Iron-modified biochar and water management regime-induced changes in plant growth, enzyme activities, and phytoavailability of arsenic, cadmium and lead in a paddy soil (2021)

Table 1: Selected physicochemical properties of the raw biochar (RawBC) and Femodified biochar (FeBC).

Biochar	**RawBC**	**FeBC**
pH	9.25 ± 0.14	4.41 ± 0.03
C (%)	69.34 ± 1.05	59.91 ± 1.21
H (%)	2.74 ± 0.23	2.24 ± 0.35
N (%)	1.11 ± 0.01	0.94 ± 0.01
Ash content (%)	9.66 ± 0.33	15.34 ± 0.20
CEC[a] (cmol kg^{-1})	21.59 ± 0.56	16.7 ± 0.37
EC[b] (dS m^{-1})	0.37 ± 0.02	4.49 ± 0.04
SA[c] (cmol kg^{-1})	215.9 ± 0.37	183.6 ± 0.38
SSA[d] (m^2 g^{-1})	110.7 ± 2.35	74.5 ± 1.43
Olsen P (mg kg^{-1})	24.47 ± 0.59	1.35 ± 0.16
Total P (g kg^{-1})	1.93 ± 0.06	3.03 ± 0.11
Total Fe (g kg^{-1})	7.59 ± 0.60	54.61 ± 3.16
Total Pb[e] (mg kg^{-1})	6.97 ± 0.56	11.92 ± 0.54

[a] CEC: cation exchange capacity.
[b] EC: electrical conductivity.
[c] SA: surface alkalinity.
[d] SSA: specific surface area.
[e] Concentration of As and Cd was below the detection limit.

Source: https://doi.org/10.1016/j.jhazmat.2020.124344

Lead Toxicity in Cereals: Mechanistic Insight Into Toxicity, Mode of Action, and Management (2021)

Table 1: Lead production and reserves.

Country	Production (1,000 m^3 ton)	Reserves	Country	Production (1,000 m^3 ton)	Reserves
USA	400	7,000	Peru	280	6,000
Australia	620	27,000	Poland	35	1,500
Bolivia	90	1,600	Russia	90	9,200
Canada	65	650	South Africa	50	300
China	1,600	13,000	Sweden	65	1,100
India	95	2,600	Other	330	4,000
Ireland	45	600	Total	4,100	80,000
Mexico	185	5,600			

Source: Geological Society of America (http://geology.com/usgs/lead/).

Table 2: Contribution of cereals in energy consumed by humans.

Consumption or energy	World	Asia	Africa	South America	North America	Europe	Oceania
g capita^{-1} day^{-1}	403	426	414	318	293	362	249
kcal capita^{-1} day^{-1}	1,292	1,422	1,284	967	812	1,007	764

Source: FAO. Food Consumption Database (FAO, 2013).

Table 3: Lead induced phytotoxic effects on the morphological and physiological attributes of cereals.

Applied Pb dose	Plant specie	Culture	Exposure hours (h) or days	Alteration in plant parameters	References
250 and 500 mg kg^{-1} $PbNO_3$	Mung bean	Hydroponic	21 days	↓ growth, photosynthetic pigments, protein synthesis, water use efficiency	Arif et al., 2019
100, 200, 300 µM $PbNO_3$	Tartary buckwheat	Hydroponic	15 and 30 days	↓ shoot and root length and biomass, Chlorophyll ↑ proline, soluble sugar, protein content	Pirzadah et al., 2020
418.64 mg kg^{-1} Pb	Rice	Hydroponic	23 days	↑ proline, soluble protein content	Rao et al., 2018
0, 50, and 250 µM	Wheat	Hydroponic		↑ radicle and coleoptile length	Kaur et al., 2015b
228 mg L^{-1}	Rice	Hydroponic	8-16 days	↑ protein carbonylation, nonprotein thiols ↓ protein thiols	Srivastava et al., 2014
4,968 mg L^{-1}	Wheat	Hydroponic	30 days	↓ growth traits, nutrients uptake	Lamhamdi et al., 2011
1,656 mg L^{-1}	Rice	Hydroponic	30 days	↑ phosphorylation of PSII core proteins, proteindegradation	Romanowska et al., 2012
1 mM	Rice	Hydroponic	4-7 days	↓ shoot or root length, biomass, nutrients uptake	Khan et al., 2018

0 and 100 μM	Rice	Hydroponic	7 days	↓ plant height, shoot, and root dry or fresh weights ↓ photosynthetic pigments, gas exchange attributes	Chen et al., 2017
0.5 and 1 mM	Wheat	Hydroponic	7 days	↓ plant growth, biomass, leaf relative water, chlorophylls ↑ proline	Hasanuzzaman et al., 2018
2 mM	Wheat	Hydroponic	63 days	↓ plant growth traits, biomass, leaf relative water, Rubisco activity, ATP sulfurylase, nutrients level, total chlorophyll	Alamri et al., 2018
1.5 mM	Wheat	Hydroponic	5 days	↓ root elongation and coleoptile growth	Turk et al., 2018
0, 1, 25, 50, 100, 200, and 500 mM	Maize	Hydroponic	14 days	↓ early growth, biomass, seed germination, total protein contents, Pb uptake	Hussain et al., 2013
500 mg kg^{-1}	Wheat	Soil	120 days	↓ growth, biomass, Pb uptake, grain yield, chlorophyll, gas exchange parameters	Rehman et al., 2017
0.1 mM	Maize	Hydroponic	4 days	↓ growth rate of coleoptiles segments ↑ membrane hyperpolarization	Kurtyka et al., 2018
0, 200, 400, 800, 1,600, and 3,200 mg kg^{-1}	Sorghum	Soil	21 days	↓ growth, dry matter, photosynthetic rate, transpiration rate, starch, proteins, total soluble sugars	Cândido et al., 2020

Table 4: Lead-induced phytotoxic effects on the oxidative markers and biochemical and metabolic traits of cereals.

Applied Pb dose	**Plant specie**	**Culture**	**Exposure hours (h) or days**	**Alteration in plant parameters**	**References**
0,100, 200, and 300 μM	Tartary buckwheat	Hydroponic	15 and 30 days	↑ H_2O_2, membrane stability index, GSH contents ↑ SOD, POD, CAT, GR, GST activities	Pirzadah et al., 2020
418.64 mg kg^{-1} Pb-contaminated soil	Rice	Hydroponic	23 days	↑ SOD, CAT, APX. Activities ↓ MDA, endogenous Pb contents	Rao et al., 2018
0,10, and 50 μM	Rice	Hydroponic	2 and 4 days	↑ SOD, APX, GR activities, MDA, α-tocopherol content ↓ CAT activity	Thakur et al., 2017
0, 16, 40, and 80 mg L^{-1}	Maize	Hydroponic	8 days	↑ MDA, H_2O_2, $O^{-\cdot}_2$, SOD, APX, GPX, GR activities ↓ CAT activity,	Kaur et al., 2015a
0, 50, and 250 μM	Wheat	Hydroponic	1 days	↑ MDA, H_2O_2, $O^{-\cdot}_2$, conjugated diene, membrane damage ↑ SOD, CAT, APX, GPX, GR activities	Kaur et al., 2015b
0, 16, 40, and 80 mg L^{-1}	Maize	Hydroponic	3, 12, and 24 h	↑ MDA, H_2O_2, thiols, APX, DHAR, MDHAR activities ↓ AsA, GSH contents	Kaur et al., 2015c
0, 50, 100, 250,	Wheat	Hydroponic	4 days	↑ SOD, CAT, MDA	Kaur et al.,

and 500 µM				↓APX, GPX, GR activities	2013
0, 50, 100, and 200 µM	Rice	Hydroponic	16 days	↑ SOD, MDA ↓CAT, POD activities	Li et al., 2020
0, 1, 2, and 4 mM	Wheat	Hydroponic	3 days	↑ SOD, CAT, POD, APX activities, MDA	Yang et al., 2011
0, 0.15, 0.3, 1.5, and 3 mM	Wheat	Hydroponic	6 days	↑ SOD, POD, APX activities, MDA ↓ CAT activities	Lamhamdi et al., 2011
0, 500, 1,000, and 2,500 µM	Wheat	Hydroponic	7 days	↑ SOD, GPX activities, MDA	Kaur et al., 2012
228 mg L^{-1}	Rice	Hydroponic	days	↑ SOD, GPX activities, MDA	Srivastava et al., 2014
0-200 µM	Sedum alfredii	Hydroponic	14 days	↑ SOD activities ↓ APX activities	Gupta et al., 2010
1 mM	Rice	Hydroponic	18 days	↑ SOD, POD activities, MDA, H2O2, OH−, O−2 levels	Khan et al., 2018
0 and 100 µM	Rice	Hydroponic	7 days	↑ SOD, GR, APX activities, AsA, G.S.H., , H_2O_2, $O-_2$ levels	Chen et al., 2017
0.5 and 1 mM	Wheat	Hydroponic	7 days	↑ MDA, , H_2O_2, $O-._2$ methylglyoxallevels, SOD, GST activities ↓AsA-GSH content, CAT, GPX, GR, glyoxalase system enzymes	Hasanuzzaman et al., 2018
2 mM	Wheat	Hydroponic	63 days	↑ MDA, H_2O_2, cysteine levels, SOD, CAT, GR activities	Alamri et al., 2018
1.5 mM	Wheat	Hydroponic	5 days	↓ AsA-GSH content, CAT activity	Turk et al., 2018
0, 200, 400, 800, 1,600, and 3,200 mg kg^{-1}	Sorghum	Soil	21 days	↑ MDA, H_2O_2 content, SOD, GPX, GR, APX. Activities ↑ SOD, CAT, APX activities, MDA, H_2O_2contents	Cândido et al., 2020

Table 5: Concentration of lead in cereal grains.

Crop	**Country**	**Study/Contamination**	**Pb contents (mg kg^{-1})**	**Crop**	**Country**	**Study/Contamination**	**Pb content (mg kg^{-1})**
Barley	Ethiopia	Market survey (Tegegne, 2015)	0.03	Rice	France	Market survey (Leblanc et al., 2005)	0.01
Barley	Ethiopia	Farmer field (Eticha and Hymete, 2015)	0.82–5.64	Rice	Nigeria	Market survey (Akinyele and Shokunbi, 2015)	<0.08
Maize	Nigeria	Contaminated soil (Orisakwe et al., 2012)	1.01	Rice	India	Organic farming (Chandorkar and Vaze, 2013)	0.10
Maize	Nigeria	Market survey (Akinyele and Shokunbi, 2015)	<0.08	Rice	Australia	Market survey (Rahman et al., 2014)	0.02–1.30
Maize	Bangladesh	Field survey (Islam et al., 2014))	0.04–1.30	Rice	India	Peri-urban areas (Tripathi et al., 1997)	0.02
Millet	Finland	Market survey (Ekholm et al., 2007)	0.02	Rice	Bangladesh	Field survey (Islam et al., 2014)	0.07–1.30
Millet	Nigeria	Contaminated field	3.54	Sorghum	Ethiopia	Market survey (Tegegne,	0.08

		(Orisakwe et al., 2012)				2015)	
Oat	Finland	Market survey (Ekholm et al., 2007)	0.05	Sorghum	Bulgaria	Contaminated area (Angelova et al., 2011)	10.30
Rice	Nigeria	Farmer field (Orisakwe et al., 2012)	61	Wheat	India	Peri-urban area (Tripathi et al., 1997)	0.02
Rice	Saudi Arabia	Market survey (Othman, 2010)	0.02–0.03	Wheat	Ethiopia	Market survey (Tegegne, 2015)	0.05
Rice	Saudi Arabia	Market survey (Ali and Al- Qahtani, 2012)	6.16	Wheat	Saudi Arabia	Market survey (Ali and Al-Qahtani, 2012)	2.80
Wheat	Belgium	Organic and conventional farming (Harcz et al., 2007)	0.04–0.10	Wheat	Bangladesh	Field survey (Islam et al., 2014)	0.03–1.30
Wheat	Brazil	Market survey (Santos et al., 2004)	<0.01–0.02	Wheat	Nigeria	Market survey (Akinyele and Shokunbi, 2015)	<0.08
Wheat	Spain	Samples from flour industry (Tejera et al., 2013)	0.04	Wheat	India	Organic farming (Chandorkar and Vaze, 2013)	0.12
Maximum permissible limit			0.20				0.20

Table 6: Advantages and limitations of phytoremediation mechanism in Pb toxicity.

Advantages	**Limitations**
Applicable to different contaminants	Requires more root surface area and depth for efficient working
Low cost bearing as compared with traditional processes	Long-term commitment because of less biomass production due to slow root growth in Pb-contaminated soils (time consuming)
Efficiently reduces contaminant	Efficiency effected with the increasing age of plants
Less disruptive as compared with physical removal and chemical treatments	Survival of plants under variable Pb toxicity
Environment friendly	Variable climatic conditions adversely affect the working efficiency of plants
Esthetically pleasing	Variable soil chemistry
Easy monitoring	Pb bioaccumulation in plants and its transportation to plant tissue.
Possibility of recovery of different metals	Availability of contaminant for primary consumer through food chain
Reuse of metals (phyto-mining)	No assurance of complete removal of contaminant from soil

Source: https://www.frontiersin.org/articles/10.3389/fpls.2020.587785/full

Phytoremediation of Nickel and Lead Contaminated Soils by *Hedera colchica* (2021)

Table 1: Physicochemical characteristics of the studied soil.

Parameter	**Unit**	**Value**
pH	-	8.3
EC	dS/m	1.8
O.M.	%	24
Lead	mg/kg	13
Nickel	mg/kg	18.6
Potassium	mg/kg	148
Phosphorus	mg/kg	15
Nitrogen	%	1
Textural class	-	Loamy clay

Table 2: Shoot and roots dry weights of H. colchica grown on the soil amended with different concentrations of Pb and Ni ($mg.kg^{-1}$ soil).

Crop species	Heavy metal	Concentration ($mg.kg^{-1}$ soil)	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)
H. colchica	**Nickel**	**Control**	**^{a}35 ± 1.03**	**^{a}5 ± 0.26**	**^{a}19.1 ± 0.89**	**^{a}3.9 ± 0.40**
		50	**^{a}34 ± 1.0**	**^{a}5.2 ± 0.32**	**^{a}18.9 ± 0.76**	**^{a}3.1 ± 0.25**
		150	**^{b}44.5 ± 1.0**	**^{a}5. 6 ± 0.25**	**^{a}19 ± 0.54**	**^{a}3.7 ± 0.21**
		300	**^{c}28.6 ± 1.0**	**^{a}4.9 ± 0.21**	**^{b}15.8 ± 0.33**	**^{a}2.5 ± 0.18**
		450	**^{c}25.9 ± 0.55**	**^{a}4.6 ± 0.18**	**^{b}15 ± 0.39**	**^{b}2.9 ± 0.15**
		600	**^{c}23 ± 1.54**	**^{a}4.1 ± 0.14**	**^{bc}13.7 ± 0.25**	**^{b}1.9 ± 0.20**
	Lead	**Control**	**^{a}35 ± 1.0**	**^{a}5 ± 0.20**	**^{a}20.1 ± 0.15**	**^{a}3 ± 0.20**
		50	**^{ac}29.7 ± 1.0**	**^{a}5 ± 0.50**	**^{b}16.3 ± 0.25**	**^{b}2 ± 0.19**
		150	**^{a}27.9 ± 1.0**	**^{a}4.7 ± 0.17**	**^{bc}13.5 ± 0.66**	**^{b}2 ± 0.17**
		300	**^{a}25.2 ± 0.50**	**^{b}3.7 ± 0.25**	**^{c}10.4 ± 0.80**	**^{b}1.9 ± 0.25**
		450	**^{d}19.6 ± 1.0**	**^{b}2.4 ± 0.25**	**^{c}10 ± 0.56**	**^{b}1.9 ± 0.20**
		600	**^{d}13.9 ± 1.59**	**^{b}2.3 ± 0.2**	**^{c}9.3 ± 0.15**	**^{b}1.2 ± 0.18**

Table 3: Shoot and root length of H. colchica grown in the soil amended with different concentrations of Pb and Ni ($mg.kg^{-1}$ soil).

Crop species	Heavy metal	Concentration ($mg.kg^{-1}$ soil)	Shoot length (cm)	Root length (cm)
H. colchica	**Nickel**	**Control**	**^{a}43 ± 4.5**	**^{a}20.6 ± 3.1**
		50	**^{b} 65.7 ± 3.75**	**^{a}24.1 ± 3.9**
		150	**^{b} 65.9 ± 4.5**	**^{a}26.3 ± 4.7**
		300	**^{c}55 ± 3.1**	**^{b}17.9 ± 2.5**
		450	**^{c}50 ± 2.6**	**^{a}21.3 ± 3.1**
		600	**^{a}44.8 ± 2.7**	**^{b}17 ± 1.9**
	Lead	**Control**	**^{a}46 ± 4.8**	**^{a}25.6 ± 3.3**
		50	**^{a}42.5 ± 3.7**	**^{a}19.4 ± 2.3**
		150	**^{ab}38.1 ± 3.9**	**^{a}18.9 ± 3.3**
		300	**^{ab}38.7 ± 2.2**	**^{ab}15.1 ± 2,3**
		450	**^{b}32.8 ± 2.1**	**^{b} 14.7 ± 2.7**
		600	**^{b}28.8 ± 1.2**	**^{b}13.3 ± 2.6**

*Means with the same letter within column are not significantly different.

Source: https://www.tandfonline.com/doi/full/10.1080/15320383.2020.1832040

Role of plant growth promoting rhizobacteria in the alleviation of lead toxicity to *Pisum sativum L.* (2021)

Table 1: Physico-chemical characteristics of soil used for pot experiment.

Characteristics	**Unit**	**Value**
pHs	–	7.7
E Ce	dS m^{-1}	1.41
Organic matter	%	0.64
Total nitrogen	%	0.06
Lead (Pb)	mg kg^{-1}	ND*
Available phosphorus	mg kg^{-1}	6.9
Extractable potassium	mg kg^{-1}	165.7
CEC	Cmolc kg^{-1}	6.8
Saturation percentage	%	36
Textural class	–	Sandy clay loam
Sand	%	51.2
Silt	%	28.30
Clay	%	20.5

ND*: Not detectable concentration.

Table 2: Effect of rhizobacterial inoculation on shoot, root and grain attributes of pea in Pb contaminated soil.

Treatments	**Shoot attributes**			**Root attributes**			**Grain attributes**		
	Length (cm)	Fresh weight (g)	Dry weight (g)	Length (cm)	Fresh weight (g)	Dry weight (g)	No. of grains per pot	Fresh weight (g)	Dry weight (g)
Control	39 ± 1.53ab	15.92 ± 0.36b	0.98 ± 0.02b	36 ± 3.61cd	3.8 ± 0.20ab	0.63 ± 0.07a	18 ± 2ab	10.77 ± 1.50bc	0.63 ± 0.11b
Pb @ 250 mg kg^{-1}	32 ± 1.53bc	11.47 ± 0.56 cd	0.77 ± 0.07 cd	28.33 ± 1.53de	2.4 ± 0.24bc	0.46 ± 0.05bc	7 ± 1.53c	6.98 ± 2.71 cd	0.24 ± 0.02e
Pb @ 500 mg kg^{-1}	25 ± 3.51d	8.3 ± 0.92de	0.65 ± 0.04de	21.33 ± 2.52ef	1.6 ± 0.30c	0.35 ± 0.04 cd	5 ± 2 cd	4.46 ± 0.27d	0.30 ± 0.03d
Pb @ 750 mg kg^{-1}	22 ± 2.08de	7.31 ± 0.53e	0.57 ± 0.05e	18.67 ± 2.52f	1.36 ± 0.16c	0.25 ± 0.04d	2 ± 0.58d	3.08 ± 0.88d	0.19 ± 0.03f
P. fluorescence A-506	42 ± 3.61a	19.15 ± 1.53a	1.30 ± 0.06a	52.33 ± 2.52a	4.83 ± 0.81a	0.67 ± 0.07a	22 ± 2a	15.94 ± 0.67a	0.80 ± 0.08a
P. fluorescence A-506 +Pb @ 250 mg kg^{-1}	37 ± 2.0b	15.14 ± 0.81b	0.94 ± 0.02b	48.67 ± 1.53ab	3.76 ± 0.35ab	0.62 ± 0.06ab	19 ± 1.53a	13.7 ± 0.57b	0.64 ± 0.01b
P. fluorescence A-506 +Pb @ 500 mg kg^{-1}	34 ± 2.52c	12.83 ± 0.75c	0.74 ± 0.04d	41 ± 3.06bc	3.21 ± 0.02b	0.42 ± 0.03cd	15 ± 2.65ab	9.12 ± 0.37c	0.48 ± 0.01c
P. fluorescence A-506 +Pb @ 750 mg kg^{-1}	30 ± 2.08bc	9.83 ± 0.23d	0.64 ± 0.04de	34.33 ± 2.52cd	3.23 ± 0.38b	0.35 ± 0.03cd	10 ±2b	7.48 ± 0.39cd	0.42 ± 0.01cd

Means sharing same letters are statistically non-significant at $p < 0.05$.

Table 3: Lead (Pb) concentrations in roots, shoots, grains and soil.

	Lead (Pb) concentration (mg kg^{-1})			
Treatments	Soil	Roots	Shoots	Grains
Control	ND	ND	ND	ND
Pb @ 250 mg kg^{-1}	17.31 ± 0.47c	14 ± 1c	9.50 ± 0.46c	4.21 ± 0.30c
Pb @ 500 mg kg^{-1}	23.97 ± 0.75b	17.50 ± 0.5b	11.77 ± 0.65b	6.41 ± 0.27b
Pb @ 750 mg kg^{-1}	26.26 ± 0.74a	20.58 ± 0.5a	17.43 ± 0.52a	9.54 ± 0.43a
P. fluorescence	ND	ND	ND	ND
P. fluorescence þ Pb @ 250 mg kg^{-1}	7.52 ± 0.52f	2.13 ± 1f	1.23 ± 0.23e	0.64 ± 0.20f
P. fluorescence þ Pb @ 500 mg kg^{-1}	10.51 ± 0.54e	4.21 ± 0.4e	2.54 ± 0.30d	1.06 ± 0.32e
P. fluorescence þ Pb @ 750 mg kg^{-1}	13.20 ± 0.26d	5.14 ± 0.4d	4.13 ± 0.16d	2.11 ± 0.26d

Means shoring same letters (a, b, c, d, e, f) are statistically non-significant at $p < 0.05$.

Table 4: Effect of rhizobacterial inoculation on bioconcentration factor and root shoot ratio of pea in Pb contaminated soil.

	Bioconcentration factor (BCF)		
Treatments	Roots	Shoots	Root/Shoot ratio
Control	—	—	0.64 ± 0.04a
Pb @ 250 mg kg^{-1}	0.81 ± 0.04a	0.54 ± 0.01a	0.60 ± 0.10ab
Pb @ 500 mg kg^{-1}	0.73 ± 0.03b	0.49 ± 0.04 b	–0.54 ± 0.02a–c
Pb @ 750 mg kg^{-1}	0.78 ± 0.03 ab	0.66 ± 0.01a	0.44 ± 0.03c
P. fluorescence	—	—	0.52 ± 0.06bc
P. fluorescence + Pb @ 250 mg kg^{-1}	0.28 ± 0.08 ab	0.16 ± 0.01c	0.65 ± 0.07a
P. fluorescence + Pb @ 500 mg kg^{-1}	0.40 ± 0.07 b	0.24 ± 0.01 b	0.57 ± 0.02ab
P. fluorescence +Pb @ 750 mg kg^{-1}	0.38 ± 0.04 ab	0.31 ± 0.02 b	0.54 ± 0.03bc

Means sharing same letters (a, b, c) are statistically non-significant at $p < 0.05$.

Source: https://doi.org/10.1080/15226514.2020.1859988

Lead availability and phytoextraction in the rhizosphere of Pelargonium species (2020)

Table 1: Physiochemical characteristics of soil used in experiment

Parameters	Values
Soil pH	7.41
Soil EC (dS m^{-1})	0.55
Texture	Clay loam
Organic matter carbon (%)	0.48
Total nitrogen content (%)	0.033
Total phosphorus content (mg kg^{-1})	6.37
Potassium (mg kg^{-1})	731
Magnesium (mg kg^{-1})	303
Iron (mg kg^{-1})	2788

Table 2: Biomass and Pb uptake factors after 15 day of culture experiment. Results are significant at $p < 0.05$, as indicated by different letters

Parameters	***S. criniflorum***				***P. hortorum***			
Soil [Pb] mg kg^{-1}	**500**	**1000**	**1500**	**2000**	**500**	**1000**	**1500**	**2000**
TF	0.30	0.25	0.30	0.21	0.24	0.23	0.23	0.22
CF_r	0.93	0.60	0.48	0.38	1.40	0.86	0.73	0.64
CF_s	0.26	0.14	0.14	0.08	0.32	0.19	0.17	0.14
$Biomass_r$ (g)	0.78^{bc}	0.58^{d}	0.50^{ed}	0.37^{e}	1.14^{a}	1.08^{a}	0.84^{bc}	0.67^{cd}
$Biomass_s$ (g)	$1.16b^{cd}$	1.20^{bcd}	1.00^{de}	0.76^{e}	1.63^{a}	1.49^{ab}	1.33^{a-d}	1.00^{de}

TF, CFr, and CFs correspond to translocation factor, root concentration factor, and shoot concentration factor; biomassr,s corresponds to biomass of root and shoot, respectively.

Source: https://link.springer.com/article/10.1007/s11356-020-08226-0

Table 1: Field soil physiochemical properties.

Characters	Soil
Type	Interceptisol
Color	Red
Texture	Clay
pH	5.55 ± 0.07
CEC (cmol/kg)	10.40 ± 0.03
OM (%)	11.05 ± 0.03
Total N (g/kg)	3.17 ± 0.09
Total P (g/kg)	81.74 ± 2.25
Total K (g/kg)	247.91 ± 4.15
Total Pb (mg/kg)	106.46 ± 4.43

Soil pH measured in water: soil (1:1, m/V) mixture; Cation exchange capacity (CEC) measured by using ammonium acetate saturation method (Chapman, 1965); Organic matter (OM) was measured by using the Walkley-Black method (Walkley and Black, 1934); Soil texture was analyzed by the hydrometer method; Total N, P, K and Pb were measured by the acid digestion method.

Table 2: Total mineral content in seed meal of different sunflower germplasms.

Germplasm	Ca	(%)	Mg (%)	K (%)	Na (%)
1	0.131	± 0.015	0.116 ± 0.011	0.540 ± 0.056	0.004 ± 0.001
2	0.115	± 0.010	0.086 ± 0.008	0.416 ± 0.037	0.003 ± 0.001
3	0.138	± 0.016	0.106 ± 0.013	0.470 ± 0.054	0.002 ± 0.001
4	0.155	± 0.026	0.085 ± 0.014	0.487 ± 0.080	0.003 ± 0.001
5	0.238	± 0.021	0.164 ± 0.016	0.513 ± 0.046	0.003 ± 0.001
6	0.163	± 0.014	0.097 ± 0.008	0.450 ± 0.041	0.003 ± 0.001
7	0.176	± 0.013	0.131 ± 0.009	0.449 ± 0.034	0.004 ± 0.001
8	0.188	± 0.022	0.158 ± 0.020	0.529 ± 0.072	0.003 ± 0.001
9	0.181	± 0.029	0.092 ± 0.014	0.520 ± 0.084	0.004 ± 0.001
10	0.193	± 0.014	0.125 ± 0.010	0.492 ± 0.037	0.005 ± 0.001
11	0.185	± 0.029	0.127 ± 0.021	0.522 ± 0.084	0.003 ± 0.001
12	0.140	± 0.007	0.111 ± 0.006	0.386 ± 0.019	0.003 ± 0.001
13	0.085	± 0.006	0.085 ± 0.006	0.338 ± 0.028	0.002 ± 0.001
14	0.158	± 0.033	0.119 ± 0.025	0.357 ± 0.072	0.004 ± 0.001
15	0.191	± 0.027	0.126 ± 0.024	0.341 ± 0.049	0.002 ± 0.001
16	0.164	± 0.021	0.091 ± 0.010	0.383 ± 0.051	0.003 ± 0.001
17	0.161	± 0.017	0.094 ± 0.009	0.405 ± 0.033	0.003 ± 0.001
18	0.204	± 0.022	0.159 ± 0.016	0.749 ± 0.077	0.002 ± 0.001
19	0.129	± 0.017	0.116 ± 0.014	0.638 ± 0.080	0.003 ± 0.001
20	0.215	± 0.041	0.165 ± 0.032	0.988 ± 0.177	0.005 ± 0.002
21	0.183	± 0.014	0.165 ± 0.013	0.913 ± 0.069	0.005 ± 0.002
22	0.297	± 0.022	0.258 ± 0.017	1.00 ± 0.066	0.007 ± 0.001
23	0.180	± 0.031	0.103 ± 0.018	0.533 ± 0.098	0.003 ± 0.001
24	0.226	± 0.029	0.175 ± 0.020	0.660 ± 0.095	0.008 ± 0.003
25	0.237	± 0.048	0.213 ± 0.040	1.402 ± 0.255	0.006 ± 0.002
26	0.150	± 0.003	0.095 ± 0.007	0.859 ± 0.010	0.003 ± 0.001
27	0.106	± 0.013	0.120 ± 0.016	0.567 ± 0.079	0.002 ± 0.001
28	0.313	± 0.035	0.237 ± 0.030	1.297 ± 0.189	0.006 ± 0.002
29	0.146	± 0.005	0.106 ± 0.007	0.549 ± 0.029	0.003 ± 0.001
30	0.231	± 0.007	0.181 ± 0.021	1.034 ± 0.084	0.005 ± 0.002
31	0.123	± 0.003	0.103 ± 0.004	0.643 ± 0.016	0.002 ± 0.001
32	0.182	± 0.033	0.130 ± 0.022	0.548 ± 0.096	0.002 ± 0.001
33	0.213	± 0.006	0.183 ± 0.003	0.735 ± 0.014	0.004 ± 0.001

34	0.197	± 0.009	0.179 ± 0.012	0.836 ± 0.045	**0.005 ± 0.001**
35	0.094	± 0.007	0.200 ± 0.001	0.578 ± 0.033	**0.003 ± 0.001**
36	0.193	± 0.020	0.208 ± 0.022	0.795 ± 0.087	**0.006 ± 0.001**
37	0.151	± 0.012	0.168 ± 0.009	0.721 ± 0.098	**0.004 ± 0.001**
38	0.148	± 0.011	0.156 ± 0.010	0.664 ± 0.045	**0.005 ± 0.002**
39	0.138	± 0.004	0.144 ± 0.006	0.685 ± 0.015	**0.004 ± 0.001**
40	0.086	± 0.010	0.102 ± 0.011	0.451 ± 0.060	**0.003 ± 0.001**

⁎ Values are Mean ± S.E. (*n* = 3 replicates).

Table 3: Fatty acid (FA) profile of Pb-accumulator sunflower germplasm grown on Pb-contaminated soil.

Serial no.	Fatty acid	Formula	Retention time (min)	Fatty acid (%)
1	Palmitic acid (16:0)	C16H32O2	16.46	**6.14 ± 0.02^{c}**
2	Stearic acid (18:0)	C18H36O2	19.68	**1.952 ± 0.01^{d}**
3	Oleic acid (18:1)	C18H34O2	20.19	**59.522 ± 3.10^{a}**
4	Linoleic acid (18:2)	C18H32O2	23.85	**32.199 ± 2.01^{b}**
5	Gadoleic acid (20:1)	C18H32O2	22.85	**0.176 ± 0.001^{d}**

⁎ Values having similar letters represent non-significant difference (*P* < 0.05) of FAs for germplasm. Values represents Mean ± S.E. (*n* = 3).

Table 4: Chromatograph and amino acid (AA) profile of high-accumulator sunflower meal grown on Pb-contaminated soil .

Serial no.	Amino acid	Formula	Retention time (min)	Concentration ng/20μl	Amino acid (%)
1	Aspartic acid	$C_4H_7NO_4$	4.960	1453.845	**10.74 ± 0.03^{b}**
2	Threonine	$C_4H_9NO_3$	5.607	597.657	**4.41 ± 0.021^{d}**
3	Serine	$C_3H_7NO_3$	6.227	686.196	**5.06 ± 0.015^{d}**
4	Glutamic acid	$C_5H_9NO_4$	6.927	3032.72	**22.40 ± 0.05^{a}**
5	Glycine	$C_2H_5NO_2$	9.913	805.158	**5.94 ± 0.014^{d}**
6	Alanine	$C_3H_7NO_2$	10.773	707.407	**5.22 ± 0.011^{d}**
7	Cysteine	$C_3H_7NO_2S$	12.160	184.491	**1.36 ± 0.01^{d}**
8	Valine	$C_5H_{11}NO_2$	12.707	694.04	**5.12 ± 0.02^{d}**
9	Methionine	$C_2H_{11}NO_2S$	13.900	276.126	**2.03 ± 0.01^{d}**
11	Isoleucine	$C_6H_{13}NO_2$	16.087	598.112	**4.41 ± 0.01^{d}**
12	Leucine	$C_6H_{13}NO_2$	17.187	997.438	**7.36 ± 0.02^{c}**
13	Tyrosine	$C_9H_{11}NO_3$	18.560	355.373	**2.62 ± 0.01^{d}**
14	Phenylalanine	$C_9H_{11}NO_2$	19.633	715.304	**5.28 ± 0.02^{d}**
15	Lysine	C6H14N2O2	22.247	534.178	**3.94 ± 0.01^{d}**
16	Histidine	$C_6H_9N_3O_2$	24.520	326.783	**2.41 ± 0.01^{d}**
17	Arginine	C6H14N4O2	28.633	1144.784	**8.45 ± 0.03^{c}**
18	Proline	$C_5H_9NO_2$	7.52	426.526	**3.15 ± 0.01^{d}**

Values having similar letters represent non-significant differences (*P* <0.05) of AAs for germplasm. Values represents Mean ± S.E. (*n* = 3).

Source:
https://www.researchgate.net/publication/333707331_Assessment_of_sunflower_germplasm_for_phytoremediation_of_leadpolluted_soil_and_production_of_seed_oil_and_seed_meal_for_human_and_animal_consumption

Bioaccumulation of lead in different varieties of wheat plant irrigated with wastewater in remote agricultural regions (2020)

Table 1: Analysis of variance for Pb concentration in water

Source	Degree of freedom	Mean square
Water source	2	0.64**
Year	1	0.21^{ns}
Water source × year	2	0.07^{ns}
Error	18	0.109

1. **Significant at 0.01 level
2. ns, non-significant

Table 2: Mean concentration (mg/l) of Pb in different types of irrigation water

Cropping year	Groundwater	Sewage water	Industrial water	Mean
Year1	7.64 ± 0.13^{ab}	7.05 ± 0.14^{c}	7.45 ± 0.25^{abc}	7.38^{a}
Year 2	7.64 ± 0.13^{ab}	7.25 ± 0.14^{bc}	7.83 ± 0.17^{a}	7.57^{a}
Mean	7.64^{a}	7.15^{b}	7.64^{a}	-

Table 3: Analysis of variance for Pb concentration in soil

Source	Degree of freedom	Mean square
Variety	4	1.32**
Water source	2	2.09**
Year	1	1.54*
Variety × water source	8	0.32^{ns}
Variety × year	4	0.08^{ns}
Water source × year	2	0.001^{ns}
Variety × water source × year	8	0.11^{ns}
Error	90	0.34

1. *, ** = significant at 0.05 and 0.01 level
2. ns, non-significant

Table 4: Mean concentration of Pb (mg/kg) in soil used to grown different varieties of wheat in two cropping years

Cropping year	Irrigation sources	Wheat varieties					Mean
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013	
Year 1	Groundwater	6.67 ± 0.19^{def}	7.12 ± 0.19^{abcdef}	7.20 ± 0.19^{abcde}	6.50 ± 0.19^{ef}	6.32 ± 0.21^{f}	6.76^{c}
	Sewage water	6.94 ± 0.28^{abcdef}	7.27 ± 0.28^{abcde}	7.39 ± 0.28^{abcd}	6.74 ± 0.28^{cdef}	7.49 ± 0.28^{abcd}	7.17^{ab}
	Industrial water	6.95 ± 0.38^{abcdef}	7.36 ± 0.38^{abcd}	7.18 ± 0.38^{abcde}	6.76 ± 0.38^{bcdef}	7.56 ± 0.38^{abc}	7.16^{ab}
Year 2	Groundwater	6.99 ± 0.19^{abcdef}	6.99 ± 0.19^{abcdef}	6.99 ± 0.19^{abcdef}	6.99 ± 1.19^{abcdef}	6.99 ± 0.19^{abcdef}	6.99^{bc}
	Sewage water	7.14 ± 0.28^{abcde}	7.49 ± 0.28^{abc}	7.59 ± 0.28^{a}	6.94 ± 0.28^{abcdef}	7.74 ± 0.28^{a}	7.38^{a}
	Industrial water	7.14 ± 0.38^{abcdef}	7.54 ± 0.38^{abc}	7.57 ± 0.38^{ab}	6.94 ± 0.38^{abcdef}	7.74 ± 0.38^{a}	7.39^{a}
All years	Mean	6.97^{bc}	7.30^{ab}	7.32^{a}	6.81^{c}	7.31^{a}	-

Table 5: Analysis of variance for Pb in roots, shoot, and grains of various varieties of wheat irrigated with different sources of water in two cropping years

Source	DF	Roots	Shoot	Grains
Variety	4	1.91***	0.56***	0.003***
Water source	2	0.58***	16.14***	0.93***
Year	1	1.003***	0.41***	0.54***
Variety × water source	8	0.12*	0.08***	0.006***
Variety × year	4	0.08^{ns}	0.003^{ns}	0.00003^{ns}
Water source × year	2	2.13***	0.17***	0.13***
Variety × water source × year	8	0.04^{ns}	0.001^{ns}	0.00004^{ns}
Error	90	0.04	0.01	0.0002

1. *, *** = significant at 0.05 and 0.001 levels
2. ns, non-significant

Table 6: Mean concentration of Pb (mg/kg) in roots of various varieties of wheat plant irrigated with different sources of water in two cropping years

Cropping year	Irrigation sources	Wheat varieties					Mean
		Seher-2006	**Punjab-2011**	**Faislabad-2008**	**Watan**	**Galaxy-2013**	
Year 1	Groundwater	3.89 ± 0.02^{ijklm}	4.35 ± 0.03^{bcd}	3.91 ± 0.16^{ghijk}	4.82 ± 0.05^{a}	4.49 ± 0.03^{b}	4.29^{a}
	Sewage water	3.46 ± 0.11^{no}	4.19 ± 0.19^{cdef}	3.89 ± 0.11^{ijklm}	4.23 ± 0.02^{bcde}	3.84 ± 0.04^{ijklm}	3.92^{d}
	Industrial water	3.69 ± 0.03^{klmn}	4.45 ± 0.35^{bc}	3.96 ± 0.03^{fghij}	4.21 ± 0.04^{cdef}	4.17 ± 0.02^{defgh}	4.09^{bc}
Year 2	Groundwater	3.23 ± 0.01^{o}	3.63 ± 0.02^{mn}	3.26 ± 0.13^{o}	4.02 ± 0.04^{efghi}	3.74 ± 0.02^{jklm}	3.58^{e}
	Sewage water	3.64 ± 0.11^{lmn}	4.05 ± 0.04^{efghi}	3.75 ± 0.08^{jklm}	4.41 ± 0.02^{bcd}	4.03 ± 0.04^{efghi}	3.98^{cd}
	Industrial water	3.90 ± 0.03^{hijkl}	4.16 ± 0.05^{defgh}	4.17 ± 0.03^{defg}	4.42 ± 0.04^{bcd}	4.38 ± 0.02^{bcd}	4.21^{ab}
All years	Mean	3.63^{d}	4.14^{b}	3.82^{c}	4.35^{a}	4.11^{b}	

Table 7: Mean concentration of Pb (mg/kg) in different varieties of wheat grains irrigated with different sources of water in two cropping years

Site	***n***	**CEC (cmol$^+$ kg^{-1})**	**Ca (cmol$^+$ kg^{-1})**	**K (cmol$^+$ kg^{-1})**	**Mg (cmol$^+$ kg^{-1})**	**Mn (cmol$^+$ kg^{-1})**	**Ni (cmol$^+$ kg^{-1})**
01	3	17 [8.0–31] ab	5.7 [0.49–14]	0.15 [0.08–0.22] b	7.9 [5.5–12] bcd	0.40 [0.16–0.58]	0.19 [0.12–0.27]
02	6	27 [22–37] ab	11 [5.5–23]	0.28 [0.18–0.45] ab	12 [10–16] bcd	0.18 [0.11–0.28]	0.20 [0.09–0.50]
03	5	25 [22–30] ab	3.6 [1.9–6.4]	0.25 [0.21–0.30] ab	18 [15–20] bcd	0.11 [0.03–0.19]	0.07 [0.02–0.10]
04	3	33 [18–49] ab	11 [1.1–28]	0.26 [0.07–0.44] ab	18 [13–23] abcd	0.13 [0.02–0.33]	0.08 [0.03–0.17]
05	4	43 [36–53] a	1.0 [0.59–1.7]	0.60 [0.45–0.73] a	35 [27–47] a	0.33 [0.18–0.50]	0.16 [0.06–0.30]
06	8	30 [18–42] ab	5.8 [0.62–17]	0.37 [0.13–0.60] ab	19 [14–29] b	0.31 [0.09–0.80]	0.16 [0.05–0.25]
07	4	30 [24–43] ab	5.0 [2.1–7.7]	0.25 [0.17–0.33] ab	21 [15–30] abc	0.06 [0.01–0.22]	0.05 [0.01–0.16]
08	6	40 [18–76] a	14 [3.2–28]	0.35 [0.09–0.86] ab	20 [7.8–40] b	0.07 [0.01–0.11]	0.05 [0.02–0.09]
09	5	12 [6.9–24] b	2.7 [1.0–5.9]	0.15 [0.07–0.28] b	5.2 [2.3–13] cd	0.33 [0.02–1.29]	0.21 [0.08–0.45]
10	8	17 [8.7–33] b	8.2 [5.0–23]	0.15 [0.09–0.25] b	5.0 [1.0–7.9] d	0.06 [0.01–0.11]	0.13 [0.03–0.25]

Table 8: Mean concentration of Pb (mg/kg) in shoots of various varieties of wheat plant irrigated with different sources of water in two cropping years

Cropping year	**Irrigation sources**	**Wheat varieties**					**Mean**
		Seher-2006	**Punjab-2011**	**Faislabad-2008**	**Watan**	**Galaxy-2013**	
Year 1	Groundwater	1.20 ± 0.02^{mno}	1.38 ± 0.07^{kl}	1.55 ± 0.04^{j}	1.17 ± 0.04^{no}	1.32 ± 0.09^{lmn}	1.32^{e}
	Sewage water	2.18 ± 0.08^{fgh}	2.12 ± 0.03^{gh}	2.20 ± 0.08^{fgh}	1.81 ± 0.03^{i}	2.12 ± 0.05^{gh}	2.09^{d}
	Industrial water	2.62 ± 0.06^{ab}	2.58 ± 0.03^{bc}	2.57 ± 0.02^{bc}	2.06 ± 0.03^{h}	2.45 ± 0.07^{cd}	2.46^{b}
Year 2	Groundwater	1.18 ± 0.02^{no}	1.35 ± 0.07^{klm}	1.50 ± 0.01^{jk}	1.14 ± 0.04^{o}	1.29 ± 0.09^{lmno}	1.29^{e}
	Sewage water	2.39 ± 0.08^{de}	2.34 ± 0.03^{def}	2.38 ± 0.01^{de}	2.09 ± 0.03^{h}	2.33 ± 0.05^{def}	2.31^{c}
	Industrial water	2.75 ± 0.09^{a}	2.75 ± 0.07^{a}	2.72 ± 0.03^{ab}	2.27 ± 0.04^{efg}	2.59 ± 0.09^{abc}	2.62^{a}
All years	Mean	2.05^{bc}	2.09^{ab}	2.15^{a}	1.76^{d}	2.02^{c}	-

Table 9: Pollution load index for Pb in soil in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.82	0.87	0.88	0.80	0.78
	Sewage water	0.85	0.89	0.91	0.83	0.92
	Industrial water	0.85	0.90	0.88	0.83	0.93
Year 2	Groundwater	0.86	0.86	0.86	0.86	0.86
	Sewage water	0.88	0.92	0.93	0.85	0.95
	Industrial water	0.88	0.93	0.93	0.85	0.95
All years	Mean	0.86	0.90	0.90	0.84	0.90

Table 10: Bioaccumulation factor for Pb in wheat shoot/soil in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.18	0.19	0.22	0.18	0.21
	Sewage water	0.31	0.29	0.30	0.27	0.28
	Industrial water	0.38	0.35	0.36	0.30	0.32
Year 2	Groundwater	0.17	0.19	0.21	0.16	0.18
	Sewage water	0.33	0.31	0.31	0.30	0.30
	Industrial water	0.39	0.36	0.36	0.33	0.33
All years	Mean	0.29	0.28	0.29	0.26	0.27

Table 11: Translocation factor for Pb in wheat shoot/root in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.11	0.11	0.11	0.11	0.11
	Sewage water	0.25	0.24	0.22	0.24	0.35
	Industrial water	0.37	0.36	0.36	0.32	0.33
Year 2	Groundwater	0.11	0.11	0.11	0.11	0.11
	Sewage water	0.48	0.47	0.46	0.46	0.58
	Industrial water	0.63	0.62	0.62	0.62	0.58
All years	Mean	0.33	0.32	0.31	0.31	0.34

Table 12: Bio-concentration factor for Pb in wheat grains/soil in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.01	0.01	0.01	0.01	0.01
	Sewage water	0.03	0.03	0.02	0.03	0.04
	Industrial water	0.04	0.04	0.04	0.04	0.04
Year 2	Groundwater	0.01	0.01	0.01	0.01	0.01
	Sewage water	0.05	0.05	0.05	0.06	0.06
	Industrial water	0.07	0.07	0.07	0.07	0.06
All years	Mean	0.04	0.04	0.03	0.04	0.04

Table 13: Enrichment factor for Pb in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.04	0.03	0.03	0.04	0.04
	Sewage water	0.08	0.07	0.07	0.08	0.10
	Industrial water	0.12	0.11	0.11	0.10	0.10
Year 2	Groundwater	0.03	0.03	0.03	0.03	0.03
	Sewage water	0.15	0.14	0.13	0.15	0.16
	Industrial water	0.19	0.18	0.18	0.18	0.16
All years	Mean	0.10	0.09	0.09	0.10	0.10

Table 14: Daily intake of Pb (mg/kg/day) in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.0004	0.0004	0.0004	0.0004	0.0004
	Sewage water	0.0009	0.0008	0.0008	0.0008	0.0010
	Industrial water	0.0010	0.0010	0.0010	0.0010	0.0010
Year 2	Groundwater	0.0004	0.0004	0.0004	0.0004	0.0004
	Sewage water	0.0020	0.0020	0.0020	0.0020	0.0020
	Industrial water	0.0020	0.0020	0.0020	0.0020	0.0020
All years	Mean	0.0011	0.0011	0.0011	0.0011	0.0011

Table 15: Health risk index of Pb via intake of *Triticum aestivum* in two cropping years

Cropping year	Irrigation sources	Wheat varieties				
		Seher-2006	Punjab-2011	Faislabad-2008	Watan	Galaxy-2013
Year 1	Groundwater	0.11	0.11	0.11	0.11	0.11
	Sewage water	0.25	0.24	0.22	0.24	0.35
	Industrial water	0.37	0.36	0.36	0.32	0.33
Year 2	Groundwater	0.11	0.11	0.11	0.11	0.11
	Sewage water	0.48	0.47	0.46	0.48	0.58
	Industrial water	0.63	0.62	0.62	0.58	0.58
All years	Mean	0.33	0.32	0.31	0.31	0.34

Source: https://link.springer.com/article/10.1007%2Fs11356-020-09138-9

In vitro lead tolerance and accumulation in three Chrysanthemum cultivars for phytoremediation purposes with ornamental plants (2020)

Table 1: Average biomass production (g dry weight ± standard deviation) for each Chrysanthemum cultivar studied and treatment with different concentrations of Pb in the culture substrate.

Cultivar	0 mg/kg	300 mg/kg	600 mg/kg	900 mg/kg	1,500 mg/kg
***Chrysanthemum* 'Renella'**	0.12 ± 0.04	0.14 ± 0.03	0.14 ± 0.03	0.12 ± 0.02	0.11 ± 0.03
		p = 0.76908	*p* = 0.76908	*p* = 0.92707	*p* = 0.92077
***Chrysanthemum* 'Reyellow'**	0.12 ± 0.06	0.12 ± 0.01	0.13 ± 0.02	0.06 ± 0.02	0.05 ± 0.01
		p = 0.78419	*p* = 0.62027	*p* = 0.34180	*p* = 0.22094
***Chrysanthemum* 'Sheena'**	0.21 ± 0.02	0.16 ± 0.00	0.17 ± 0.07	0.05 ± 0.02	0.07 ± 0.01
		p = 0.31154	*p* = 0.46360	***p* = 0.01348**	***p* = 0.02675**

Table 2: Root length (mm ± standard deviation) for each Chrysanthemum cultivar studied and each concentration of Pb in the culture substrate.

Cultivar	0 mg/kg	300 mg/kg	600 mg/kg	900 mg/kg	1,500 mg/kg
***Chrysanthemum* 'Renella'**	20.67 ± 8.02	12.47 ± 2.54	11.10 ± 4.71	5.23 ± 0.87	4.60 ± 0.69
		p = 0.35915	*p* = 0.35915	*p* = 0.02658	*p* = 0.01789
***Chrysanthemum* 'Reyellow'**	8.77 ± 3.02	11.97 ± 4.05	5.57 ± 1.60	6.60 ± 2.25	3.47 ± 1.27
		p = 0.58320	*p* = 0.28682	*p* = 0.48060	*p* = 0.15849
***Chrysanthemum* 'Sheena'**	22.67 ± 9.29	10.00 ± 6.14	6.93 ± 5.40	1.10 ± 0.85	1.50 ± 0.40
		p = 0.31530	*p* = 0.13379	*p* = 0.02467	*p* = 0.03524

The *p* values (obtained by the Conover test and Benjamini & Hochberg correction) indicate the probability that the root length reached with the Pb treatment is equal to the root length of the control (0 mg/kg). Significant *p* values ($p < 0.05$) are marked in bold.

Table 3: Average concentration of Pb in the tissues of plants (mg/kg ± standard deviation) for each *Chrysanthemum* cultivar studied and each concentration of Pb in the culture substrate, as well as the average concentration values for all treatments.

Cultivar	0 mg/kg	300 mg/kg	600 mg/kg	900 mg/kg	1,500 mg/kg	Average values all treatments
***Chrysanthemum* 'Renella'**	0.00 ± 0.00	1431.57 ± 173.46	1464.91 ± 440.22	1699.98 ± 239.18	5029.36 ± 1031.69	1925.16
		p = 0.16937	*p* = 0.16937	*p* = 0.07021	*p* = 0.00389	
***Chrysanthemum* 'Reyellow'**	0.00 ± 0.00	1321.14 ± 247.25	1178.46 ± 138.00	3863.58 ± 2700.26	3224.82 ± 1895.88	1917.60
		p = 0.18985	*p* = 0.19963	*p* = 0.02395	*p* = 0.02675	
***Chrysanthemum* 'Sheena'**	22.53 ± 3.54	2289.01 ± 986.20	2322.66 ± 1945.12	3884.05 ± 1388.57	1937.87 ± 246.73	2091.22
		p = 0.11044	*p* = 0.08921	*p* = 0.01036	*p* = 0.14412	

The *p* values (obtained by the Conover test and Benjamini & Hochberg correction) indicate the probability that the amount of Pb in the tissues grown under different treatments is equal to that of the control treatment (0 mg/kg). Significant *p* values ($p < 0.05$) are marked in bold.

Table 4: Average bioaccumulation factor (BF) for each *Chrysanthemum* cultivar studied and each treatment with different concentrations of Pb in the substrate, as well as the average values for all treatments.

Cultivar	300 mg/kg	600 mg/kg	900 mg/kg	1,500 mg/kg	Average values all treatments
***Chrysanthemum* 'Renella'**	4.77	2.39	1.89	3.35	3.10
***Chrysanthemum* 'Reyellow'**	4.40	1.96	4.29	2.15	3.20
***Chrysanthemum* 'Sheena'**	7.63	3.87	4.32	1.29	4.27

Source: https://www.tandfonline.com/doi/full/10.1080/15226514.2020.1731730

Lead induces oxidative stress in Pisum sativum plants and changes the levels of phytohormones with antioxidant role (2019)

Table 1: Quantification of Pb in different organs of P. sativum. Pb content (μg g^{-1} DM), plant height (cm) and hormone content (ng g^{-1} FW) in control and Pb exposed pea plants. Values are means ± SD (n = 3-6). For each line, different letters indicate significant differences between treatments at a significant level equal to 0.05.

		0 mg Pb Kg^{-1}	10 mg Pb Kg^{-1}	100 mg Pb Kg^{-1}	500 mg Pb Kg^{-1}
Plant height	Shoots	65.4±3.6[a]	63.2±3.573[a]	61.2±2.6[a]	**51.7±4.6[b]**
	Roots	20.3±3.9[a]	21.1±5.6[a]	19.4±5.6[a]	**13.4±2.3[a]**
Pb	Leaves	8.2±1.4[c]	55.0±8.0[b]	64.5±10.1[ab]	**75.2±15.6[a]**
	Roots	14.0±8.1[d]	595.5±57.9[c]	1238.0±278.8[b]	**2333.0±335.6[a]**
ABA	Leaves	28.7±1.5[b]	29.5±1.9[b]	31.5±4.9[b]	**56.1±4.9[a]**
	Roots	3.0±0.1[a]	2.0±1.2[a]	1.7±0.3[a]	**2.3±0.4[a]**
SA	Leaves	7.4±2.5[b]	8.5±0.8[ab]	10.8±0.5[ab]	**12.4±1.1[a]**
	Roots	2.9±1.1[c]	7.5±2.5[ab]	4.74±1.2[bc]	**9.8±2.1[a]**
IAA	Leaves	9.7±3.6[a]	4.8±3.2[a]	6.3±2.1[a]	**10.3±2.8[a]**
	Roots	nd	nd	nd	**nd**
JA	Leaves	37.9±9.3[b]	153.0±50.1[a]	132.8±59.8[a]	**82.3±18.3[ab]**
	Roots	**76.0±4.8[c]**	**257.1±18.1[a]**	**144.6±16.1[b]**	**159.0±23.2[b]**

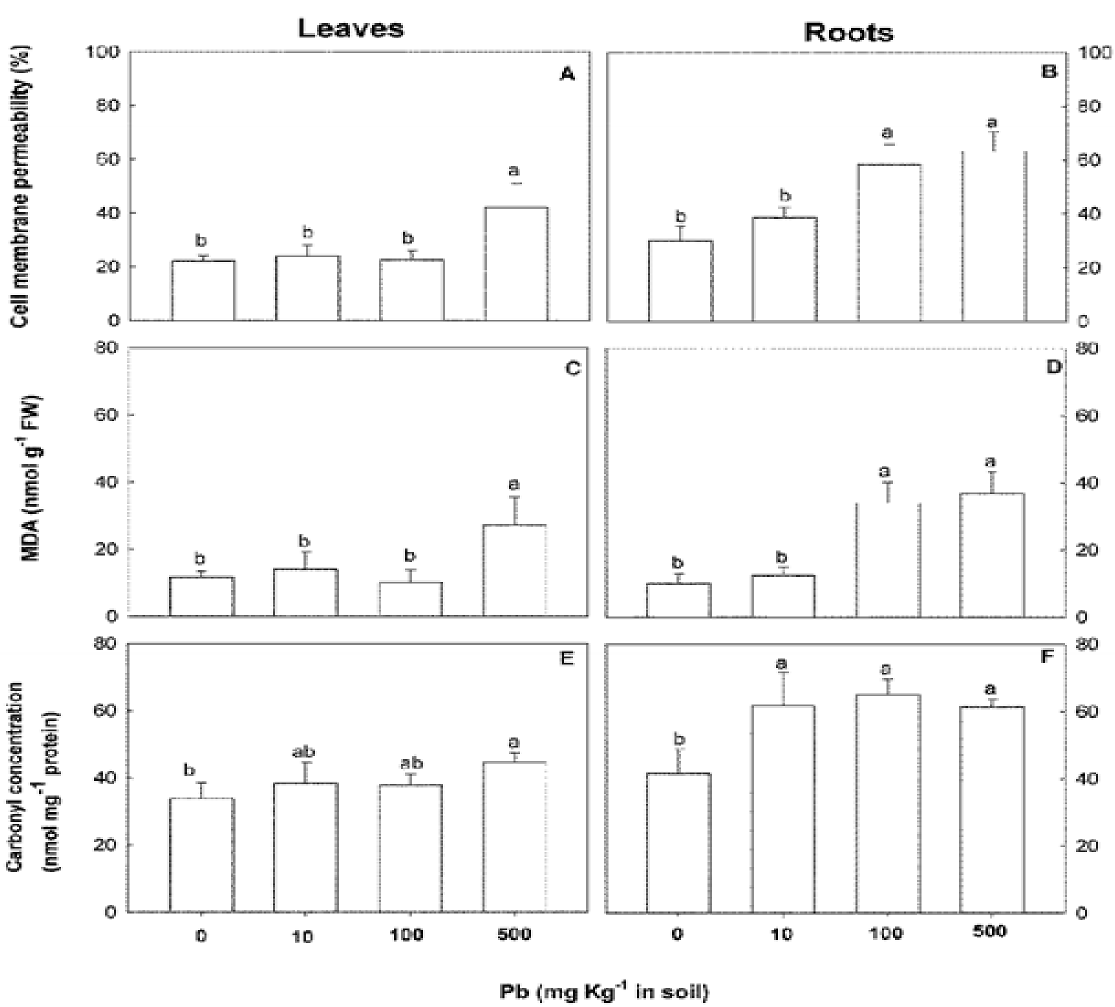
(ABA: abscisic acid; IAA: indolacetic acid; JA: jasmonic acid; nd: not detectable; SA: salicylic acid)

Lead accumulation in roots and shoots significantly increased with the increase of Pb content in the medium, with maximal accumulation values observed at 500 mg kg^{-1}. Most of the metal was accumulated in roots Lead exposure did not induce plant death (100% survival rate). Also, leaves from all conditions had no symptoms of necrosis nor chlorosis. Whilst no differences were observed in roots' length in comparison to controls, plants exposed to 500 mg Pb kg^{-1} had a shorter (P<0.05) aerial part (reduction of 21%).

Hormone levels showed different profiles in leaves and roots. ABA and SA levels increased significantly (49% and 40%, respectively) in leaves exposed to 500 mg Pb kg^{-1} compared to control plants. In roots, ABA content were not affected (P>0.05) by Pb, while the SA content was significantly higher in 10 and 500 mg Pb kg^{-1} compared to control plants (increased 61% and 70%, respectively). No significant differences were observed between IAA levels in control and Pb-exposed plants. The levels of this hormone in roots were below the detection levels. Leaves exposed to 10 and 100 mg Pb kg^{-1} and roots exposed to all Pb content showed levels of JA higher.

Source: https://www.ncbi.nlm.nih.gov/pubmed/30772622

Lead induces oxidative stress in Pisum sativum plants and changes the levels of phytohormones with antioxidant role (2019)



Evaluation of the leaves/roots damages. Effect of Pb exposure on cell membrane permeability, MDA (malondialdehyde) content and carbonyl concentration in leaves (A, C and E) and roots (B, D and F). Values are means ± SD (n = 6-8). Different small letters indicate significant differences between treatments at a significant level equal to 0.05.

Source: https://www.ncbi.nlm.nih.gov/pubmed/30772622

Evaluation of sunflower (*Helianthus annuus L.*) for phytoremediation of lead contaminated soil (2019)

Table 1: Effect of lead concentrations on some physiological traits of sunflower plant.

Treatment	Dose Pb mg.kg^{-1}						Mean	LSD 0.05
	0	50	100	150	200	250		
(%) RWC (Relative water content	85	79	76	63	61	51	69	**29.44**
Chl a (mg.g^{-1} fresh weight)	5.62	5.51	4.81	5.03	4.61	4.24	4.97	**N.S**
Chl b(mg.g^{-1} fresh weight)	3.17	3.16	3.35	2.72	2.86	3.04	3.05	**N.S**
Carotenoids (mg.g^{-1} fresh weight)	**2.59**	**2.90**	**2.34**	**2.31**	**1.99**	**2.10**	**2.37**	**N.S**

The exposure to Pb ions decreased the relative water content. In the control plants a very high relative water content (RWC) was observed accompanied by very good cell turgor. Plants treated 250mg Pb.kg^{-1} soil showed significant decrease in RWC by 67% at 250mg Pb.kg^{-1} soil. Pb can alter the water relations by disturbing water balance throughout the effects on stomatal conductance, water transport and cell wall elasticity, and thereby influences the cell turgor pressure (Elzbieta and Miroslawa, 2005). Results of current study reveal no significant change in chlorophll a, and b and carotinoids, indicated that sunflower plant may has a high ability to tolerate Pb stress.

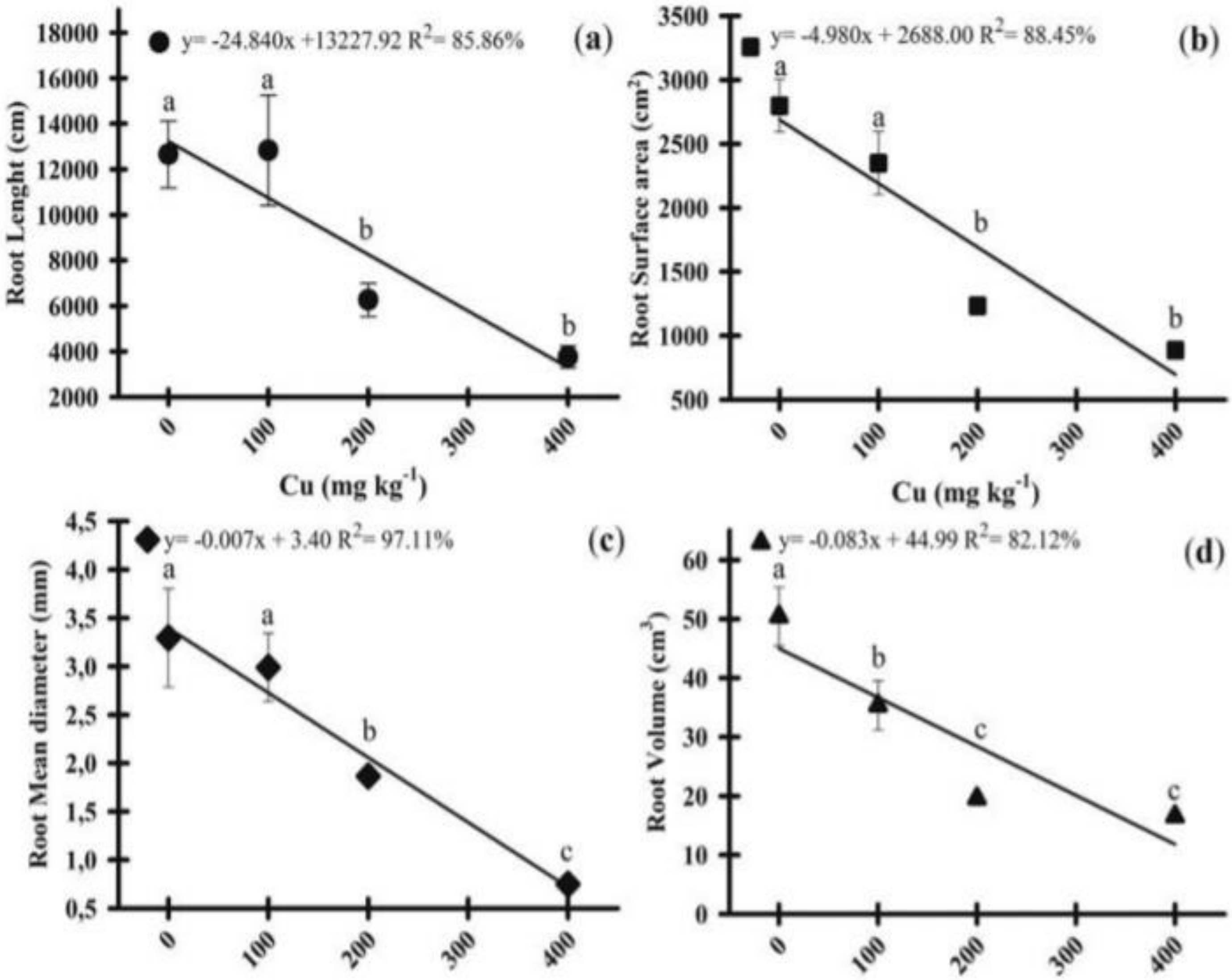
Table 2: Lead concentrations of tested soil before and after treatment with lead.

Test soil	Dose Pb mg.kg^{-1}						Mean	LSD (Least significant difference) 0.05
	0	50	100	150	200	250		
Before treatment	3.88	3.88	3.88	3.88	3.88	3.88	3.88	-
After treatment	**2.80**	**26.03**	**51.74**	**154.84**	**193.91**	**2.19.31**	**108.11**	**58.13**

The findings of Fulekar (2016) have proved the potential of sunflower plants for remediation of metals from contaminated soil-water environment. After harvesting, Pb concentrations in the soil increased linearly ($p \geq 0.05$) with increase of Pb doses added to the soil, the higher rate was (219.31 mg.kg^{-1}) at 250 mg Pb.kg^{-1} soil. Pb accumulation in soil increased significantly in Pb treatments (p p $\geq$0.05) compared to control treatment. The table shows that at the concentrations 150,200 and 250 mg.kg^{-1} soil the effect of Pb was higher and gave 154.84, 193.91 and 291.31 mg.kg^{-1} than at 50 and 100 mgPb.kg^{-1} soil which gave 26.03 and 51.74 mg.kg^{-1}.

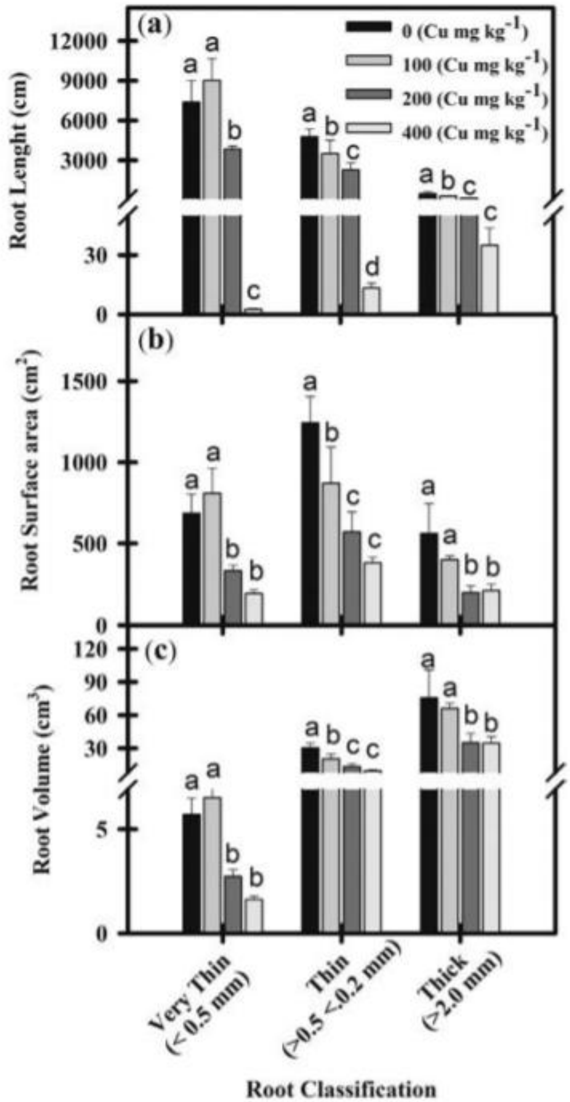
Source:https://search.proquest.com/openview/7e4eea8c2ab721e20eb9481b4a2a96b0/1?pq-origsite=gscholar&cbl=54977

Root morphology and leaf gas exchange in Peltophorum dubium (Spreng.) Taub. (Caesalpinioideae) exposed to copper-induced toxicity (2019)



Root and dry weight characteristics of P. dubium roots including the (a) length, (b) surface area, (c) mean diameter and (d) volume after plants were exposed to different copper concentrations ($p \leq .05$). Means between treatments followed by the same letter are not statistically different by the Skott-Knott test at 5% probability ($p \leq .05$). Each value indicates mean ± SE.

As soil Cu concentrations increased, there was a linear decrease in length, surface area, mean diameter and root volume in P. dubium ($p \leq .05$). Plants grown in soil that contained 200 and 400 mg kg^{-1} Cu had reduced root length (2.5×), root surface area (2.4×) and root mean diameter (2.4×) compared to plants treated with 100 mg kg^{-1} Cu or the control treatments (Fig. a–c). In addition, plants exposed to 400 mg kg−1 Cu presented a significant reduction in their root volume, which was 3× less than that measured in the the control plants (Fig. d).



Root length, (b) root surface area and (c) root volume organized by diameter class in P. dubium exposed to different Cu concentrations. Means between treatments followed by the same letter do not statistically differ from one another by the SkottKnott test at 5% probability ($p \leq .05$). Each value indicates mean ± SE.

Approximately 90% of the P. dubium root system consists mainly of very thin roots (b0.5 mm). These thin roots were significantly reduced in length, surface area and volume (Fig. a–c) when grown in soil with 200 and 400 mg kg $^{-1}$ Cu compared to control plants ($p \leq .05$). Low Cu treatment (100 mg kg^{-1}) affects negatively TR and THR, but improved VTR, although this later effect was not significant. In addition, the number fine (TR) and thick roots (THR) were also reduced with the application of 400 mg kg^{-1} Cu compared to control conditions (Fig. a–c).

Source: http://sci-hub.tw/https://doi.org/10.1016/j.sajb.2018.11.007

Mechanisms of copper stress alleviation in Citrus trees after metal uptake by leaves or roots (2018)

Table 1: Nutrient concentrations in the sap leakage from trunk and twigs of sweet orange trees 180 days after Cu application via soil or leaf sprays ($CuSO_4$ or $Cu(OH)_2$)

Cu treatment	$N-NO_3$	$N-NH_4$	P	K	Ca	Mg	S	Cu
Cu per plant (g)	mg L^{-1}							
Soil application of $CuSO_4$								
8.0	3.8 ± 0.6§	4.0 ± 1.2	0.6 ± 0.2	100 ± 18	277 ± 30	76 ± 9	3.8 ± 0.5	1.5 ± 0.3
Foliar application of $CuSO_4$								
0.5	2.7 ± 0.4	4.7 ± 0.7	3.0 ± 0.9	9 ± <1	410 ± 26	36 ± 1	8.9 ± 2.2	10.3 ± 1.3
2.0	3.0 ± 0.2	4.3 ± 0.3	2.0 ± 0.9	9 ± 3	405 ± 12	55 ± 11	3.8 ± 0.3	15.5 ± 1.7
Foliar application of $Cu(OH)_2$								
2.0	3.1 ± 0.3	4.9 ± 0.8	1.7 ± 0.6	8 ± 2	459 ± 14	41 ± 4	6.9 ± 2.2	10.3 ± 0.4

Standard deviation of the mean (n = 4)

Source: https://link.springer.com/content/pdf/10.1007%2Fs11356-018-1529-x.pdf

Copper excess reduces nitrate uptake by Arabidopsis roots with specific effects on gene expression (2018)

Category	Product	N	Ni content (μg kg^{-1})			
			Mean	Minimum	P50	Maximum
Beer	Pilsener	46	4.5	1.5	4.4	8.1
	Top-fermented beer	67	7.7	2.0	6.7	21.4
	Sour beer	35	12.9	2.0	10.5	33.8
Coffee beverages[a] (prepared with ultrapure water through domestic protocol)	Ground	5	16.8	6.0	8.1	36
	Unground	5	7.0	3.0	5.4	13
Coffee beverages[b] (prepared with ultrapure water through Golden coffee protocol)	Ground	5	12	2.0	7.8	26
Commercial coffee drinks[c]		3	17	4.0	9.0	38
Tea beverages[d] (prepared with ultrapure water through domestic protocol)	Black tea	4	85	72	73	121
	Green tea	4	194	112	207	252
Tea beverages[e] (prepared with ultrapure water through ISO 3130 protocol)	Black tea	2	56	28	56	84
	Green tea	2	85	66	85	105
Ice tea	Without flavour	6	34	13	32	58
	Lemon	5	26	14	28	34

Elevated copper (Cu) affected the concentration of phosphorus (P), calcium (Ca), iron (Fe), manganese (Mn) and boron (B) in the shoots and Fe and Mn in the root of Arabidopsis thaliana supplied with different Cu levels in the nutrient solution for 72 h or 15 days (15d).

a

For the Cu treatments for 72 h different lowercase letters indicate mean values are significantly different among the [Cu] (0.16, 5.0, 10.0 and 20.0 μM) by Tukey's test ($p < 0.05$).

b

For the Cu treatments for 15 days different uppercase letters indicate mean values are significantly different between the [Cu] (0.16 and 5.0 μM) by Tukey's test ($p < 0.05$).

Source: https://www.sciencedirect.com/science/article/pii/S0176161718302888

Copper toxicity and date palm (Phoenix dactylifera) seedling tolerance: Monitoring of related biomarkers (2017)

Table: Copper (Cu) effect on different physiological parameters of date palm (Phoenix dactylifera) seed germination

Cu (mM)	SG (s/d)	MDG (s/d)	MGT (d)	PV (s/d)	SLM (%)	GI (%)
0	159.36 ± 5.6	0.163 ± 0.01	287.77 ± 6.4	0.49 ± 0.16	2.78 ± 0.33	100
0.02	167.2 ± 4.3	0.164 ± 0.04	289.28 ± 4.6	0.49 ± 0.03	2.78 ± 0.33	98.04
0.2	172.32 ± 5.3	0.166 ± 0.00	293.93 ± 2.4	0.66 ± 0.00	0 ± 1	84.36
2	138.09 ± 5.9	0.134 ± 0.01	234.11 ± 3.3	0.40 ± 0.02	3.05 ± 2.5	8.37

SG = speed of germination; MDG = mean daily germination; MGT = mean germination time; PV = peak value; SLM = seedling mortality; GI = germination index.

Source: https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4007

Effect of copper on nutrients content (mg g^{-1} dry wt.) of radish (45^{th} day) (2017)

Copper added in the soil (mg kg^{-1})	N	P	K	Na	Ca	Mg
Control	32.66	6.31	43.52	1.70	13.56	3.99
50	37.35(+14.36)	6.97(+10.45)	52.09(+19.69)	2.11 (+24.11)	15.98 (+17.84)	4.91 (+23.05)
100	25.28 (22.59)	5.71 (-9.50)	36.78 (-15.48)	1.39 (-18.23)	12.25 (-9.66)	3.48 (-12.78)
150	23.73 (27.34)	5.06 (-19.80)	32.17 (-26.07)	1.28 (-24.70)	11.14 (-17.84)	3.05 (-23.55)
200	20.98 (35.76)	4.81 (-23.77)	30.37 (-30.21)	1.16 (-31.76)	11.30 (-19.05)	2.75 (-31.07)
250	18.07 (44.67)	3.90 (-38.19)	25.11 (-42.30)	1.10 (-35.29)	10.68 (-21.23)	2.11 (-47.11)

Average of five replications
Per cent over control values are given in parentheses

Source: https://ijarbs.com/pdfcopy/apr2017/ijarbs12.pdf

Changes in the plant height, root length, total dry weight, and leaf area of the lentil plants subjected to different treatments of copper stress and P. vermicola inoculation (2016)

	Plant height (cm)	Root length (cm)	Total dry weight	
T0	$34.67{\pm}4.5^{a}$	$14.76{\pm}1.3^{b}$	$11.87{\pm}0.75^{ab}$	$110.00{\pm}3.79^{b}$
T1	$22.78{\pm}3.8^{c}$	$7.34{\pm}0.50^{d}$	$7.20{\pm}1.0^{c}$	$77.00{\pm}3.19^{c}$
T2	$37.30{\pm}5.9^{a}$	$16.80{\pm}1.15^{a}$	$12.40{\pm}1.4^{a}$	$136.00{\pm}5.03^{a}$
T3	$29.90{\pm}2.1^{b}$	$11.21{\pm}1.06^{c}$	$9.90{\pm}1.2^{b}$	$101.00{\pm}4.73^{b}$

Values are means±S.E. (n=3). Values carrying different letters are significantly different at P≤ 0.05 level As determined by Duncan'stestT0 non-contaminated soil, T1 Cu amended soil, T2 non-contaminated soil+P. vermicolainoculation,T3 Cuamended soil+P. vermicolainoculation

Source: Environ Sci Pollut Res (2016) 23:220–233

P. vermicola inoculation and copper induced changes in different photosynthetic attributes of lentil plants (2016)

Treatments	Gs (mol m^{-2} s^{-1})	Ci (ì mol mol^{-1})	E(mmol H2O $m^{-2}s^{-1}$)	A(ì mol CO2 $m^{-2}s^{-1}$)	A/E (ì mol CO_2 /mmol H_2O)
T0	0.049±0.003[b]	281±5.568[b]	0.512±0.012[b]	10.36±0.606[b]	0.291±0.011[b]
T1	0.023±0.001[d]	190±5.686[d]	0.255±0.104[d]	4.48±0.211[d]	0.103±0.003[d]
T2	0.079±0.002[a]	327±8.686[a]	0.595±0.014[a]	13.33±0.620[a]	0.331±0.007[a]
T3	0.037±0.00[c]	236±8.386[c]	0.423±0.012[c]	7.83±0.500[c]	0.243±0.006[c]

Values are means±S.E. (n=3). Values carrying different letters are significantly different at$P \leq 0.05$ level as determined by Duncan's testT0non-contaminated soil,T1Cu amended soil,T2non-contaminated soil+P. vermicolainoculation,T3Cu amended soil+P. vermicolainoculation

Source: springer.com/static/pdf/568/art%253A10.1007%252Fs11356-015-5354-1.pdf

Effect of Cu and castasterone on contents of various polyphenols (µg g^{-1}) in 60 days old B. juncea plants (2016)

Polyphenol detected	Control	10^{-7} M CS	0.50 mM Cu	0.50 mM Cu +10^{-7} M CS
Catechin	nd	nd	32.348	161.128
Chlorogenic acid	96.824	108.236	91.516	63.064
Epicatechin	nd	nd	32.94	48.188
Caffeic acid	509.832	443.156	482.524	416.696
Coumaric acid	0.6	0.3	5.14	0.824
Rutin	37.9	31.548	44.676	55.04
Quercetin	2.524	0.832	nd	nd
Umbelliferone	nd	1.544	47.752	7.436
Ellagic acid	61.248	87.732	41.288	338.328
Kaempferol	nd	22.832	28.584	42.592
Tert-butyl hydroquinone	nd	nd	1.332	nd
Total content	708.928	696.18	808.1	1,133.296

Note: nd—not detected.

Poonam at al.(2016), Castasterone assisted accumulation of polyphenols and antioxidant to increase tolerance of B. juncea plants towards copper toxicity, Cogent Food & Agriculture

Source: https://www.tandfonline.com/doi/full/10.1080/23311932.2016.1276821

Relationship between copper concentration in growth medium and its uptake in crops. Copper was mainly accumulated in roots and less translocated to shoots. Cu in plant parts did not linearly increase with increasing Cu levels in the growth medium (2015)

Exp.	**Cu concentration in medium**	**Duration (days)**	**Crop type**	**Uptake and accumulation (mg kg^{-1})**	**References**
Hydroponics	50 to 150 μM	10	Rapeseed	Leaves 107.9–203.1	Ivanova et al. 2010
				Root 297.3–383.7	
	0.1 to 10 mM	6	Maize	Root 5.9–1668.2	Benimali et al. 2010
	10 to 50 μM	14	Rapeseed	Root 740.40–2478	Feigl et al. 2013
				Shoot 57.6–82.01	
				Shoot 5.83–594.8	
				Leaves 13.5–160.9	
	10 to 50 μM	14	Indian mustard	Root 686.1–3637	Feigl et al. 2013
				Shoot 49.7–88.2	
	4 to 80 μM	15	Maize	Root 299–7790	Ouzounidou et al. 1995
	75 μM	7	Wheat	Root 618.5	Gajewska and Sklodowska
				Shoot 21.5	2010
	10^{-3} M	6	Maize	Root 1070	Lin et al. 2003
				Shoot 56	
	1.6 to 192 μM	35	Soybean	Leaves 67	Sanchez-Pardo et al. 2014
Sand	20 mg kg^{-1}	20	Cucumber	Root 299	Alaoui-Sossé et al. 2004
Soil	1338 mg kg^{-1}	50	Green gram	Root 60	Wani et al. 2007
				Shoot 26.2	
	50 to 250 mg kg^{-1}	45	Green gram	Shoot 46.6–150	Manivasagaperumal et al. 2011

Source:https://www.researchgate.net/profile/Muhammad_Rizwan16/publication/274963313_The_effect_of_excess_copper_on_growth_and_physiology_of_important_food_crops_a_review/links/5711f8c308aeff315ba038e1/The-effect-of-excess-copper-on-growth-and-physiology-of-important-food-crops-a-review.pdf