinia minima* Baker 1886	Aquatic macrophyte	Increased anti-oxidant activity	[152]
Solanaceae	*Solanum viarum Dunal*	Perennial shrub	Hyper-accumulation	[124]

Source: https://www.mdpi.com/2071-1050/13/9/4629

Pennisetum sinese: A Potential Phytoremediation Plant for Chromium Deletion from Soil (2020)

Table 1: Growth traits of *P. sinese* cultured in pots at maturity in the second year after planting.

Traits	**Range**	**Average**
Height (cm)	198.7–372.8	335.7
Length of internode (cm)	6.4–14.3	10.7
Effective tillers	3–8	5.8
Leaf length (cm)	33.5–85.6	56.7
Maximum stem circumference (cm)	1.9–2.9	2.5
Root/shoot ratio	0.31–0.64	0.51
Biomass of aerial part (kg/pot FW)	/	1.68
Theoretical yield (t/hm^2 FW)	/	168

Effects of Cr on P. sinese Growth

Source: https://www.mdpi.com/2071-1050/12/9/3651

Table 1: Chromium-induced seed germination inhibition in various plant species.

Plant Species	Common Name	Chromium Concentration	Medium	Time of Exposure (Days)	Seed Germination (%)
Avena sativa	Oat	500 mg/kg Cr(VI)	Soil	7	≈82
		2000 mg/kg Cr(III)			≈95
Beta vulgaris	Swiss chard	50 µM Cr(III)	Distilled water	12	71
Brassica juncea	Mustard	300 µM Cr(VI)	1/2-strength Hoagland	3	80.8
Brassica oleracea	Cabbage	300mg/kg Cr(VI)	Distilled water	3	≈65
Cajanus cajan	Pigeon Pea	100 ppm	Distilled water	3	93
CUCUMIS sativus	Cucumber	300 mg/kg Cr(VI)	Distilled water	3	≈96
Glycine MAX	Soybean	200 mg/L Cr(VI)	Hydroponic	-	72.6
Lactuca sativa	Lettuce	300 mg/kg Cr(VI)	Distilled water	3	≈50
Lactuca sativa	Lettuce	50 µM Cr(III)	Distilled water	12	94
Oryza sativa	Rice	100 µM Cr(VI)	Distilled water	4	≈50
SorGHUM bicolor	Sorghum	500 mg/kg Cr(VI)	Soil	7	≈60
		2000 mg kg Cr(III)			≈10
Spinacia oleracea	Spinach	50 µM Cr(III)	Distilled water	15	64
TRITICUM AESTIVUM	Wheat	100 ppm			63
		300 mg/kg Cr(VI)	Distilled water	0.17	≈90
		500 mg/kg Cr(VI)	Distilled water	3	≈70
		2000 mg/kg Cr(III)	Soil	7	≈25
Zea MAYS	Corn	300 mg/kg Cr(VI)	Distilled water	3	≈99

Table 2: Chromium-induced reduction in root growth as compared to control of various plant species.

Plant Species	Common Name	Chromium Concentration	Medium	Time of Exposure (Days)	Root Growth (%)
Arabidopsis thaliana	Arabidopsis	200 µM Cr(VI)	1/2 MS	1	92.8
Avena sativa	Oat	500 mg/kg Cr(VI)	Soil	7	≈40
		2000 mg/kg Cr(III)			≈55
Brassica CAMPESTRIS	Cabbage	1 mg/L Cr(VI)	1/2-strength Hoagland	21	≈35 FW
Brassica juncea	Mustard	300 µM Cr(VI)	1/2-strength Hoagland	15	43.7
Brassica napus	Oilseed Rape	400 µM Cr(VI)	Hoagland's	6	≈50
Brassica oleracea	Cabbage	300 mg/kg Cr(VI)	Distilled water	3	≈25
Cajanus cajan	Pigeon Pea	100 ppm	Distilled water	10	32
CUCUMIS sativus	Cucumber	300 mg/kg Cr(VI)	Distilled water	3	≈15
Lactuca sativa	Lettuce	300 mg/kg Cr(VI)	Distilled water	3	<10
Oryza sativa	Rice	80 µM Cr(VI)	1/4 -strength Kimura B	7	78
SorGHUM bicolor	Sorghum	500 mg/kg Cr(VI)	Soil	7	≈10
		2000 mg/kg Cr(III)			≈30
		500 µM Cr(VI)		-	≈57
		10 mg/kg Cr(VI)	Sand	7	≈20
		300 mg/kg Cr(VI)	Quartz sand	3	< 10
Triticum aestivum	Wheat	500 mg/kg Cr(VI)	Distilled water	7	≈10
		2000 mg/kg Cr(III)	Soil		≈45
Zea mays	Corn	300 mg/kg Cr(VI)	Distilled water	3	≈43%
		173 µM Cr(VI)	Hydroponic	7	≈70%

Table 3: Chromium-reduced shoot growth as compared to control in various plant species.

Plant Species	Common Name	Chromium Concentration	Medium	Time of Exposure (Days)	Shoot Growth (%)
Arabidopsis thaliana	Arabidopsis	800 μM Cr(VI)	1/2-strength MS	2	≈50 FW
Avena sativa	Oat	500 mg/kg Cr(VI)	Soil	7	Reduced
		2000 mg/kg Cr(III)			
Brassica CAMPESTRIS	Cabbage	1 mg/L Cr(VI)	1/2-strength Hoagland	21	≈70 FW
Brassica juncea	Mustard	300 μM Cr(VI)	1/2-strength Hoagland	15	89.1
Brassica napus	Oilseed Rape	400 μM Cr(VI)	Hoagland	6	58–67
Cajanus cajan	Pigeon Pea	100 ppm	Distilled water	10	Reduced
HORDEUM vulgare	Barley	100 μM Cr(VI)	Nutrient solution	50	≈7–20 DW
Oryza sativa	Rice	80 μM Cr(VI)	Hydroponic	7	77
PARTHENIUM hysterophorus SOLANUM NIGRUM	Santa Maria BlackNightshade	500 μM Cr(VI)	Soil	21	43 FW
					65 DW
					110 FW
SorGHUM bicolor	Sorghum	500 mg/kg Cr(VI)	Soil	7	115 DW
		2000 mg kg Cr(III)			Reduced
TRITICUM AESTIVUM	Wheat	500 μM Cr(VI)	Sand	7	≈80%
		10 mg/kg Cr(VI)	Quartz sand		≈80%
Zea MAYS	Corn	173 μM Cr(VI)	Hydroponic	7	≈80%

Table 4: Chromium-altered leaf morphology and growth as compared to control in various plant species.

Plant Species	Common Name	Chromium Concentration	Medium	Time of Exposure (Days)	Induced Changes in Leaf Growth and Morphology
Arabidopsis thaliana	Arabidopsis	800 μM Cr(VI)	1/2-strength MS	2	Reduced: growth, water content (RWC), chlorophyll (chl), cell and tissue viability
Brassica juncea	Mustard	300 μM Cr(VI)	Semi-hydroponic medium	5	Reduced: growth, RWC, and chl content
Brassica napus	Oilseed Rape	400 μM Cr(VI)	Hoagland	6	61–71% Reduced biomass
HORDEUM vulgare	Barley	100 μM Cr(VI)	Nutrient solution	50	≈62–67% Reduced DW
Oryza sativa	Rice	80 μM Cr(VI)	Hydroponic	7	Chlorosis
Zea MAYS	Corn	173 μM Cr(VI)	Hydroponic	7	Reduced leaf number

Table 5: Chromium-meditated reduction in the total plant biomass as compared to control in various plant species.

Plant Species	Common Name	Chromium Concentration	Medium	Time of Exposure (Days)	Total Biomass Production (%)
Amaranthus viridis* and *Amaranthus cruentus	Green and Blood Amaranth	50 µM	1/2-strength Hoagland	7	>50 FW ≈80 FW
Arabidopsis thaliana	Arabidopsis	800 µM Cr(VI)	1/2-strength MS	2	50 FW 75 DW
Brassica juncea	Mustard	300 µM Cr(VI	Semi-hydroponic medium	5	80–89 growth
Brassica juncea	Mustard	100 µM Cr(VI)	Soil	20	>50 FW and DW
Brassica napus	Oilseed Rape	400 µM Cr(VI)	Hoagland	6	67 DW
Brassica napus	Rapeseed	500 µM Cr	Soil	56	30.6 FW 28 DW
Citrus reticulata	Kinnow Mandarin	750 µM Cr(VI)	Soil	120	63 DW
Cyperus alternifolius* and *Coix lacryma-jobi	Umbrella Palm and Adlay Millet	40 mg/L Cr(VI)	Soil	120	77 DW 44 DW
Hordeum vulgare	Barley	100 µM Cr(VI)	Quartz sand	60	≈23.7DW
Lemna minor	Duckweed	500 µM Cr(VI)	SIS growth medium	7	60
Oryza sativa	Rice	80 µM Cr(VI)	Hydroponic	7	58
Parthenium hysterophorus Solanum nigrum	Santa Maria Black Nightshade	500 µM Cr(VI)	Soil	21	65.5 FW 64.DW 110 FW 106 DW
Solanum melongena	Eggplant	25 µM Cr(VI)	1/2-strength Hoagland	7	87 FW 83 DW
Triticum aestivum	Wheat	500 µM Cr(VI)	Sand Quartz sand	7	≈65%
Zea mays	Corn	173 µM Cr(VI)	Hydroponic	7	≈85 FW

Table 6: Chromium-induced alteration in the uptake and translocation of the essential nutrients in various plant species.

Plant Species	Common Name	Nutrients	Alteration in Uptake/Translocation
Brassica juncea	Brown Mustard	Na, K, Ca, Mg, C, H, and N	Reduced both
Cocos mucifera	Coconut Palm	Fe, K, Cu, Zn, Mn, and Mg	Uptake
Hordeum vulgare	Barley	P, K, Mg, S, Fe, Zn, Mn, and Ca	Uptake and Translocation
Lactuca sativa	Lettuce	K, Mg, Fe, and Zn	Uptake/translocation
Oryza sativa	Rice	N, P, K, Ca, Mg, Mn, Zn, Fe, and Cu	Uptake/translocation
Pisum sativum	Pea	Decreased micro and macronutrients (except S)	Uptake/translocation
Raphanus sativus	Radish	Fe, S, P, Zn, Mn, Cu, and B	Translocation
Solanum lycopersicum* and *Solanum melongena	Tomato and Eggplant	Affected N, P and K content	Translocation

Source: https://pubmed.ncbi.nlm.nih.gov/32365493/

Comparative growth analysis of okra (*Abelmoschus esculentus*) in the presence of PGPR and press mud in chromium contaminated soil (2020)

Table: 1: Effect of plant growth promoting rhizobacteria alone and in combination with press mud on shoot and fruit attributes of okra in Cr contaminated soil.

Treatments	Shoot attributes			Fruit attributes	
	SL (cm)	SFW (g)	SDW(g)	FFW (g)	FDW (g)
Control	34.23 ± 0.60 fg	27.05 ± 1.15b-d	4.68 ± 0.11b-d	43.23 ± 1.16de	14.41 ± 0.20de
Cr (20 mg kg-1)	27.476 ± 0.78h	14.00 ± 0.82f	1.91 ± 0.07 f	25.77 ± 3.45g	8.38 ± 0.21g
Str-1	48.89 ± 1.06bc	34.26 ± 0.75b	6.56 ± 0.17b	54.74 ± 1.35bc	19.44 ± 0.74bc
Str-2	46.73 ± 0.58cd	30.37 ± 1.78bc	5.37 ± 0.38bc	57.67 ± 0.68b	18.54 ± 0.68b
PrM@2%	44.55 ± 0.34c-e	33.86 ± 0.91b	5.93 ± 0.10b	47.73 ± 1.09cd	16.15 ± 0.29cd
Str-1+PrM@2%	62.44 ± 0.73a	54.75 ± 1.54a	11.52 ± 0.86a	97.37 ± 0.76a	32.72 ± 0.28a
Str-2+ PrM@2%	54.93 ± 1.77b	49.25 ± 0.68a	10 ± 0.07a	101.63 ± 2.42 a	27.76 ± 0.88a
Str-1 + Cr (20 mg kg-1)	31.07 ± 1.74gh	21.74 ± 1.25d-f	2.46 ± 0.05d-f	36.18 ± 1.45ef	12.18 ± 0.58ef
Str-2 + Cr (20 mg kg-1)	28.67 ± 1.20gh	18.67 ± 2.68ef	2.07 ± 0.14ef	33.37 ± 1.16 fg	11.41 ± 0.47 fg
Str-1 + PrM@2% + Cr (20 mg kg-1)	40.67 ± 1.09de	24.8 ± 1.87c-e	4.4 ± 0.19c-e	49.26 ± 1.09cd	16.84 ± 1.03b-d
Str-2 + PrM@2% + Cr (20 mg kg-1)	39.33 ± 1.83ef	22.24 ± 1.19c-e	4 ± 0.07c-e	51.18 ± 0.71bc	17.92 ± 1.47b-d
PrM@2% + Cr (20 mg kg-1)	28.67 ± 1.46gh	20.89 ± 1.01d-f	2.26 ± 0.08 d-f	38.78 ± 0.55ef	13.5 ± 1.04ef

Treatment-Means apportioning same letter (s) do not differ significantly at $p \leq 0.5$.

Table: 2: Effect of plant growth promoting rhizobacteria alone and in combination with press mud on root attributes of okra in Cr contaminated soil.

Treatments	Root attributes		
	Root length (cm)	Root fresh weigh(g)	Root dry weigh (g)
Control	17.66 ± 0.34de	7.67 ± 1.19 b-d	3.06 ± 0.48b-d
Cr (20 mg kg-1)	11 ± 0.58f	4.20 ± 1.01d	1.68 ± 0.41d
Str-1	24.33 ± 0.60 c	11.02 ± 1.56b	4.40 ± 0.62b
Str-2	21.43 ± 0.31cd	9.86 ± 1.32bc	3.94 ± 0.53bc
PrM@2%	20 ± 1.00cd	9.26 ± 1.84bc	3.70 ± 0.73bc
Str-1+ PrM@2%	35 ± 1.15 a	18.34 ± 0.39a	7.33 ± 0.16a
Str-2+ PrM@2%	29.33 ± 2.03 b	17.96 ± 0.26a	7.18 ± 0.10a
Str-1 + Cr (20 mg kg-1)	14.66 ± 0.88ef	6.92 ± 0.10b-d	2.77 ± 0.04b-d
Str-2 + Cr (20 mg kg-1)	13.18 ± 0.74ef	6.19 ± 0.25cd	2.47 ± 0.10cd
Str-1 + PrM@2% + Cr (20 mg kg-1)	17.83 ± 0.60de	7.82 ± 0.43b-d	3.19 ± 0.18 b-d
Str-2 + PrM@2% + Cr (20 mg kg-1)	17.43 ± 0.44de	7.53 ± 0.23b-d	3.09 ± 0.09b-d
PrM@2% + Cr (20 mg kg-1)	13.83 ± 0.44ef	5.53 ± 0.08cd	2.21 ± 0.04cd

Treatment-Means apportioning same letter (s) do not differ significantly at $p \leq 0.5$.

Table 3: Effect of plant growth promoting rhizobacteria alone and in combination with press mud on physiological parameters of okra in Cr contaminated soil.

Treatments	Physiological attributes		
	Photosynthesis rate (µmol m^{-2} s^{-1})	**Transpiration rate (mmol H_2O m^{-2} s^{-1})**	**WUE (mmol CO_2 mol^{-1} H_2O)**
Control	11.83 ± 0.67 d-f	5.37 ± 0.24 b-d	2.05 ± 0.04 b-d
Cr (20 mg kg-1)	8.16 ± 0.60 h	3.74 ± 0.47 d	1.44 ± 0.03 d
Str-1	14.16 ± 0.33 cd	6.37 ± 0.48 b	2.63 ± 0.04 b
Str-2	15.1 ± 0.80 c	6.09 ± 0.40 bc	2.36 ± 0.03 bc
PrM@2%	13.6 ± 0.31 cd	5.67 ± 0.44 b-d	2.26 ± 0.32 b-d
Str-1+PrM(2%)	19.03 ± 0.23 b	9.99 ± 0.01 a	4.29 ± 0.10 a
Str-2+PrM(2%)	22.16 ± 0.57 a	8.88 ± 0.20 a	4.09 ± 0.14 a
Str-1 + Cr (20 mg kg-1)	9.2 ± 0.47 f-h	4.48 ± 0.61 b-d	1.68 ± 0.01 cd
Str-2 + Cr (20 mg kg-1)	10.36 ± 0.32 e-h	4.33 ± 0.62 cd	1.57 ± 0.10 cd
Str-1 + PrM@2% + Cr (20 mg kg-1)	11.53 ± 0.52 d-g	5.45 ± 0.23 b-d	2.2 ± 0.06 b-d
Str-2 + PrM@2% + Cr (20 mg kg-1)	12 ± 0.78 de	5.13 ± 0.15 b-d	2.01 ± 0.46 b-d
PrM@2% + Cr (20 mg kg-1)	8.86 ± 0.59 gh	4.10 ± 0.12 d	1.56 ± 0.19 cd

Treatment-Means apportioning same letter (s) do not differ significantly at $p \leq 0.5$.

Source: https://www.sciencedirect.com/science/article/pii/S0045653520320609

Citric Acid Assisted Phytoremediation of Chromium through Sunflower Plants Irrigated with Tannery Wastewater (2020)

Table 1: The physicochemical characteristics of the soil used in the pot study.

Texture	Sandy Loam
Silt	15.0%
Sand	67.9%
Clay	17.10%
EC	1.96 dS m^{-1}
pH	7.61
SAR	1.89 (mmol $L^{-1})^{1/2}$
Available P	2.11 mg kg^{-1}
Organic matter	0.59 %
HCO_3^{-1}	2.51 mmol L^{-1}
SO_4^{-2}	11.44 mmol L^{-1}
Cl^-	5.45 mmol L^{-1}
Ca^{2+} + Mg^{2+}	13.98 mmol L^{-1}
K^+	0.04 mmol L^{-1}
Na^+	5.23 mmol L^{-1}
Available Zn^{2+}	0.77 mg kg^{-1}
Available Cu^{2+}	0.31 mg kg^{-1}
Available Cr	0.16 mg kg^{-1}

The EC stands for electrical conductivity and SAR stands for sodium adsorption ratio.

Table 2: Characteristics of tannery wastewater used for irrigation.

Parameters	Values
COD	2897 mg L^{-1}
BOD	876 mg L^{-1}
TOC	969 mg L^{-1}
Oil & grease	11 mg L^{-1}
pH	4.13
EC	91.8 dS/m
TDS	64,968
Total Cr	329 mg L^{-1}
K^+	41 mg L^{-1}
Carbonate	ND
Ca^{2+}+Mg^{2+}	3.1 $mmol_c$ L^{-1}

COD stands for chemical oxygen demand, BOD stands for biological oxygen demand, TOC stands for total organic compounds, EC stands for electrical conductivity, TDS stands for total dissolved solids, and ND stands for not detected.

Source: https://www.mdpi.com/2223-7747/9/3/380

Amelioration effect of chromium-tolerant bacteria on growth, physiological properties and chromium mobilization in chickpea (*Cicer arietinum*) under chromium stress (2020)

Table 1: Identification Cr tolerance bacteria based on the 16S rRNA gene sequencing and their closest sequence similarity in NCBI, GenBank

Strain name	Name of Identified Bacteria	NCBI accession number	Most closely related species (sequence similarity, %)	Length (bp) of 16S rRNA
S2VWR5	*Bacillus subtilis*	KT254653	*Bacillus subtilis* strain AMUBS-1 (99)	758
S1VKR11	*Stenotrophomonas maltophilia*	KT355715	*Stenotrophomonas maltophilia* strain AK2 (99)	1417
S3VKR16	*Stenotrophomonas maltophilia*	KT355717	*Stenotrophomonas maltophilia* strain AK2 (99)	1416
S3VKR17	*Bacillus cereus*	KT254652	*Bacillus cereus* strain PPB11 (99)	686
S3VKR2	*Bacillus thuringiensis*	KT254642	*Bacillus thuringiensis* strain YWC2-8 (100%)	1487

Table 2: Plant growth promoting properties of Cr tolerant bacteria

Isolate name	Siderophore	PO_4	K
S1VKR11	_	+	_
S3VKR2	_	+	+
S3VKR16	_	+	_
S3VKR17	+	_	+
S2VWR5	+	+	+

+ positive; – negative

Source: https://link.springer.com/article/10.1007%2Fs00203-019-01801-1

Synergistic use of biochar and acidified manure for improving growth of maize in chromium contaminated soil (2020)

Table 1: Basic soil and biochar properties.

Parameters	Soil parameters	Biochar parameters	Acidified manure
pH	8.2 ± 0.01	6.28 ± 0.04	3.50 ± 0.20
EC (dS m^{-1})	1.36 ± 0.04	1.99 ± 0.10	4.12 ± 2.23
Soil texture	Silty loam	–	–
CEC (cmol kg^{-1})	11.56 ± 0.71	36.5 ± 0.90	15.21 ± 3.6
C (%)		54.81 ± 1.79	69.13 ± 5.1
Total nitrogen (%)	0.054 ± 0.01	1.02 ± 0.07	1.21 ± 0.20
Available phosphorus (g kg^{-1})	4.46 ± 0.13	2.34 ± 0.04	0.86 ± 0.05
Extractable potassium (g kg^{-1})	94 ± 4.36	12.40 ± 0.85	2.10 ± 0.15
Calcium (g kg^{-1})	–	23.3 ± 1.90	6.50 ± 0.95
Magnesium (g kg^{-1})	–	7.34 ± 0.09	4.20 ± 0.25
Sulfur (g kg^{-1})	–	3.72 ± 0.13	–
Iron (Fe) (mg kg^{-1})	–	83.3 ± 2.59	–
Chromium-III (mg kg^{-1})	40.45 ± 1.90	–	–
Chromium VI (mg kg^{-1})	12.02 ± 1.02	–	–
Total chromium	55.47 ± 2.81 (mg kg^{-1})	0.05 ± 0.01 (μg kg^{-1})	–

Table 2: Treatment plan for pot experiment.

CK	Control
B1	1.5% biochar
B2	3% biochar
AML	5% (w/w) acidified farm yard manure (FYM) (slurry)
B1 + AML	1.5% biochar + 5% (w/w) acidified FYM (slurry)
B2 + AML	3% biochar + 5% (w/w) acidified FYM (slurry)
AMS	5% (w/w) acidified manure (solid)
B1 + AMS	1.5% biochar + 5% (w/w acidified FYM (solid)
B2 + AMS	3% biochar + 5% (w/w) acidified FYM (solid)

Table 3: Biochar and acidified manure effect on agronomic parameters.

Treatments	Plant height (cm)	Root length (cm)	Shoot dry weight (g)	Root dry weight (g)
CK	28 ± 2.05 e	8.6 ± 0.9 e	5 ± 0.26 f	1.1 ± 0.01 e
B1	38 ± 1.87 cd	19 ± 0.8 cd	6 ± 0.16 de	2.1 ± 0.13 cd
B2	48 ± 2.27 ab	25 ± 2.3 ab	7 ± 0.12 abc	2.7 ± 0.08 ab
AML	32 ± 3.17 de	17 ± 0.8 d	6 ± 0.15 e	1.9 ± 0.08 d
B1 + AML	43 ± 3.06 bc	22 ± 0.8 bc	7 ± 0.08 cd	2.4 ± 0.13 bc
B2 + AML	51 ± 1.31 ab	27 ± 1.9 a	8 ± 0.16 ab	2.8 ± 0.13 a
AMS	34 ± 2.72 de	21 ± 1.3 cd	6 ± 0.09 de	2.0 ± 0.07 d
B1 + AMS	44 ± 1.87 bc	28 ± 1.3 a	7 ± 0.22 bc	2.4 ± 0.06 bc
B2 + AMS	54 ± 1.12 a	29 ± 1.9 a	8 ± 0.10 a	2.9 ± 0.04 a

CK: Control; B1: 1.5% biochar; B2: 3% biochar; AML: 5% (w/w) acidified manure-slurry; AMS: 5% (w/w) acidified farm yard manure-solid. Column showed mean of three repeats and bars showed standard error ($p \leq 0.05$).

Table 4: Biochar and acidified manure effect on physiological parameters.

Treatments	RWC	EL	Photo. R	TR	SC	WUE	Chlorophyll contents
CK	66 ± 3.20 c	11 ± 0.65 a	10.7 ± 1.59 c	2 ± 0.25 e	143 ± 6.98 e	1.63 ± 0.31 f	28 ± 2.2 e
B1	70 ± 0.72 bc	10 ± 0.30 ab	11.9 ± 1.28 bc	3 ± 0.60 cde	166 ± 7.02 de	2.80 ± 0.36 de	38 ± 2.9 cd
B2	76 ± 3.47 ab	6 ± 0.42 cd	13.5 ± 1.73 bc	4 ± 0.65 bc	199 ± 10.57 bc	3.63 ± 0.35 cd	46 ± 2.2 ab
AML	68 ± 1.74 c	10 ± 0.20 a	11.9 ± 1.31 bc	2 ± 0.25 de	149 ± 7.79 e	2.40 ± 0.26 ef	35 ± 2.6 d
B1 + AML	71 ± 0.95 bc	8 ± 0.95 b	12.3 ± 1.21 bc	3 ± 0.17 bcd	178 ± 9.75 cd	3.17 ± 0.15 cde	39 ± 2.40 cd
B2 + AML	76 ± 2.69 ab	6 ± 0.42 cd	14.7 ± 1.35 b	4 ± 0.60 abc	210 ± 9.63 ab	3.97 ± 0.42 bc	47 ± 2.24 ab
AMS	68 ± 1.64 c	10 ± 0.35 a	13.4 ± 0.81 bc	3 ± 0.45 bcd	159 ± 8.76 de	3.37 ± 0.45 cd	37 ± 2.25 cd
B1 + AMS	71 ± 2.73 bc	7 ± 0.51 c	19.1 ± 0.82 a	5 ± 0.40 ab	208 ± 7.28 ab	4.60 ± 0.40 ab	42 ± 2.29 bc
B2 + AMS	79 ± 0.91 a	5 ± 0.25 d	20.4 ± 0.90 a	5 ± 0.35a	225 ± 5.31 a	4.97 ± 0.15 a	51 ± 1.50 a

CK: Control; B1: 1.5% biochar; B2: 3% biochar; AML: 5% (w/w) acidified manure-slurry; AMS: 5% (w/w) acidified farm yard manure-solid. RWC: Relative water content; EL: electrolyte leakage; TR: transpiration rate; SC: stomatal conductance; WUE: water use efficiency. Column showed mean of three repeats and bars showed standard error ($p \leq 0.05$).

Table 5: Biochar and acidified manure effect on anti-enzyme activities.

Treatments	SOD	POD	CAT	APX
CK	176 ± 2.85 a	200 ± 5.26 a	10 ± 1.06 a	17.2 ± 1.95 a
B1	131 ± 7.79 cd	157 ± 7.59 c	9 ± 0.46 ab	14.6 ± 0.72 abc
B2	124 ± 6.62 de	110 ± 4.90 d	8 ± 0.75 ab	10.6 ± 1.67 de
AML	165 ± 5.11 ab	184 ± 6.76 ab	10 ± 0.42 a	16.7 ± 0.49 ab
B1 + AML	146 ± 10.35 bc	149 ± 7.10 c	9 ± 0.36 ab	13.9 ± 0.25 bc
B2 + AML	119 ± 8.60 def	108 ± 3.90 d	8 ± 0.70 b	9.6 ± 0.79 ef
AMS	159 ± 8.82 ab	176 ± 7.55 b	8 ± 0.20 b	13.2 ± 0.75 cd
B1 + AMS	103 ± 2.72 f	113 ± 8.89 d	8 ± 0.21 b	8.1 ± 0.35 ef
B2 + AMS	104 ± 6.49 ef	99 ± 2.79 d	8 ± 0.38 b	7.6 ± 0.38 f

CK: Control; B1: 1.5% biochar; B2: 3% biochar; AML: 5% (w/w) acidified manure-slurry; AMS: 5% (w/w) acidified farm yard manure-solid. SOD: Superoxide dismutase; POD: peroxidase dismutase; CAT: catalase activity assay; APX: ascorbate peroxidase activity. Column showed mean of three repeats and bars showed standard error ($p \leq 0.05$).

Source: https://www.tandfonline.com/doi/full/10.1080/15226514.2019.1644286

Assisted phytoremediation of chromium spiked soils by *Sesbania Sesban* in association with *Bacillus xiamenensis* PM14: A biochemical analysis (2020)

Table 1: Basic properties of soil.

Properties of soil	Value
Soil texture	Loamy
Soil pH	7.1
Soil EC (dsm^{-1})	0.3
Organic matter (%)	0.7
Phosphorus (ppm)	4.3
Potassium (ppm)	110
Nitrate-nitrogen (ppm)	0.02
Extractable Cr (ppm)	0.5

Table 2: Effects of plant growth promoting bacteria PM14 on Growth parameters of *S. sesban* in Cr polluted soil.

Cr	Treatment	Root length	Shoot Length	Fresh wt	Dry wt
(mg kg^{-1})		**(Cm)**	**(Cm)**	**(g)**	**(g)**
0	Uninoculated	3.33 ± 0.10a	15 ± 0.24c	17.03 ± 0.23c	3.5 ± 0.17b
	PM14	3.5 ± 0.09a	17.40 ± 0.05a	21.06 ± 0.18a	4.33 ± 0.12a
50	Uninoculated	2.66 ± 0.03bc	13.06 ± 0.31e	15.06 ± 0.14e	3.2 ± 0.12bc
	PM14	3.46 ± 0.14a	16.06 ± 0.07b	18.03 ± 0.12b	3.56 ± 0.20b
100	Uninoculated	2.03 ± 0.14d	12.53 ± 0.07e	12.06 ± 0.31f	2.95 ± 0.01c
	PM14	3.2 ± 0.08 ab	15 ± 0.24c	17.03 ± 0.07c	3.43 ± 0.04b
200	Uninoculated	1.99 ± 0.01d	10.03 ± 0.12f	10.5 ± 0.19g	2.5 ± 0.07d
	PM14	2.4 ± 0.36cd	14 ± 0.09d	16 ± 0.33d	3 ± 0.05c

Uninoculated: non-inoculated control, PM14: *B. xiamenensis* PM14.

Table 3: Effects of plant growth promoting bacteria PM14 on the photosynthetic pigments of S. sesban in Cr polluted soil.

Cr	Treatment	Chlorophyll *a*	Chlorophyll *a*	Carotenoids
(mg kg^{-1})		**(μg^{-1} ml)**	**(μg^{-1} ml)**	**(μg^{-1} ml)**
0	Uninoculated	2.28 ± 0.02b	0.32 ± 0.04 ab	10.46 ± 0.21b
	PM14	3.15 ± 0.34a	0.55 ± 0.32a	12.40 ± 1.21a
50	Uninoculated	1.45 ± 0.32cde	0.28 ± 0.08 ab	8.39 ± 1.31c
	PM14	2.50 ± 0.17 ab	0.40 ± 0.10 ab	9.91 ± 0.01b
100	Uninoculated	1.35 ± 0.38de	0.27 ± 0.05 ab	7.81 ± 0.12cd
	PM14	2.10 ± 0.09bc	0.33 ± 0.04 ab	8.36 ± 0.38c
200	Uninoculated	0.85 ± 0.70e	0.21 ± 0.08b	6.90 ± 0.03c
	PM14	1.90 ± 0.09dbcd	0.26 ± 0.10 ab	8.12 ± 0.46cd

Uninoculated: non-inoculated control, PM14: *B. xiamenensis* PM14.

Source: https://www.sciencedirect.com/science/article/pii/S0981942819304619

Zinc-lysine Supplementation Mitigates Oxidative Stress in Rapeseed (*Brassica napus* L.) by Preventing Phytotoxicity of Chromium, when irrigated with Tannery Wastewater (2020)

Table 1: Physicochemical properties of loam sand used in the pot experiment.

Texture	Clay Loam
Silt	12.9
Sand	63.4
Clay	22.3
pH (H_2O mixture)	7.1
Electrical conductivity (dS m^{-1})	3.83
Cation exchange capacity (cmol kg^{-1}) 4.9	4.89
Soluble CO_3^{-2} (mmol L^{-1})	0.87
Soluble HCO_3 (mmol L^{-1})	3.78
Soluble Cl^- (mmol L^{-1})	6.31
Soluble Ca^{2+} + Mg^{2+} (mmol L^{-1})	15.89
Organic matter (%)	0.49
Ni (mg kg^{-1})	0.21
Cu (mg kg^{-1})	0.35
Zn (mg kg^{-1})	0.84
Cr (mg kg^{-1})	0.24

Table 2: Characteristics of tannery wastewater used for irrigation of the soil used in the pot experiment.

Parameters	Values	Permissible Limits *
EC (dS m^{-1})	1.41	<1.5
Sodium absorption rate (mmol $L^{-1})^{1/2}$	4.02	<7.5
Residual sodium carbonate (mmol c L^{-1})	2.24	<2.0
Ni (mg L^{-1})	0.09	0.20
Cd (mg L^{-1})	0.04	0.01
Pb (mg L^{-1})	1.24	5.0
Co (mg L^{-1})	0.02	0.05
Cr (mg L^{-1})	4.03	0.10
Zn (mg L^{-1})	1.95	2.00

Table 3: Effect of different levels of tannery wastewater on plant growth and biomass under the same concentrations of Zinc-lysine application in *B. napus*.

Treatments	Plant Height (cm)	Number of Leaves	Leaf Area (cm^2)	Root Length (cm)	Root Fresh Weight (mg)	Root Dry Weight (mg)	Leaf Fresh Weight (mg)	Leaf Dry Weight (mg)
Ck	31 ± 0.6ab	11 ± 1ab	110 ± 7ab	13 ± 0.4cd	4025 ± 55b	837 ± 36b	19,336 ± 740b	2457 ± 50b
T1	34 ± 1.0a	13 ± 1a	126 ± 5a	17 ± 1a	5038 ± 70a	999 ± 46a	23,675 ± 1200a	2658 ± 64a
T2	22 ± 1.6de	6 ± 0.6bc	72 ± 5d	12 ± 0.6de	1661 ± 57d	334 ± 13d	11,991 ± 467d	1573 ± 56d
T3	29 ± 1.2bc	8 ± 0.6b	91 ± 4c	15 ± 0.7ab	2191 ± 64c	470 ± 18c	15,599 ± 561c	1804 ± 50c
T4	17 ± 0.6ef	6 ± 1c	38 ± 3f	10 ± 0.3e	798 ± 37f	198 ± 12e	5005 ± 100f	729 ± 30f
T5	24 ± 1.7cd	8 ± 0.6b	53 ± 3e	14 ± 0.8bc	1179 ± 53e	292 ± 19d	6872 ± 170e	909 ± 30e
T6	10 ± 0.6g	5 ± 0.6c	17 ± 1g	8 ± 0.5f	414 ± 13g	88 ± 6f	3142 ± 70g	433 ± 24g
T7	11 ± 2.8fg	6 ± 0.6bc	19 ± 3g	10 ± 0.6e	505 ± 19g	103 ± 10f	3665 ± 75fg	507 ± 28g

Values are demonstrated as means of three replicates along with standard deviation (SD; n = 3). One-way ANOVA was performed and mean differences were tested by highest significant deviation (HSD) at $p < 0.05$. Different lowercase letters indicate a significant difference between the treatments. Different abbreviations used in the table are as follows: Ck (without irrigation with wastewater + 0 mg/L Zn-lysine), T1 (without irrigation with wastewater + 10 mg/L Zn-lysine), T2 (33% irrigation with wastewater + 0 mg/L Zn-lysine), T3 (33% irrigation with wastewater + 10 mg/L Zn-lysine), T4 (66% irrigation with wastewater + 0 mg/L Zn-lysine), T5 (66% irrigation with wastewater + 10 mg/L Zn-lysine), T6 (100% irrigation with wastewater + 0 mg/L Zn-lysine) and T7 (100% irrigation with wastewater + 10 mg/L Zn-lysine).

Source: https://www.mdpi.com/2223-7747/9/9/1145/htm

Phytoremediation: elimination of hexavalent chromium heavy metal using corn (*Zea mays* L.) (2020)

Table 1: Chemical and physical values of the experiment soil

Parameter	Result	Unit	Evaluation
pH	7.72	-	Slightly alkaline
Salt	0.08	%	Low
Lime	0.70	%	Low
Sand	33.33	%	Clay Loam (CL)
Silt	32.13	%	
Clay	34.53	%	
Organic matter	0.58	%	Insufcient
Available phosphorus (P)	20.42	mg/kg	Medium
Exchangeable potassium (K)	50.98	mg/kg	Little
Exchangeable calcium (Ca)	170.3	mg/kg	Little
Exchangeable magnesium (Mg)	60.1	mg/kg	Sufcient
Available copper (Cu)	0.58	mg/kg	Sufcient
Available iron (Fe)	2.61	mg/kg	Medium
Available manganese (Mn)	5.60	mg/kg	Sufcient
Available zinc (Zn)	3.25	mg/kg	Sufcient
Extractable chromium Cr(VI)	0.80	mg/kg	Non toxic

Source:https://www.researchgate.net/publication/343897871_Phytoremediation_elimination_of_hexavalent_chromium_heavy_metal_using_corn_Zea_mays_L

Mitigation of chromium toxicity in Arabidopsis thaliana by sulfur supplementation(2019)

Table1: Effects of Cr(III) and Cr(VI) on glutathione (GSH), soluble protein (SP), malondialdehyde (MDA), catalase (CAT), superoxide dismutase (SOD) and peroxidase (POD) activities, in the roots of Arabidopsis thaliana.

Treatment	GSH [nmol/gFW]	SP [mg/g]	MDA [nmol g^{-1}FW]	CAT [mmol/g/min FW]	SOD [U g^{-1}FW]	POD [mmol/g/min FW]
CK	42.5±3.54[c]	6.75±0.35[a]	5.30 ± 1.21[d]	0.45 ± 0.05[a]	575.27 ± 35.36[a]	**44.12 ± 4.49[a]**
CK + S	50.0±7.10[c]	7.50±0.71[a]	4.95 ± 1.31[d]	0.46 ± 0.07[a]	595.34 ± 7.07[a]	**45.50 ± 7.78[a]**
Cr(III)	65.0±7.08[b]	5.50 ± 0.70[b]	10.75 ± 3.35[b]	0.37 ± 0.03[b]	365.04 ± 49.50[b]	**33.44 ± 2.12[b]**
Cr(III)+S	95.0±7.09[a]	6.50 ± 0.69[a]	7.85 ± 2.25[c]	0.44 ± 0.01[a]	509.93 ± 42.43[a]	**39.50 ± 4.95[ab]**
Cr(VI)	65.0±7.10[b]	4.50 ± 0.70[c]	23.95 ± 3.45[a]	0.36 ± 0.08[b]	224.76 ± 35.36[c]	**21.11 ± 5.99[c]**
Cr(VI) +S	**85.0±7.09[a]**	**5.50 ± 0.71[b]**	**12.15 ± 3.12[b]**	**0.40 ± 0.07[ab]**	**475.35 ± 35.35[a]**	**37.50 ± 3.54[b]**

All the values are the means of three replicates. Different letters on mean values are statistically different ($P < 0.05$).

Source: https://www.sciencedirect.com/science/article/abs/pii/S0147651319307006

Appraisal of chromium and cobalt contents of vegetables grown in soil irrigated with sewage water: A risk for consumers' health(2019)

Table1: Analysis of variance and mean values of chromium (mg/kg) in soil and vegetables treated with canal and sewage water

	Chromium		
	Mean ± S.E.		Mean Square
	CW	SW	
Soil	0.900±0.198	1.800±0.063	**9.720***
R. sativus	0.303±0.075	0.600±0.227	**0.177***
B. rapa	0.110±0.184	0.216±0.198	**7.375***
Z. officinale	0.241±0.113	0.470±0.227	**42.074****
C. baccatum	0.196±0.063	0.393±0.075	**2.928ns**
C. frutescens	0.144±0.126	0.288±0.126	**39.089****
C. annuum	0.190±0.075	0.378±0.184	**16.892***
S. lycopersicum	0.221±0.198	0.428±0.113	**17.947ns**
C. longa	**0.250±0.184**	**0.525±0.063**	**7.118***

*, **, ***= significant at 0.05, 0.01 and 0.001 levels, ns = non-significant

*Canal water (CW) and sewage water (SW).

The highest value of Cr was observed in Solanum lycopersicum irrigated with SW and the lowest in Brassica rapa irrigated with CW. In all vegetables, the daily intake of metal values for Cr was higher in SW as compared to the CW.

The mean Cr concentration in soil varied from 0.9 to 1.80 mg/kg. Higher Cr values in soil were observed during sewage water irrigation and lower values were found in canal water irrigation.

Source:https://www.researchgate.net/publication/330669207_Appraisal_of_chromium_and_cobalt_contents_of_vegetables_grown_in_soil_irrigated_with_sewage_water_A_risk_for_consumers'_health

Chromium detoxification mechanism induced growth and antioxidant responses in vetiver *(Chrysopogon zizanioides (L.) Roberty)* (2019)

Table1: Effect of Cr stress on growth, tolerance indices (TI), biomass and translocation factor (TF) of Vetiver

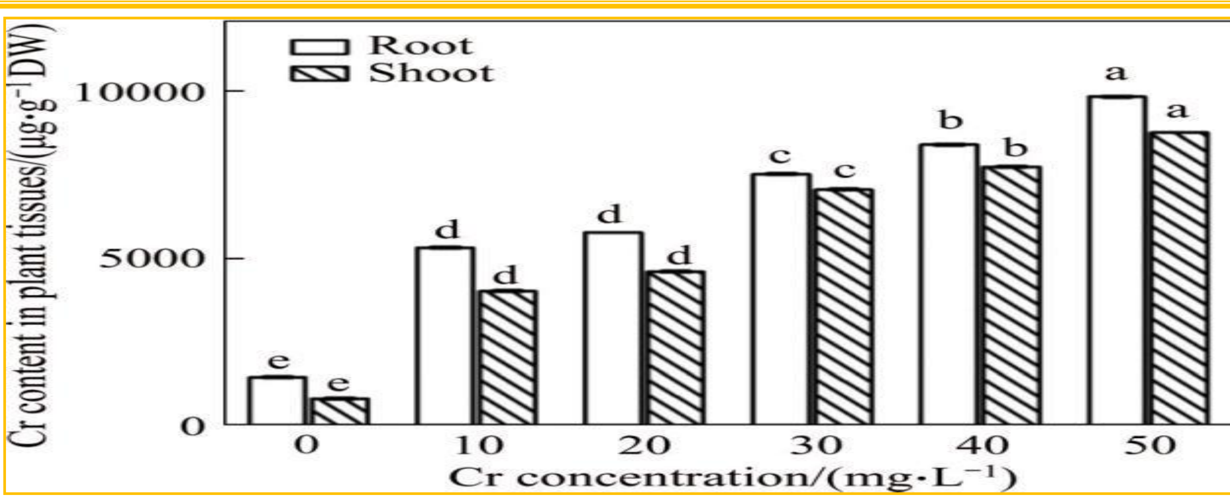
Cr Concentration / (mg.L^{-1})	Shoot length/cm	Root length/cm	IT/%		Biomass/g	TF/%
			Shoot	Root		
0	48.0 ± 0.57^{a}	19.3 ± 0.33^{a}	—	—	4.112 ± 0.00^{a}	—
10	43.3 ± 0.88^{b}	16.3 ± 0.88^{b}	90.2	84.4	4.043 ± 0.02^{a}	**75.6**
20	40.0 ± 0.57^{c}	13.6 ± 0.33^{c}	83.3	70.4	4.020 ± 0.01^{a}	**85.8**
30	36.3 ± 0.88^{d}	13.0 ± 0.57^{c}	75.6	67.3	3.800 ± 0.05^{ab}	**94.0**
40	35.3 ± 0.88^{d}	13.1 ± 0.60^{c}	73.5	67.8	3.641 ± 0.02^{b}	**96.0**
50	**30.3 ± 0.88^{e}**	**10.6 ± 0.88^{d}**	**63.1**	**54.9**	**3.630 ± 0.01^{b}**	**89.0**

Data are means± S.E. (n=3). Different letters on each error bar indicate significant differences at P<0.05.

Shoot and root growth varied significantly depending on the concentration of Cr treatment. After 16 d of exposure, plant growth decreased by 36.8% and 45.0% in shoots and roots, respectively, in the 50 mg/L Cr treatment. Similarly, the root and shoot index of tolerance (IT) values also decreased under Cr-induced stress conditions. However, the decline in root length was more pronounced than that of shoot length under Cr stress. Vetiver plant biomass declined with increasing Cr concentration in the growth medium. The maximum biomass reduction was 12.1% in the 50 mg/L Cr treatment.

Source: https://link.springer.com/content/pdf/10.1007%2Fs11771-019-4021-y.pdf

Chromium accumulation in root and shoot tissues of vetiver grown with its different concentration.(2019)



Root and shoot Cr accumulation was increased gradually with the increase of Cr concentration. The higher level of Cr accumulation was 9808 μg/g DW and 8731 μg/g DW for roots and shoots, respectively, at the 50 mg/L Cr concentration, with Cr accumulation higher in root than in shoot. This result indicated that roots served as a partial barrier against the transport of Cr to the shoot and Cr concentration was largely acquired then stored in vetiver roots.

Source: https://link.springer.com/article/10.1007/s11771-019-4021-y

Toxic effects of chromium on some quality parameters of *Sorghum bicolor (L.)* (2018)

Table1: Effect of Cr (VI) on total chlorophyll and chlorophyll-a and b (mg g^{-1} fresh weight) in leaves of sorghum (*Sorghum bicolor (L.)* plant at different growth stages

Cr (VI) mg kg^{-1} soil						Days			
	35	70	90	35	70	90	35	70	90
		Total chlorophyll			Chlorophyll-a			Chlorophyll-b	
T_1	3.25	4.61	2.90	1.77	2.88	1.45	1.48	1.73	**1.45**
1.0	3.12	5.10	2.91	1.69	2.44	1.41	1.43	2.66	**1.50**
2.0	2.73	4.45	2.32	1.57	2.00	1.26	1.16	2.45	**1.06**
4.0	2.40	4.04	-	1.37	1.98	-	1.03	2.06	**-**
	A	B	A×B	A	B	A×B	A	B	**A×B**
SE (m)	0.09	0. 10	0. 17	0.03	0.03	0.05	0.09	0. 10	**0. 17**
CD at 5%	**0. 26**	**0. 30**	**0.51**	**0.08**	**0. 09**	**0. 16**	**0. 26**	**0. 30**	**0. 51**

Each value is the mean of three determinations. T1= control, *Plants unable to survive with 4.0 mg Cr (VI) kg^{-1} soil at 90 DAS, A = Treatment, B = Stages, A×B = Interaction

Table2: Effect of Cr (VI) on crude protein content (per cent dry weight) in leaves, stem and root of sorghum (*Sorghum bicolor (L.)* plant at different growth stages

Cr (VI) mg kg^{-1} soil					Days a				
	35	70	90	35	70	90	35	70	90
		Leaves			Stem			Root	
T_1	8.96	11.54	10.11	5.69	7.89	4.13	2.35	4.57	**3.32**
1.0	6.16	7.91	6.44	4.46	5.67	4.88	2.07	3.57	**3.35**
2.0	6.03	7.46	6.25	3.88	4.68	3.88	1.87	2.77	**2.46**
4.0	4.67	5.73	-	3.35	3.68	-	1.45	1.88	-
	A	B	A×B	A	B	A×B	A	B	**A×B**
SE (m)	0.03	0.03	0.06	0.03	0.04	0.06	0.03	0.03	**0.05**
CD at 5%	**0.07**	**0.08**	**0.13**	**0.09**	**0.07**	**0.10**	**0.08**	**0.09**	**0.13**

Each value is the mean of three determinations, T1= control, *Plants unable to survive with 4 .0 mg Cr (VI) kg^{-1} soil at 90 DAS, A = Treatment, B = Stages, A×B = Interaction

Table3: Effect of Cr (VI) on in vitro dry matter digestibility (per cent dry weight basis) in leaves and stem of sorghum (*Sorghum bicolor (L.)* plants at different growth stages.

Cr (VI) mg kg^{-1} soil			Days			
	35	70	90	35	70	90
		Leaves			Stem	
T_1	55.60	51.80	48.40	43.60	42.40	**38.60**
1.0	54.4	48.50	46.83	40.20	37.40	**35.50**
2.0	50.40	48.50	46.83	38.40	34.40	**32.40**
4.0	48.80	46.40	-	33.60	31.40	-
	A	B	A×B	A	B	**A×B**
SE (m)	0.07	0.09	0.15	0.08	0.09	**0.16**
CD at 5%	**0.16**	**0.24**	**0.42**	**0.21**	**0.23**	**0.36**

Each value is the mean of three determinations, T1= control, *Plants unable to survive with 4.0 mg Cr (VI) kg^{-1} soil at 90 DAS, A = Treatment, B = Stages, A×B = Interaction

Source: https://pdfs.semanticscholar.org/83b1/d138e7a18c62fc90e2dc688a1dbbe39b44ba.pdf

Interactive effect of cadmium and zinc on chromium uptake in spinach grown in Vertisol of Central India (2018)

Table1: Effect of Cr, Cd and Zn application on respective metal concentration and uptake

Cr levels (mg/kg)	Cr concentration		Cr uptake (mg/pot)		Cd levels (mg/kg)	Cd concentration		Cd uptake (mg/pot)		Zn levels (mg/kg)	Zn concentration		Zn uptake (mg/pot)	
	(lg/g)					(lg/g)					(lg/g)			
	Shoot	Root	Shoot	Root		Shoot	Root	Shoot	Root		Shoot	Root	**Shoot**	**Root**
0	6.24	8.99	0.102	0.009	0	11.47	19.08	0.177	0.019	0	11.89	24.26	**0.164**	**0.019**
50	9.38	32.6	0.029	0.144	1	12.24	27.53	0.180	0.022	10	11.92	30.06	**0.177**	**0.025**
100	18.5	43.9	0.028	0.249	2	13.42	34.95	0.200	0.033	20	13.32	32.34	**0.219**	**0.030**
LSD (5%)	1.67	6.31	0.041	0.072		1.21	4.38	NS	0.012		NS	NS	**NS**	**NS**
SEm±	**0.23**	**1.15**	**0.001**	**0.011**		**0.02**	**1.05**	**–**	**0.002**		–	–	–	–

Mean data of all the treatment combinations

Source: https://link.springer.com/content/pdf/10.1007%2Fs13762-017-1396-x.pdf

Chromium accumulation in maize and cowpea after successive applications of composted tannery sludge (2018)

Table1: Bioaccumulation factor of Cr in different parts of maize and cowpea plant cultivated in soil submitted to consecutive applications of composted tannery sludge

applications of composted tannery sludge.				
CTS (Mg ha^{-1})	Maize			
	Roots	Stems	Leaves	Grains
0	12.26 ± 3.64	0.46 ± 0.26	1.14 ± 0.30	1.08 ± 0.23
2.5	2.98 ± 0.53	0.07 ± 0.03	0.16 ± 0.05	0.08 ± 0.04
5	2.89 ± 0.44	0.05 ± 0.03	0.13 ± 0.04	0.02 ± 0.02
10	1.51 ± 0.42	0.03 ± 0.00	0.06 ± 0.02	< 0.01
20	0.98 ± 0.36	0.01 ± 0.01	0.07 ± 0.02	< 0.01
CTS (Mg ha^{-1})	Cowpea			
	Roots	Pods	Leaves	Grains
0	5.53 ± 1.59	1.02 ± 0.26	2.00 ± 0.70	0.12 ± 0.03
2.5	1.31 ± 0.16	0.17 ± 0.03	0.34 ± 0.04	0.03 ± 0.00
5	0.88 ± 0.29	0.09 ± 0.05	0.23 ± 0.07	0.07 ± 0.01
10	0.60 ± 0.28	0.07 ± 0.05	0.26 ± 0.06	0.07 ± 0.03
20	0.56 ± 0.05	0.03 ± 0.00	0.18 ± 0.04	0.03 ± 0.01

± standard error of the mean (n = 4).

Source: https://sci-hub.tw/10.4025/actasciagron.v40i1.35361

Chromium toxicity and ultrastructural deformation of Cicerarietinum with special reference of root elongation and coleoptile growth (2017)

Table1: Variation of percentage of germination, coleoptile growth and root length with different concentration of Cr 6þ solution.

Concentration of $Cr^{6þ}$ solution	Germination (% of reduction)	Coleoptyl growth (% of reduction)	Root length (% of reduction) 48 h
Control	100^{a}	100^{a}	**100^{a}**
20	$10^{d} \pm 0.010$	$2.27^{e} \pm 0.117$	**$22.48^{e} \pm 0.170$**
40	$13^{c} \pm 0.061$	$4.55^{d} \pm 0.081$	**$25.84^{d} \pm 0.219$**
80	$30^{b} \pm 0.413$	$29,55^{bc} \pm 0.114$	**$47.85^{bc} \pm 0.011$**
100	**$31^{b} \pm 0.011$**	**$31.82^{b} \pm 0.710$**	**$50.72^{b} \pm 0.910$**

Mean ± SD of three replicate. Means followed by the same letter (S) within treatment are not significantly different at 5% using Duncan's multiple range test (DMRT). Means of three replicates are taken. Present results indicate that the growth of coleoptiles is also affected by Cr(VI) solution and abrupt reduction occur at 80 mg/L.

Source: https://www.sciencedirect.com/science/article/pii/S1512188717300404