

Original Research Article

Effect of Lead Contamination on morphological attributes and biomass allocation of *Bambusa balcooa*(Roxb.)

Abstract

Lead contamination in the agricultural soil by anthropogenic activities, industrialization and modernization poses a great concern to human health. A pot experiment was completed to evaluate the effect of Pb concentrations (0, 150, 500, 1000, 1700 mg kg⁻¹) of lead nitrate on *Bambusa balcooa* plantlets grown in earthen pots placed in a fenced enclosure. For each concentration, three replicates were taken and to reduce the heterogeneity in the results, pots were placed in randomized manner. Thereafter, plantlets were transplanted in the pots and grown in the natural condition, only rainfall was controlled by covering the fenced enclosure with polythene sheet. The result showed that a higher concentration of Pb caused a minimum increase the number of culm (0%), nodes (25%), leaves (58.53%), length of internode (19.04%), plant height (32.89%) and leaf area (62.91%). Biomass of the plant ranged from 5.33± 0.57 to 37.33±6.42g and moisture content was found maximum in Pb 500 mg kg⁻¹ (38.78%) throughout the experiment. Findings of the study indicates that *B. balcooa* can tolerate the elevated level of Pb toxicity and can be used for remediation purpose.

Keywords: *Bambusa balcooa*, Phytoremediation, Lead, Soil, Environment

1 Introduction

Lead (Pb) is a persistent, highly noxious and non-disintegrative heavy metal after arsenic which comprises 0.002% of Earth's crust (Zulfiqar et al., 2019). In the environment, Pb has various origin as it can arise from natural processes such as rock weathering, volcanic eruptions, forest fires, and soil-forming or can be originated from anthropogenic processes such as industrial waste, fertilizer applications, smelting, and sewage disposal. Excessive Pb concentration causes deleterious effects in plants such as a decline in photosynthetic rate, chlorophyll synthesis, disturbed Calvin cycle, closed stomata due to deficiency of CO₂, growth inhibition which is inseparably connected with cell division, limits the mineral nutrition and water balance and enzyme activities. It also brings the alteration in lipid composition and chlorophyll b content (Collin et al., 2022). At higher concentrations

sunflower plants showed reduction in height, number of leaves and dry matter of the plant (Hung et al., 2014). Collin et al. (2022) recorded 4.5-fold higher Pb concentration in Blackberry plant's leaves than the fruits. And blackberry contain 71% more Pb content which exceeds 29 times more of the WHO threshold. The consumers are at high risks who take 100g fresh blackberries which consist 8.51 mg Pb. Opeolu et al. (2010) reported a lesser number of flowers in sunflowers under high concentration of Pb and in soybean, histological changes in leaves such as thin blade leaf, minified xylem and phloem in vascular bundle, reduction in diameter of xylem vessels were observed under Pb contamination (Hadi and Aziz, 2015). The increasing amount in the environment causes harmful effects on climate and human health (Lathwal et al., 2023a). Lead is also known as protoplasmic poison (Hadi and Aziz, 2015). The maximum acceptable intake of Pb in human food is about $25 \mu\text{g kg}^{-1}$ of human body weight per week. In soil, Pb content may occur up to 10ppm (Agrawal, 2009) but for humans, the maximum permissible range is 0.003mg/l (WHO, 2017) and 0.005mg/l by Rani et al. (2023). To overcome these issues, remediation of the soil is needed and many approaches are available to reduce the contaminants from the soil but phytoremediation is one of the best remediation strategies.

Phytoremediation is the process of remediation in which plants are used to restore the degraded land either by heavy metal (such as Pb) or by soil erosion and other cause. Grasses are more suitable for the remediation of heavy metal-contaminated soil due to their large biomass production, ability to easily reproduce and robust rhizome and root system (Malik and Biswas, 2012). Among the grasses, bamboo is a widely distributed, fast growing, renewable, and environment-enhancing resource which has great potential to environmental conservation (control soil erosion, rehabilitation, carbon sequestration, water conservation and biodiversity conservation) and improve poverty alleviation. An extensive rhizome-root system and accumulation of bamboo leaf mulch serves as an efficient agent in preventing soil erosion, runoff reduction, facilitating infiltration, moisture conservation and accumulation of contaminants in the plant parts. These special characteristics make bamboo a good candidate for the phytoremediation of heavy metal-contaminated soil (Lathwal et al., 2023b). The objective of the current study is to evaluate the efficiency of *B. balcooa* in the remediation of Pb contaminated soil and their effects on the growth parameter of the plants.

2 Material and Methods

2.1 Test plant

B. balcooa, a perennial, hardy, tropical clumping and multipurpose bamboo was chosen as the test plant for this study. It is indigenous to Northeast India, Bangladesh, Laos, Myanmar, Nepal, and Vietnam (Rajput et al., 2020). It can be found up to an altitude of 600 m in various climate conditions and found throughout India. It can grow up to 25 cm in height and a diameter of 1-15cm. The leaves are dull and greyish-green. The average estimated carbon storage in the above-ground biomass is 65.3 tons/ha (Nath et al., 2018). It has the ability to grow on any soil type but prefer low pH, heavy texture and good drainage soil. It maybe cultivated by farmers and generates 104.7 Mg ha⁻¹ of above-ground biomass (Devi and Singh, 2021). In Bangladesh, it has reported that *B. balcooa* producing 120-1700 culms per hectare per year (Mulatu et al., 2016).

2.2 Experimental design and soil characteristics

The experiment was conducted in the Department of Botany, Panjab University, Chandigarh (India) in a well-protected dome covered with a transparent polythene sheet.

2.2.1 Soil collection and analysis

The soil was taken from P.N. Mehra Botanical Garden of Panjab University, Chandigarh. The collected soil was analysed for their initial physicochemical properties such as soil type, pH, cation exchange capacity, electrical conductivity, exchangeable sodium percentage, sodium absorption ratio, nitrogen, phosphorus and potassium. Initial content of the lead (Pb) was also measured through Inductively coupled plasma atomic absorption spectrometry (ICP-OES).

2.2.2 Plantlet collection and transplantation

Five months old *B. balcooa* plantlets that were gathered from the Forest department, Rupnagar, Punjab. For the experiment, plantlets were transplanted into earthen pots filled with 7 kg air-dried soil. Five different concentration of lead nitrate (0, 150, 500, 1000, and 1700 mg kg⁻¹ soil) were taken for the study. Three replicates of each concentration were used and doses were applied in aqueous form. To reduce the heterogeneity in the findings, the experiment was carried out from January to December 2021 (a period of 365 days).

2.3 Vegetative characters

After the application of different doses, morphological characteristics such as the number of culms, nodes, leaves, the length of the internode, the height of the plant, and the area of the leaves were counted in every 30 days.

- a) Number of culms, number of leaves and nodes were counted manually.
- b) The length of internodes was measured by measuring scale. Three internodes length were taken from the 2nd internode from the base of the plant and expressed in the cm.
- c) Height of the plant was measured by measuring scale from the bottom of the pot to the tip of the plants and expressed in the centimetre.
- d) Leaf area was measured by the scale by measuring maximum width and length of the three leaves of each replicate and measured by the following formula:

$$\text{Leaf area (cm}^2\text{)} = (\text{length} \times \text{breadth}) \times 0.7 \text{ (Shi et al., 2021)}$$

- e) Biomass was calculated after uprooting the plants. The plant parts were separated as stem, root and leaves and their fresh weight (f.w.) was taken. The plant parts were oven dried at 50-60°C for 72 hours and their dry weight (d.w.) was measured in grams (g).
- f) Moisture Content: Moisture content was measured with the help of fresh and dry weight and expressed in percentage (%)

$$\text{Moisture (\%)} = \frac{\text{Fresh weight (f.w.)} - \text{Dry weight (d.w.)}}{\text{Fresh weight (f.w.)}} \times 100$$

Statistical Analysis

Data was statistically analysed through IBM 26 SPSS software. All the estimated values are the average of the three independent variables. Multivariate analysis of variance (three-way ANOVA) is used to assess the data at significant $p < 0.05$ probability levels to examine the effects of treatment doses, days after treatment (DAT), and their interactions.

3 Results and discussion

3.1 Physicochemical properties of the soil

Initial physicochemical characteristics of the soil indicated that the soil is sandy loam (sand 60%, silt 20%, and clay 20%), neutral pH (7.1), EC (0.33), CEC (7.0 meq/100 g), ESP (8.14 meq/100g), SAR (0.048), OC (1.00%), WHC (4.11 g g⁻¹) Ca+Mg (1.8), N (246 kg/ha), P (12.7 kg/ha) and K (107.44 kg/ha). Initial Pb content in the soil was 9.3 mg/kg (Table 1).

These characteristics showed that the soil is fertile and suitable for the growth of the selected plant (*B. balcooa*) for the experiment.



Fig.1. ICP-AES- Determination of Heavy metal concentration in soil

Table 1 Physicochemical properties of the soil

Sr. No.	Parameter	Value	Methods used for analysis
1.	Texture	Sandy loam soil	International Pipette Method
2	CEC (meq/100 g)	7.0	Centrifuge method (Ross and Kettering, 1995)
3.	ESP (meq/100g)	8.14	Centrifuge method (So et al., 2006)
4	SAR (meq L ⁻¹)	0.048	$SAR = \frac{[Ca^{2+} + Mg^{2+}]}{[C + M]}$
5.	EC _{1:2} (dS m ⁻¹)	0.33	Digital EC meter
6.	pH _{1:2}	7.1	Digital pH meter
7.	OC (%)	1.0	Wet digestion Method (Sangmanee et al., 2016)

8.	Water holding capacity (g g ⁻¹)	4.11	Cylinder method (Wilke, 2005)
9.	Ca+Mg (meq L ⁻¹)	1.8	EDTA method (Bascomb, 1964)
10.	Available N (kg ha ⁻¹)	246	Kjeldahl- Distillation method (Ravi et al., 2023)
11.	Available P (kg ha ⁻¹)	12.7	Olsen, 1965 method (Correia et al., 2023)
12.	Available K (kg ha ⁻¹)	107.44	Ammonium acetate method (Kobayashi et al., 2023)
13.	Pb (mg kg ⁻¹)	9.3	ICP-OES

3.2 Effect of Pb on morphological traits

The following morphological characteristics, including the number of culms, leaves, nodes, length of internodes, plant height, and leaf area, were noted in order to assess the impact of lead concentration.

3.2.1 Number of culms

The heavy metal content had a significant impact on the number of culms ($F_{4,15} = 3.496$, $p < 0.01$) as well as the days after treatment ($F_{12,15} = 3.251$, $p < 0.00$) according to an ANOVA analysis. As a result, between treatments and DAT, the number of culms ranged from 2 to 4 (Fig 2).

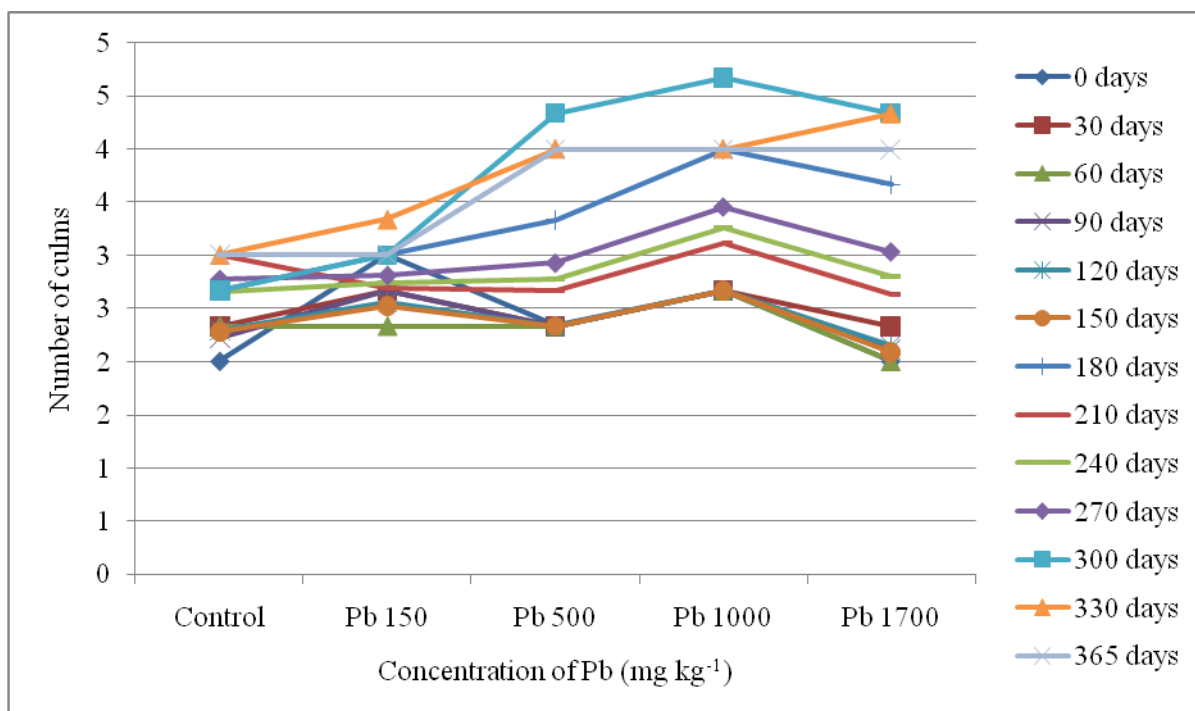


Fig 2. Effect of Pb on number of culms

3.2.2 Number of leaves

heavy metal concentrations and DAT had a significant impact on the number of leaves ($F_{4,15} = 4.097$, $p < 0.004$ and $F_{12,15} = 10.249$, $p < 0.000$) respectively. From initial to 210 DAT, there was an increase in the number of leaves, which thereafter dropped by 27.16%, 46.4%, 70.9%, and 66.06% at 150, 500, 1000, and 1700 mg/kg, respectively (Fig 3). The reduction in number of leaves may be due to limitation in the intake and transport of numerous minerals (Ca, Mg, P, and K) and reduction in photosynthetic activity (Chen et al. 2022).

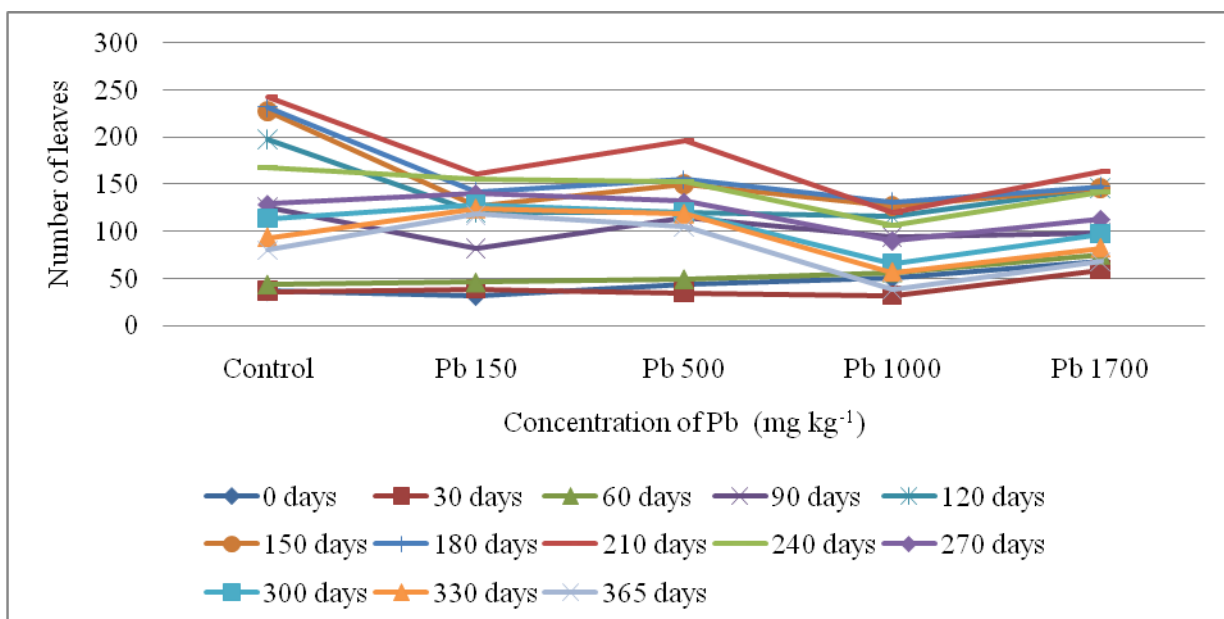


Fig 3 Effect of different Pb concentrations on number of leaves

3.2.3 Number of Nodes

Pb-treated plants showed a substantial drop in the number of nodes with the increase in heavy metal content when compared to the control, which varied from 4 to 10 (Fig 4). The decrease in number of nodes may be caused by oxidative stress induced by Pb stress that leads to decrease in mitotic activity in the cell (Shehzad et al., 2023).

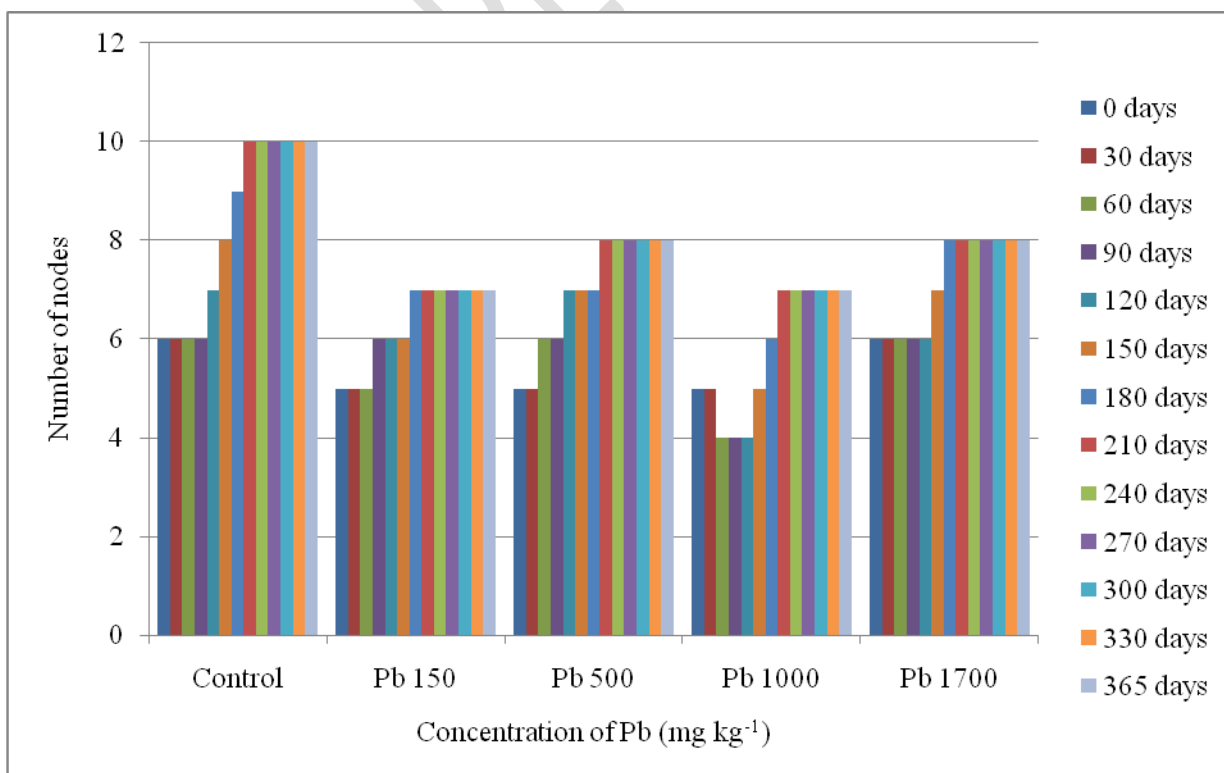


Fig 4 Effect of various concentrations on number of nodes

3.2.4 Leaf Area

Maximum and minimum increases in leaf area were recorded at 150 and 1700 mg kg⁻¹ (65.32±12.71 cm² and 43.01±28.80 cm² respectively) (Fig 5). Statistical analysis indicated that Pb concentration had a significant impact on leaf area ($F_{4,15} = 3.214$, $p < 0.01$) and DAT had a significant impact ($F_{12,15} = 16.242$, $p < 0.000$). The decrease in leaf area may be caused by a reduction in gaseous exchange in the leaves, the closing of stomata, and water stress, which led to a decline in photosynthetic rate (Huihui et al., 2020). Shu et al. (2012) also reported the decrease in leaf area, root length and protein content under Pb stress.

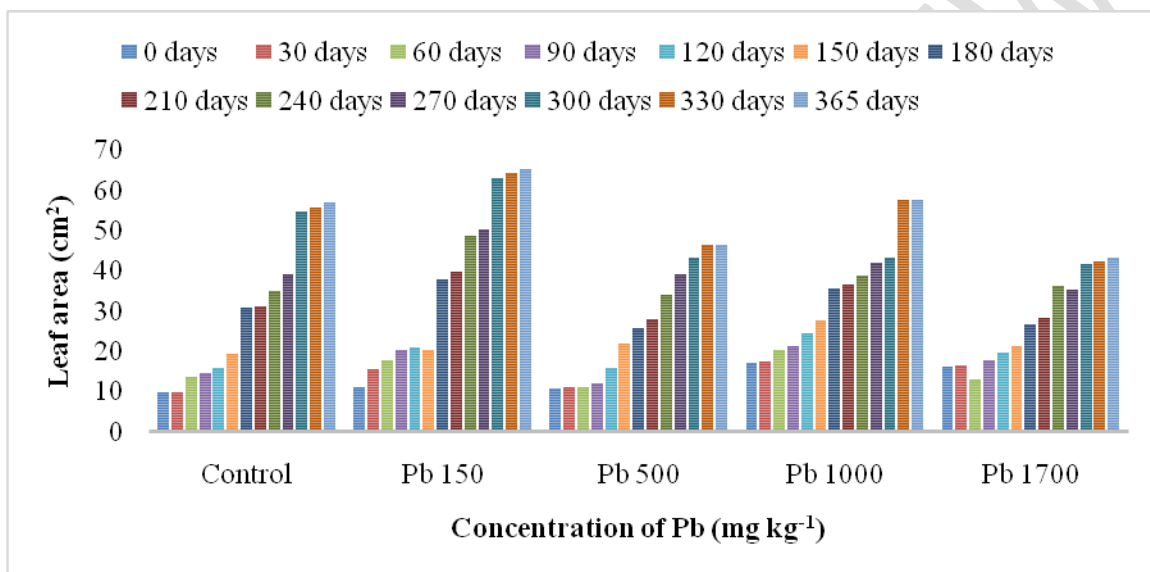


Fig 5 Effect of different doses of Pb on leaf area

3.2.5. Plant height

There was a significant change in the plant height with varying concentrations of Pb ($F_{4,15} = 2.384$, $p < 0.05$) and DAT ($F_{12,15} = 8.739$, $p < 0.000$). As a result, this growth parameter values ranged from 44.36 cm to 135.66 cm in all the concentrations. the maximum and minimum increase in plant height was recorded in control and Pb 1700 mg kg⁻¹ (64.69% and 32.89%) respectively when compared to other treatments (Fig 6). Insufficient water and nutrient availability can limit plant growth including the elongation of stems and overall plant height. Similar results were reported by Ghani et al. (2021) in *Daucus carota* where the plant height decreased with the elevated level of Pb.

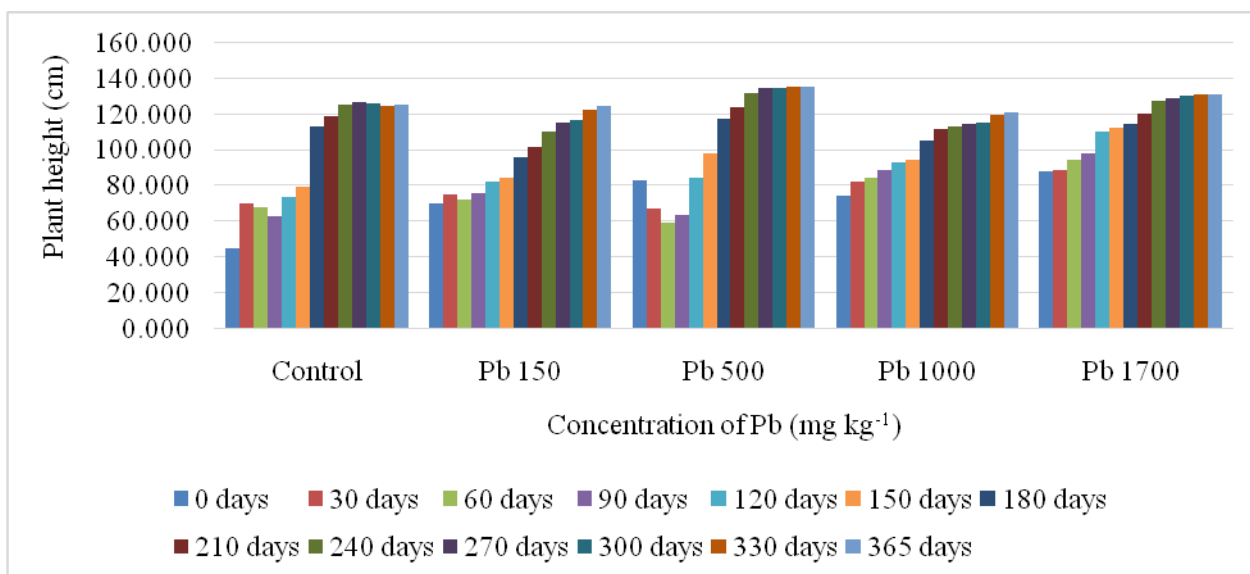


Fig 6 Effect of Pb on plant height of the plant

3.2.6 Internode Length

Internode length decreased with a high Pb concentration, and treatments and DAT both significantly affected internode length ($F_{4,15} = 10.486$, $p < 0.00$) and DAT ($F_{12,15} = 4.784$, $p < 0.00$) (Fig 7). The most significant drop for this vegetative property was in 1700 mg kg⁻¹, ranging from 8.10 to 16.12 cm. Water stress due to Pb stress can lead to a reduction in cell expansion, which ultimately caused decrease in internode length (Asati et al., 2016).

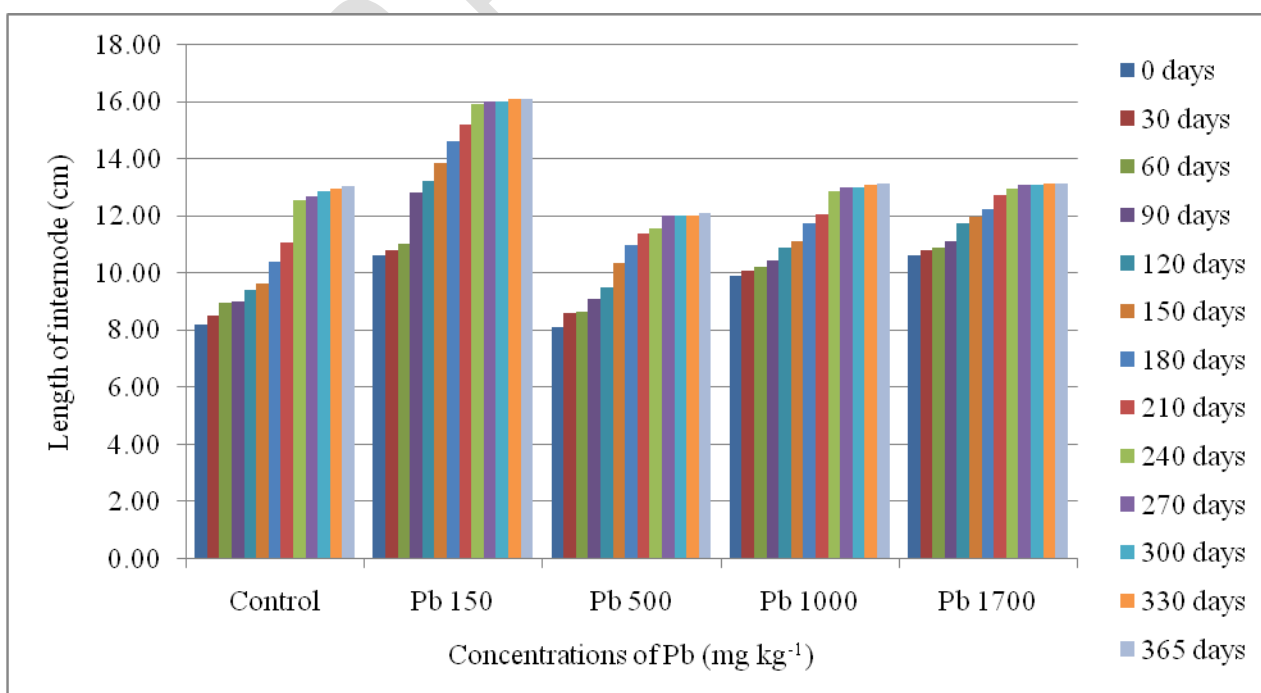


Fig 7 Effect of different Pb concentration on length of the Internode of the plant

3.2.7. Biomass

Biomass was significantly influenced by the various concentration of Pb. At lower concentration biomass was positively stimulated but at higher concentration it declined. The fresh and dry root, stem and leaf biomass was ranges from 20.00-33.67g, 21.33-37.33g and 6.67-22.67g; 13.33-24.67g, 17.33-27.33g and 5.33-18.67g respectively (Table 2). At higher concentration plant may be unable to tolerate the oxidative stress caused by Pb toxicity and inhibits the cell division, cell expansion and reduction in photosynthetic activity by destroying the chloroplast structure (Kaur et al., 2014; Silva et al., 2017). In *Brassica napus*, Pb stress significantly reduced the plant biomass, leaf chlorophyll contents, nutrients uptake in the leaves and roots (Ali et al., 2014).

Table 2. Data represents mean± S.D. of three replicates (n=3). Different letters superscript in column indicates the significant difference (p<0.05) in the biomass content under different concentration of Pb.

Doses of Pb (mg/kg soil)	Root biomass (g)		Stem biomass (g)		Leaf biomass (g)	
	f.w.	d.w.	f.w.	d.w.	f.w.	d.w.
Control	22.33±10.5 ^{ab}	18.67±9.01 ^{ab}	21.33±5.68 ^a	17.33±3.05 ^a	10.0±2.00 ^a	8.67±1.52 ^a
Pb 150	33.67±5.13 ^b	24.67±3.51 ^b	37.33±6.42 ^b	27.33±7.02 ^b	22.67±5.13 ^b	18.67±5.50 ^b
Pb 500	32.67±11.71 ^{ab}	20.00±5.00 ^b	27.33±9.01 ^{ab}	22.67±6.80 ^{ab}	10.67±1.52 ^a	8.67±0.57 ^a
Pb 1000	20.00±6.92 ^a	13.33±4.16 ^a	23.33±7.37 ^a	18.67±5.85 ^a	7.33±1.15 ^a	5.33±0.57 ^a
Pb 1700	20.67±1.154 ^a	13.33±1.15 ^a	23.33±4.61 ^a	20.00±4.35 ^{ab}	6.67±2.51 ^a	5.33±2.08 ^a

3.2.8. Moisture content

Moisture content measures the water content in the plants. Under Pb stress, roots had the highest moisture content at Pb 500 mg kg⁻¹ (38.78%). By increasing the moisture content, plant tries to mitigate the toxic effects of the Pb stress but at higher concentration moisture content decreased (Malar et al., 2016).

Table 3 Effect of Pb concentration on moisture content in plant parts.

Concentration of Pb in soil (mg/kg)	Moisture content (%)		
	Root	Stem	Leaf
Control	16.39	18.75	13.30
Pb 150	26.73	26.79	17.64
Pb 500	38.78	17.05	18.74
Pb 1000	33.35	19.97	27.29
Pb 1700	35.51	14.27	20.09

Conclusion

The current study highlights the toxic effect of lead on different growth parameters of the *B. balcooa*. Lead poses a significant effect on the number of culms, nodes, leaves, plant height, internode length and leaf area. The impact of lead on these growth parameters are correlated with the biomass of the plant. Results indicated that *B. balcooa* can tolerate the higher concentration of Pb (1700 mg/kg) as there is 100% survival efficiency was recorded. Therefore, better utilization of *B. balcooa* can be implemented to remediate the lead contaminated soil which in turn will provide a better environment.

References

Ali, B., Mwamba, T.M., Gill, R.A., Yang, C., Ali, S., Daud, M.K., Wu, Y. and Zhou, W., 2014. Improvement of element uptake and antioxidative defense in *Brassica napus* under lead stress by application of hydrogen sulfide. *Plant growth regulation*, 74:261-273.

Asati, A., Pichhode, M. and Nikhil, K., 2016. Effect of heavy metals on plants: an overview. *International Journal of Application or Innovation in Engineering & Management*, 5(3):56-66.

Bascomb, C.L., 1964. Rapid method for the determination of cation- exchange capacity of calcareous and non- calcareous soils. *Journal of the Science of Food and Agriculture*, 15(12):821-823.

Chen, F., Aqeel, M., Maqsood, M.F., Khalid, N., Irshad, M.K., Ibrahim, M., Akhter, N., Afzaal, M., Ma, J., Hashem, M. and Alamri, S., 2022. Mitigation of lead toxicity in *Vigna radiata* genotypes by silver nanoparticles. *Environmental Pollution*, 308:119606.

Collin, M.S., kumar Venkataraman, S., Vijayakumar, N., Kanimozhi, V., Arbaaz, S.M., Stacey, R.S., Anusha, J., Choudhary, R., Lvov, V., Tovar, G.I. Senatov, F., 2022. Bioaccumulation of lead (Pb) and its effects on human: A review. *Journal of Hazardous Materials Advances*, p.100094.

Correia, B.L., Kovar, J.L., Thompson, M.L., Pavinato, P.S. and Alleoni, L.R.F., 2023. Sugarcane green harvest management influencing soil phosphorus fractions. *Soil and Tillage Research*, 231:105713.

Devi, A.S. and Singh, K.S., 2021. Carbon storage and sequestration potential in aboveground biomass of bamboos in North East India. *Scientific Reports*, 11(1):837.

Ghani, M.A., Abbas, M.M., Ali, B., Aziz, R., Qadri, R.W.K., Noor, A., Azam, M., Bahzad, S., Saleem, M.H., Abualreesh, M.H. and Alatawi, A., 2021. Alleviating role of gibberellic acid in enhancing plant growth and stimulating phenolic compounds in carrot (*Daucus carota* L.) under lead stress. *Sustainability*, 13(21):12329.

Hadi, F. and Aziz, T. 2015. A mini review on lead (Pb) toxicity in plants. *Journal of Biology and Life Science*. 6(2):91-101.

Huihui, Z., Xin, L., Zisong, X., Yue, W., Zhiyuan, T., Meijun, A., Yuehui, Z., Wenxu, Z., Nan, X. and Guangyu, S., 2020. Toxic effects of heavy metals Pb and Cd on mulberry (*Morus alba* L.) seedling leaves: Photosynthetic function and reactive oxygen species (ROS) metabolism responses. *Ecotoxicology and environmental safety*, 195:110469.

Hung, N.M., Hiep, N.V., Dung, B.N. Hai, N.X., 2014. Lead Accumulation in different parts of okra plant (*Abelmoschus esculentus*). *ARNP Journal of Agricultural and Biological Science*, 9(6):190-194.

Kaur, G., Singh, H.P., Batish, D.R. and Kohli, R.K., 2014. Pb-inhibited mitotic activity in onion roots involves DNA damage and disruption of oxidative metabolism. *Ecotoxicology*, 23:1292-1304.

Kobayashi, R., Masumori, M., Tange, T., Tanoi, K., Kobayashi, N.I. and Miura, S., 2023. Effect of Exchangeable and Nonexchangeable Potassium in Soil on Cesium Uptake by *Quercus serrata* Seedlings. In *Agricultural Implications of Fukushima Nuclear Accident (IV) After 10 Years* Singapore: Springer Nature Singapore, p 171-184.

Lathwal, M., Rani, M., Indira, A. Chongtham, N., 2023a. Bamboo: A Sustainable Alternative for Biochar Production. In *Bamboo Science and Technology* (pp. 265-295). Singapore: Springer Nature Singapore.

Lathwal, M., Rani, M., Singh, A.N. and Chongtham, N., 2023b. Impacts of Bamboo Biochar Amendment on Growth, Morphological Traits, and Biomass Allocation of *Bambusabalcooa* under Copper-Contaminated Soil Conditions. *International Journal of Plant & Soil Science*, 35(19):599-611.

Malar, S., Shivendra Vikram, S., JC Favas, P. and Perumal, V., 2016. Lead heavy metal toxicity induced changes on growth and antioxidative enzymes level in water hyacinths [*Eichhorniacrassipes* (Mart.)]. *Botanical studies*, 55(1):1-11.

Malik NA, Biswas, 2012. Role of higher plants in remediation of metal contaminated sites. *Sci Rev Chem Commun* 2:141-146

Mulatu, Y., Alemayehu, A. and Tadesse, Z., 2016. Bamboo Species Introduced in Ethiopia.

Nath, A.J., Sileshi, G.W. and Das, A.K., 2018. Bamboo based family forests offer opportunities for biomass production and carbon farming in North East India. *Land Use Policy*, 75: 191-200.

Opeolu, B.O., Adenuga, O.O., Ndakidemi, P.A. and Olujimi, O.O., 2010. Assessment of phyto-toxicity potential of lead on tomato (*Lycopersicon esculentum* L) planted on contaminated soils. *International Journal of the Physical Sciences*.

Rajput, B.S., Jani, M., Ramesh, K., Manokari, M., Jogam, P., Allini, V.R., et al., 2020. Large-scale clonal propagation of *Bambusabalcooa*Roxb.: An industrially important bamboo species. *Ind. Crop. Prod.* 157:112905.

Rani, M., Lathwal, M., Singh, A.N. Chongtham, N., 2023. Bamboo Act as a Phytoremediation Candidate for Heavy Metal Contaminated Soil: A Synthesis. In *Bamboo Science and Technology* (pp. 125-161). Singapore: Springer Nature Singapore.

Ravi, S., Jadhav, R.L., Bhat, S.N. and Shankar, K.A., 2023. Response of Iron and Boron on Uptake of Nutrients and Soil Nutrient Status after Harvest of Safflower Crop (*Carthamus tinctorius* L.) in Kalyan Karnataka, India. *International Journal of Plant & Soil Science*, 35(18):24-31.

Ross, D.S. and Ketterings, Q., 1995. Recommended methods for determining soil cation exchange capacity. Recommended soil testing procedures for the northeastern United States, 493(101):62.

Sangmanee, P., Dell, B., Harper, R.J. and Henry, D.J., 2016. Quantification of deep soil carbon by a wet digestion technique. *Soil Research*, 55(1):78-85.

Shehzad, J., Mustafa, G., Arshad, H., Ali, A., Naveed, N.H., Riaz, Z. and Khan, I., 2023. Morpho-physiological and biochemical responses of Brassica species toward lead (Pb) stress. *Acta Physiologiae Plantarum*, 45(1):8.

Shi, P.J., Li, Y.R., Niinemets, Ü., Olson, E. and Schrader, J., 2021. Influence of leaf shape on the scaling of leaf surface area and length in bamboo plants. *Trees*, 35:709-715.

Shu, X., Yin, L., Zhang, Q. and Wang, W., 2012. Effect of Pb toxicity on leaf growth, antioxidant enzyme activities, and photosynthesis in cuttings and seedlings of *Jatropha curcas* L. *Environmental Science and Pollution Research*, 19:893-902.

Silva, S., Pinto, G. and Santos, C., 2017. Low doses of Pb affected *Lactuca sativa* photosynthetic performance. *Photosynthetica*, 55(1):50-57.

So, H.B., Menzies, N.W., Bigwood, R. and Kopittke, P.M., 2006. Examination into the accuracy of exchangeable cation measurement in saline soils. *Communications in soil science and plant analysis*, 37(13-14):1819-1832

Wilke, B.M., 2005. Determination of chemical and physical soil properties. *Monitoring and assessing soil bioremediation*, p 47-95.

World Health Organization. 2017. Lead poisoning and health fact sheet.

Zulfiqar, U., Farooq, M., Hussain, S., Maqsood, M., Hussain, M., Ishfaq, M., Ahmad, M. and Anjum, M.Z., 2019. Lead toxicity in plants: Impacts and remediation. *Journal of environmental management*, 250:109557.

UNDER PEER REVIEW