The potential of *Monstera sp.* phytoremediation in various lead-contaminated water samples

A A Darmawan[1*], C L Suryani[1], U Aiman[1], A S Alikasturi[2], M R Anuar[2], W Mildaryani[1], Z U Maulida[1], W R Kurniasari[1], R Sambodo[1], B Sriwijaya[1], B Nugroho[1]

[1]Universitas Mercu Buana Yogyakarta, Faculty of Agroindustry, Indonesia
[2]Universiti Kuala Lumpur Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET), Malaysia

*Corresponding author: batharadarmawan@gmail.com
Authors ORCID ID: 0000-0003-3045-6212

Abstract. Ornamental plants have a variety of commodities which have high economic value, expected to improve the community's economy. In parts of Southeast Asia today there is a booming of ornamental plants type Pokok (Malaysia) or Janda Bolong (Indonesia), However, data related to its ability to absorb heavy metals does not yet exist. Ornamental plants of the type Monstera sp. has potential in phytoremediation technology, based on this, this study was investigate the potential absorption of leads by monstera sp. This study used the RCBD method. The first factor used of water samples including mineral water (W1), distilled water (W2), and surface water (W3). The second factor used in the form of Monstera types includes *Monstera obliqua* (M1), *Monstera tetrasperma* (M2), *Monstera sp.* Peru (M3), then 9 treatment combinations were 3 replication, so that a total of 27 units were obtained. The results of this research indicate that various of *Monstera sp.* have different absorption capacities of lead. This is also influenced by several factors such as light intensity, leaf area, and the type of water used as a medium. The results of this study proving that the plant Monstera sp. can reduce heavy metals in fields

1. Introduction

One group of metals known as non-essential trace elements, lead (Pb), has the highest toxic levels in the human body [1,2]. Pb can be found in waste originating from various sources. This includes waste from the use of coal and oil, waste from iron and steel smelting plants, waste from cement production plants, and waste from the use of metals for products, such as batteries, textiles, pesticides, glass, ceramics, and so on [3].

Currently, heavy metal waste pollution containing lead (Pb) is a problem for the environment. Almost all industrial waste contains heavy metals. More industry will increase pollution of water sources because untreated industrial waste is discharged into waters [4]. The soil's properties of soil can alter due to the accumulation of contaminats caused by heavy metals that settling in the soil. Soil containing heavy metals can reduce microbial activity, fertility and overall soil quality. This can lead to worse outcomes and the introduction of toxic substances into the food chain [5].

Phytoremediation is an effort to restore the environment of various types of media contaminated with contaminants, both organic and inorganic, by utilizing plants [6,7]. Phytoremediation techniques are considered innovative, economical, and relatively safe technologies to the environment [8]. The media that can be remediated with phytoremediation are soil, groundwater, and surface water [9]. The types of organic contaminants that can be processed are agrochemicals such as hydrocarbon compounds, pesticides that are commonly found in agriculture and mining. As for inorganic contaminants, they include metalloids, salinity, radioactive compounds, and some heavy metals [10].

The main factor of phytoremediation success is determined by plant selection [11]. There is a limit to the concentration of pollutants that plants can tolerate, causing phytoremediation techniques to typically use certain types of plants that are tolerant of certain pollutants. Plants can die if the concentration of pollutants is high and exceeds the tolerant limit [12]. Plants in general can only live on waste with a BOD of less than 300 mg l^{-1} [13].

Nowadays, phytoremediation technology uses a lot of aquatic plants, which have the potential to absorb heavy metals. Plants that are widely used such as Water hyacinth (*Eichhornia crassipes*), because they are able to grow on media polluted with heavy metal pollutants [14]. But the plant has not made an economically significant contribution. Water hyacinth processing is only limited to the use of fiber that is processed into handicraft raw materials [15]. On this basis, researchers want to try the innovation of phytoremediation technology using ornamental plants [16]. Ornamental plants have a variety of commodities which have high economic value, expected to improve the community's economy. In parts of Southeast Asia, there is currently a booming in ornamental plants of the Pokok (Malaysia) or Janda Bolong (Indonesia) types, but data related to their ability to absorb heavy metals does not yet exist. Therefore, this research was investigate various aspects regarding the *Monstera sp.* in absorbing Pb and determine effect of microclimate on Pb absorption by Monstera sp.

2. Materials and methods

2.1. Site description and research design

The research was prosessed from July-October 2023 in Soil Science Laboratory at Agrotechnology department, Agroindustry faculty, Universitas Mercu Buana Yogyakarta. Analysis of concentration of Lead was conducted in the Chem-Mix Pratama Laboratory. This research used the Randomized Completely Block Design with two factors. RCBD was chosen with the assumption of a population of experimental units with non-homogeneous conditions, the population of experimental units in this study was divided into multiple relatively homogeneous subpopulations or blocks. Blocks often indicate distinct levels of variation in environmental factors that are unrelated to treatment. Variation between blocks can be partitioned from experimental error (MSE) in the analysis, decreasing this amount and enhancing the test's power. This method is used on several considerations based on microclimates that can be influenced by several things such as differences in lighting levels, temperature and air humidity in the laboratory. The first factor used is the use of water samples consisting mineral water (W1), distilled water (W2), and surface water (W3). The second factor used in the form of Monstera plant types includes *Monstera obliqua* (M1), *Monstera tetrasperma* (M2), *Monstera sp*. Peru (M3), then 9 treatment combinations were 3 replication, and than total of 27 units were obtained.

2.2. Air temperature (^oC), relative humidity (%), and light intensity (lux)

In each treatment, we measured the microclimate using a thermohyrometer for air temperature and relative humidity, as well as a lux meter for light intensity. Every day, three measurements are taken to determine the maximum and minimum values for each microclimate parameter.

2.3. Leaf area (cm^2)

We measured of Leaf area was conducted at harvest used the scanning method using a scanner on the printer and the imageJ.exe application. This method is similar to the leaf area meter (LAM) method but with a cheaper and simpler tool with results similar to the LAM method. The steps taken are scanning the leaves with a printer, then making a scale on the scanned image, then measuring the leaf area, steps for measuring the leaf area using the imageJ.exe application.

2.4. Concentration of Lead (ppm) and efficiency absorption of Lead

The test plant sample was weighed at 3 g, placed in a porcelain cup, added 10 ml of 65% HNO_3 and left for 1 night. Then the test sample was destroyed using a digestion flask until it produced NO_2 gas which was reddish in color and after it had cooled, 2 - 4 ml of 70% $HClO_4$ was added. The test sample is reheated and allowed to evaporate until the volume is low. The test sample was then transferred to a volumetric flask and diluted with distilled water to a volume of 20 mL. The next example is ready to be analyzed using atomic absorption spectroscopy (AAS).

The concentration of lead in shoot and root were measured using a Perkin Elmer Analyst 100 flame atomic absorption spectrometer (AAS) at 283.3 nm wavelength. This assay result is used to quantify the quantity of lead absorbed from all samples.

The potential for lead absorption in each plant represents the level of effectiveness of the shoots and roots in carrying out the phytoremediation process on contaminated water samples, and is calculated using the following formula: [17]:

$$Efficiency\ absorption\ of\ \ Lead\ (\%) = \frac{Ct}{Co}\ x\ 100$$

Where : *Co = initial concentration in water samples (ppm), and Ct = variable concentration in shoot and root (ppm)*

2.5. Research setup

Each bottle contained mineral water, distilled water, and surface water, followed by 30 ppm Pb (II) nitrate. Following that, the plant is planted according to its treatment, with the roots already cleansed out of the soil with water. At the same time, a set of bottles is filled with mineral, distilled and surface water without each plant being prepared as an experimental control. This research carried out in the Soil Science Laboratory the application of experimental designs was carried out based on the level of illumination where the light source was obtained from the lamp for 14 hours and without light for 10 hours. Furthermore, the microclimate, including air temperature, relative humidity, and light intensity, was assessed daily. In addition, 1% nitric acid (HNO_3) was added to reduce precipitation, limit microbiological activity, retain the majority of metal, and avoid absorption loss through the bottle's walls.

2.6. Data analysis

Data processing of the research results was conducted using Microsoft Excel 2016. Data analysis of research results with One way ANOVA and if it has a significant it will be further tested with Fisher's LSD. Relationships between factors are tested with Fornell-Larker Criteration to determine the degree of relationship between parameters. The software used in this analysis is Minitab 18 and Smart PLS.

3. Result and discussion

3.1. Microclimate factor

Microclimate parameters measured in the laboratory include air temperature, relative humidity, and light intensity. Throughout the investigation, the air temperature ranged from 26.9ºC to 28.55ºC (Figure 1). The lowest relative humidity is 61.5%, while the highest is 69.5% (Figure 2). The lowest light intensity is 51.35 lux, whereas the highest intensity is 72.44 lux (Figure 3).

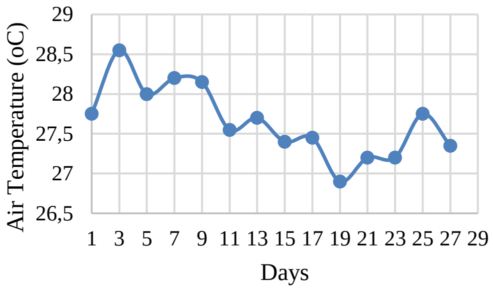

Figure 1. The average air temperature in laboratory in August - September 2023.

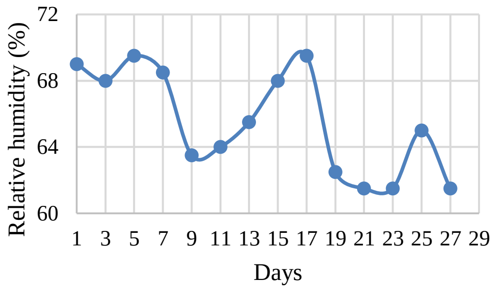

Figure 2. The average relative humidity in laboratory in August - September 2023.

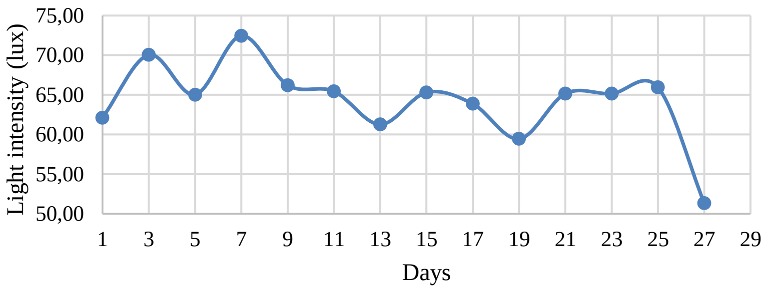

Figure 3. The average light intensity in laboratory in August - September 2023.

In general, air temperature, relative humidity and light intensity have been known as principal actuators among the various microclimate factors for plant growth and development, especially biomass production [18]. Microclimate is a critical parameter for crop production as it influences the water balance and photosynthesis process in the plants [19].

3.2. Effect the treatment of various water media and Monstera sp.

ANOVA of the treatment of various water media and *Monstera sp.* on the analysis variables can be seen in Tables 1. Based on Table 1, various of water samples has a significant effect on the concentration of Lead in shoot and root. Next, various *Monstera sp.* has a significant effect on leaf area. The interaction of water sample and *Monstera sp.* has a significant effect on the leaf area, concentration of Lead in shoot and root, total concentration of Lead, Efficiency of absorption of Lead.

Table 1. ANOVA of the treatment of various water media and *Monstera sp.*

Parameter	Water	Monstera	Water >< Monstera
Microclimate			
Air temperature	ns	ns	ns
Relative humidity	ns	ns	ns
Light intensity	ns	ns	ns
Plant properties			
Leaf area	ns	*	*
Concentration of Lead in Shoot	*	ns	*
Concentration of Lead in Root	*	ns	*
Total Lead concentration	ns	ns	*
Efficiency of absorption of Lead	ns	ns	*

Note: * (significant at 0.05 level), **ns** (not significant)

IOP Conf. Series: Earth and Environmental Science 1317 (2024) 012002 doi:10.1088/1755-1315/1317/1/012002

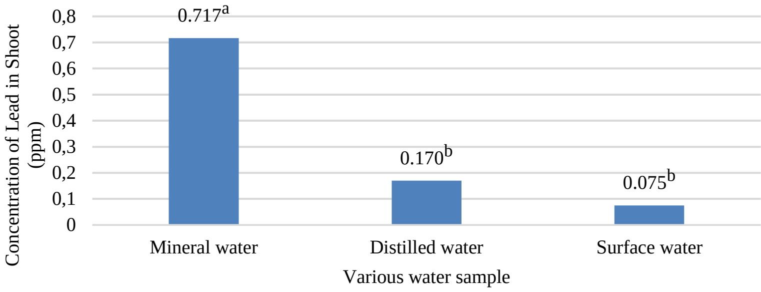

Figure 4. The average concentration of lead in shoot.

Concentration of lead in shoot in mineral water is the highest with 0.717 ppm and while the lowest was in the distilled water and surface water with 0.170 ppm and 0.075 ppm, respectively (Figure 4). In this study, the concentration of lead in shoot was influenced by the type of water sample used. It is suspected that mineral water has a pH that matches *Monstera's* ability to absorb lead. pH is related to the balance of cation exchange capacity in plants, the more neutral the pH in the media, the more nutrients are absorbed by plants [20]. The correlation between pH and heavy metal uptake usually shows negative results, but plants are able to absorb heavy metals optimally when the pH is neutral. Low pH conditions of organic acids and H+ ions will compete, which can mobilize heavy metal ions in media and increased possibility absorbtion of Lead [21]. Inversely proportional if the pH is high the ions exist by insoluble oxide, hydroxide statement, which the plants hardly absorb heavy metals. Aside from that, the absorption of heavy metals is dependent on several aspects such as plant features, root zone, water properties, ambient circumstances, bioavailability of the metal, and the chemical properties of the heavy metal. [22].

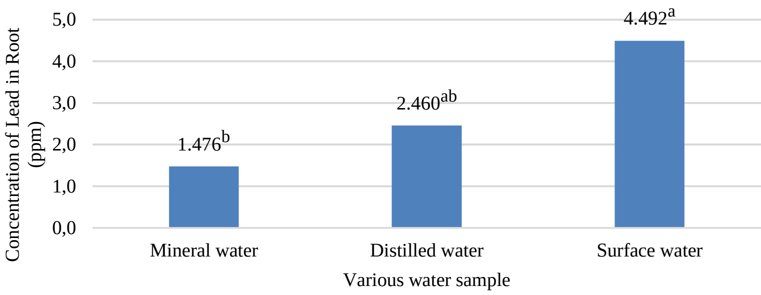

Figure 5. The average concentration of lead in root.

Concentration of Lead in root in surface water is the highest with 4.492 ppm and while the lowest was in the mineral water with 1.476 ppm, respectively (Figure 5). In this study, the concentration of lead in root was influenced by root, where roots are agents for absorbing nutrients in soil and water. Lead availability is highly dependent on environmental conditions. Lead binds to other elements in the media, surface water is thought to have many elements available. When plants absorb nutrients, Lead is bound to other forms such as Pb(II) nitrate ($Pb(NO_3)_2$) and Pb(II) sulfate (PbSO4). Apart from that, it is related to cation exchange capacity and plant properties such as root surface area, root exudate, transpiration rate and influence Pb absorption [23].

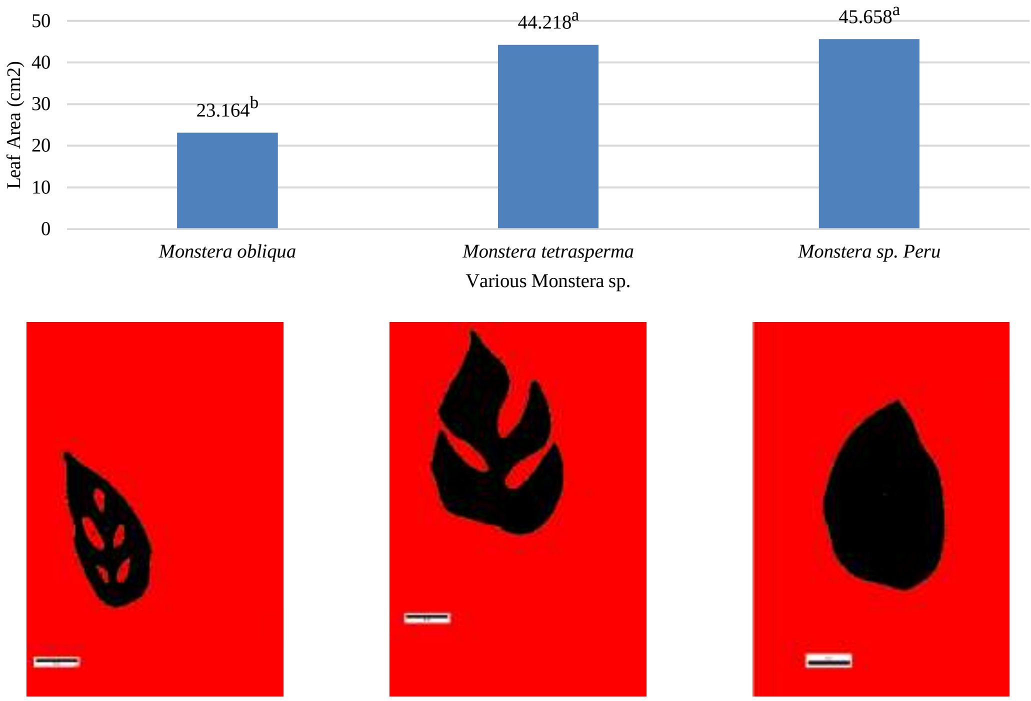

Figure 6. The average leaf area of various of *Monstera sp.*

Average of Leaf area in *Monstera sp.* Peru and *Monstera tetrasperma* are the highest with 45,66 cm^2 and 44,22 cm^2, while the lowest was in the *Monstera obliqua* with 23,164 cm^2, respectively (Figure 6). In this study, leaf area is an agent in the process of photosynthesis and transpiration, where the greater the surface area of the leaf, the higher the photosynthesis process, followed by the absorption of nutrients so that the photosynthate produced is high and can be used for plant growth. Apart from that, leaf area is also influenced by the type of plant, each plant has its own characteristics, especially in leaf morphology, number of stomata, and chlorophyll content. In this study, we wanted to show whether there was a correlation between leaf area and heavy metal absorption. Many studies show that leaf area is negatively correlated with plant growth, because it has many factors.

3.3. Interraction the treatment of various water media and Monstera sp.

Table 2. Average of leaf area, lead in shoot, lead in root, total lead and efficiency absorption of lead.

Treatment	Leaf Area (cm^2)	Lead in Shoot (ppm)	Lead in Root (ppm)	Total Lead concentration (ppm)	Efficiency of absorption of Lead (%)
Mineral water + *M. obliqua*	22.890^{c}	0.957^{a}	1.972^{b}	2.929^{ab}	9.76^{ab}
Mineral water + *M. tetrasperma*	43.198^{ab}	0.696^{ab}	1.615^{b}	2.312^{ab}	7.70^{ab}
Mineral water + *M. sp.* Peru	45.877^{ab}	0.498^{abc}	0.842^{b}	1.341^{b}	4.47^{b}
Distilled water + *M. obliqua*	18.317^{c}	0.180^{bc}	3.851^{ab}	4.032^{ab}	13.44^{ab}
Distilled water + *M. tetrasperma*	53.640^{a}	0.159^{bc}	2.317^{ab}	2.476^{ab}	8.25^{ab}
Distilled water + *M. sp.* Peru	55.111^{a}	0.170^{bc}	1.212^{b}	1.382^{b}	4.60^{b}
Surface water + *M. obliqua*	28.284^{bc}	0.081^{c}	6.712^{a}	6.793^{a}	22.64^{a}
Surface water + *M. tetrasperma*	35.818^{abc}	0.041^{c}	3.540^{ab}	3.581^{ab}	11.93^{ab}
Surface water + M. sp. Peru	35.987^{abc}	0.104^{bc}	3.224^{ab}	3.328^{ab}	11.09^{ab}

Note: Numbers followed by different letters in the same column indicate a significant difference according to LSD (P=0.05)

Leaf area in the distilled water + *M. sp.* Peru was not significantly different from distilled water + *M. tetrasperma*, but was significantly different from other treatments. The highest leaf area was in the distilled water + *M. sp.* Peru and distilled water + *M. tetrasperma* was 55.11 cm2 and 53.64 cm2 respectively. The narrowest leaves area in the mineral water + *M. obliqua* and distilled water + *M. obliqua* were 22.89 cm^2 and 18.32 cm^2 respectively (Table 2).

Leaves are photosynthetic agents that are associated to nutrient absorption in the medium [24], leaf area was assessed in this study to establish whether there was an affect on Pb absorption. Research is needed to determine whether wider leaves absorb more than narrow leaves. Many studies imply that metabolic activities in leaves regulate cell division and cell enlargement, which are the primary processes in leaf area expansion and plant growth [25]. and that the findings in this study may have an adverse effect on these two physiological processes. Aside from that, we wish to demonstrate the adaptability of each kind of Monstera sp. to disruptions generated by less supportive media conditions due to the presence of Pb. a wide range. A variety of mechanisms may be involved in the reduced growth of plants exposed to heavy metal toxicity [26]. Lead accumulation in plants has a bigger effect, producing a decrease in photosynthetic rate, termination of chlorophyll synthesis, disrupting the Calvin cycle, creating a lack of CO_2, and closing stomata [27,28]. $Pb(NO_3)_2$ promotes alterations in chlorophyll structure by lowering photocatalytic activity in Ceratopyllum dersum [29].

The concentration of lead in shoots in the mineral water + *M. obliqua* was significantly different from the other treatments. The highest concentration of lead in shoots in the mineral water + *M. obliqua* was 0.957 ppm and the lowest in the surface water + *M. obliqua* and surface water + *M. tetrasperma* was 0.081 ppm and 0.041 ppm respectively. Pb concentration in plants, through phytoavailability, controls the transfer of the element from soil to plants. In this study, mineral water + M. obliqua was able to absorb more Pb than the others in the title. This is due to the influence of pH on the media used, namely mineral water which has a pH of 6.5 which is suitable for the growth of *M. obliqua*. Pb content in shoots increased significantly by 78% with increasing Pb concentration at certain pH conditions. In other research, it was stated that P. hortorum accumulated 89% of Pb in shoot [30]. In general, the phytoavailability of Pb depends on pH [31,32]. The pH of the rhizosphere decreases due to plant activity which releases H+ ions, in this condition as expected by plants, thereby increasing the accumulation of Pb from the soil [33,34].

Concentration of lead in root in the surface water + *M. obliqua* treatment was significantly different from other treatments. The highest concentration of lead in root in surface water + *M. obliqua* was 6,712 ppm and followed by the highest total lead concentration of 6,793 ppm of all treatments. This results in an efficiency of absorption of Lead (%) of 22.64%. This is thought to be due to the use of surface water media which has a higher nutrient content compared to mineral water and distilled water. This nutrient content increases M. obliqua in absorbing Pb in the media, especially when it is accumulated in the roots.

Previous research found that the roots retained approximately 90% of the total Pb ingested by plants [35]. This is assumed to be because roots take nutrients from the soil, therefore Pb that accumulates in plants is largely located in the roots. Plant roots swiftly respond, forming a barrier that prevents Pb from entering [36]. Immobilization in cell walls, deposition of insoluble Pb in the intercellular space, accumulation in the plasma membrane, and sequestration in vacuoles all impede Pb transport from roots to shoots [37,38]. Heavy metal uptake by plants, accumulation in roots without interfering with primary functions, and limited translocation to shoots are all thought to contribute to species tolerance to heavy metals [39].

3.4. Relationship between microclimate parameters and efficiency of absorption of Lead

Relationship between microclimate parameters such as temperature and relative humidity, light intensity to efficiency of absorption of lead (Table 3). This study showed that there is a significant between Concentration of lead in root and Efficiency of absorption of lead, Total lead concentration and efficiency of absorption of lead, so there is a very significant between concentration of lead in root and total lead concentration. In this study, the relationship between parameters was determined using an experimental model based on the SEM-PLS (Figure 7).

In this research, there are 2 influences on the efficiency of absorption of lead, namely direct influence and indirect influence. Lead concentration in shoots and roots, as well as total lead concentration, have a direct effect on the efficiency of lead absorption is -19.9%, 89%, and 67.8%, respectively. The indirect influence can be seen in table 19 showing that the influence varies greatly. Light intensity, temperature, relative humidity, leaf area, Concentration of lead in shoot and root, and total lead concentration indirectly affect the efficiency of absorption of lead respectively by 10.2%; -5.3%; 14.3%; -23.6%; 11.5%; 69.2%; 67.8%, but the indirect relationship between leaf area is negative, meaning that narrow leaves have a higher efficiency of absorption of lead compared to other treatments.

Table 3. Relationships between microclimate parameters and efficiency absorption of lead

Correlation	Efficiency of absorption of Lead	Leaf area	Light intensity	Relative humidity	Lead in Root	Lead in Shoot	Temp.
Leaf area	-0.273						
Light intensity	-0.137	-0.262					
Relative humidity	-0.016	-0.006	0.225				
Lead in Root	**0.708****	-0.323	0.083	0.239			
Lead in Shoot	0.201	-0.099	-0.163	-0.064	0.124		
Temperature	-0.284	0.131	-0.120	-0.285	-0.429	-0.212	
Total Lead concentration	**0.753****	-0.327	0.014	0.195	**0.968*****	0.305	-0.413

Notes: * (significant), *** (very significant)

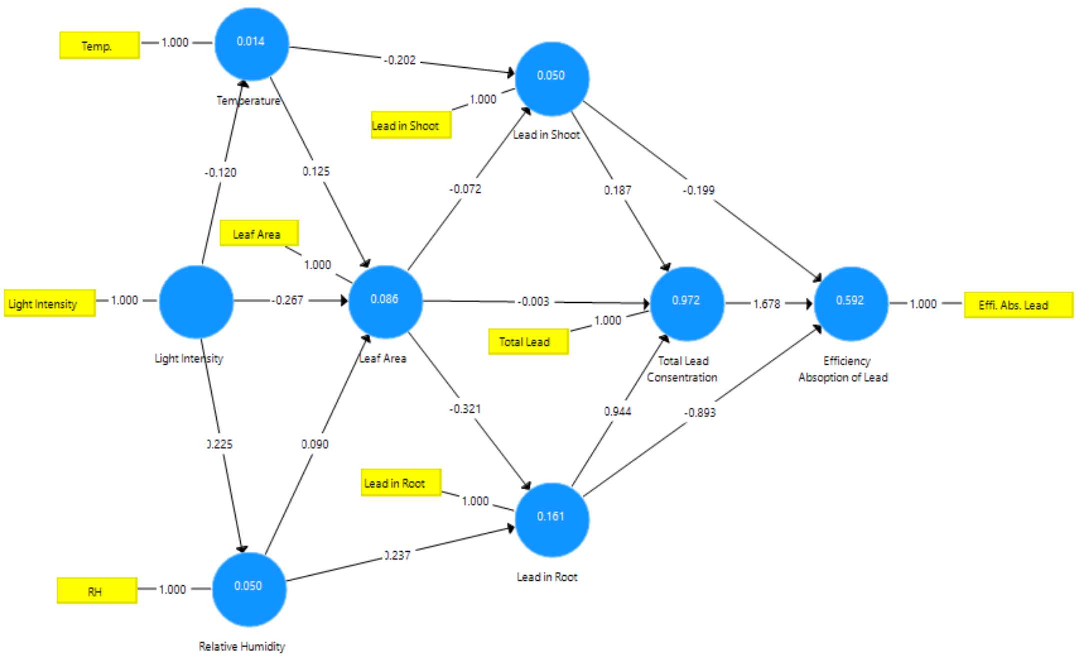

Figure 7. Model depicting the relationship between microclimate parameters and efficiency absoption of lead.

Microclimate is an important factor in crop production because it affects water balance and photosynthesis in plants. In this study, the lighting used was LED lights with an average of 57 lux which can affect temperature and humidity. Furthermore, microclimate will influence the photosynthesis process which is represented using leaf area, where leaves will contribute to plant growth and development. The figure showed that air temperature influences 12.5% and relative humidity influences 9%. These leaves affect Pb absorption in plants. In this research, Pb concentration in the shoot was influenced by leaf area by 7.2%, which was negative, indicating that plants with narrow leaves had higher Pb uptake compared to plants with wide leaves. Narrow leaves have a lower net leaf carbon gain but have higher stomata resistance compared to wide leaves. Stomata have a role in gas exchange during photosynthesis and also serve as a tool for adapting to different environmental conditions [29].

In this study, it is represented by *M. obliqua* which is planted in mineral water media which absorbs higher levels of Pb. Pb absorption in shoot is a mechanism to reduce the impact of plant damage. In previous studies, it was found that plants translocate it to above-ground plant parts in the case of hyperaccumulator plants, but at lower levels [40]. Furthermore, the Pb concentration in plant roots is influenced by leaf area by -32.1%, where negative indicates that plants with narrow leaves have higher Pb uptake compared to plants with wide leaves. In this research, it is represented by *M. obliqua* which is planted in surface water. It is suspected that there is a high nutrient content in the surface water because the water samples were taken from irrigation canals which have passed through the land a lot and carried these nutrients. Apart from that, because of the mechanism of resistance to Pb, plants store it in the roots so that it does not interfere with activities in the canopy [30,41].

The overall amount of Pb absorbed by plants is the sum of the concentrations in the shoots and roots, which influence 18.7% and 94.4% of the total Pb concentration, respectively. Thus, *M. obliqua* planted with surface water medium had a Pb absorption efficiency of 22.64%, with a total Pb concentration of 6,793 ppm consisting of 0.081 ppm accumulated in the shoot and 6,712 ppm accumulated in the roots. As a result, *Monstera obliqua* has a larger Pb absorption capacity than *Monstera tetrasperma* and *Monstera sp.* Peru, and can be employed as a Pb hyperaccumulator plant.

4. Conclusions

Water samples affect lead absorption when using Monstera obliqua. Monstera obliqua had a better phytoremediation capability in absorbing lead from water samples than Monstera tetrasperma and Monstera sp. Peru. Microclimate and leaf area both have an impact on lead uptake.

Acknowledgements

The author would like to thank Universitas Mercu Buana Yogyakarta for sponsoring collaborative research with Universiti Kuala Lumpur's Malaysian Institute of Chemical & Bioengineering Technology (UniKL MICET) under a foreign cooperation research program. The authors also to thank the academics and technicians who took part in the study.

References

[1] Nag R and Cummins E. 2022. *Sci. Total Environ.* **810** 151168
[2] Zwolak A, Sarzyńska M, Szpyrka E and Stawarczyk K. 2019. *Water. Air. Soil Pollut.* **230**
[3] Tchounwou P B, Yedjou C G, Patlolla A K and Sutton D J. 2012. *Mol. Clin. Environ. Toxicol.* **101** 133–64
[4] Velayatzadeh M. 2023. *Heavy Metals - Recent Advances* pp 1–9
[5] Elgarahy A M, Elwakeel K Z, Mohammad S H and Elshoubaky G A. 2021. *Clean. Eng. Technol.* **4** 100209
[6] Alikasturi A S, Kamil M Z A M, Shakri N A A M, Serit M E, Rahim N S A, Shaharuddin S, Anuar M R and Radzi A R M. 2019. *Today Proc.* **19** 1489–96
[7] Solomou A D, Germani R, Proutsos N, Petropoulou M, Koutroumpilas P, Galanis C, Maroulis G and Kolimenakis A. 2022. *Agric.* **12** 1–19
[8] Sidauruk L and Sipayung P. 2015. *J. Pertan. Trop.* **2** 178–86
[9] Martino L, Yan E and LaFreniere L. 2019. *Environ. Earth Sci.* **78** 1–16
[10] Ahmed A, Sara Taha A ., Sundas R Q and and Man-Qun W. 2021. *Toxics* **9** 42
[11] Pang Y L, Quek Y Y, Lim S and Shuit S H. 2023. *Sustainability* **15** 1290

[12] Bhat S A, Bashir O, Ul Haq S A, Amin T, Rafiq A, Ali M, Américo-Pinheiro J H P and Sher F. 2022. *Chemosphere* **303**
[13] Zahro N and Nisa' V C. 2021. *JCAE (Journal Chem. Educ.)* **4** 73–83
[14] Singh N and Balomajumder C. 2021. *Appl. Water Sci.* **11**
[15] Amante K, Ho L, Lay A, Tungol J, Maglaya A and Fernando A. 2021. Design, fabrication, and testing of an automated machine for the processing of dried water hyacinth stalks for handicrafts. *IOP Conf. Ser. Mater. Sci. Eng.* **1109** 012008
[16] Lina H, Budi W and Henna R S 2018 Phytoremediation of Lead Contaminated Soils using Cordyline fruicosa (L) *E3S Web Conf.* **73** 0–4
[17] Alikasturi A S, Izzuddin Mokhtar M, Asyraf Zainuddin M, Empina Serit M and Syafiiqah Abdul Rahim N. 2020. *Mater. Today Proc.* **31** A175–9
[18] Reshi Gusta A and Same M 2021 Micro Climate Modifications to Increase Growth and Production of Shrubs Pepper *IOP Conf. Ser. Earth Environ. Sci.* **1012**
[19] Yang L, Liu H, Cohen S and Gao Z. 2022. *Agric.* **12**
[20] Neina D. 2019. *Appl. Environ. Soil Sci.* **2019**
[21] Jeyakumar P, Debnath C, Vijayaraghavan R and Muthuraj M. 2023. *Environ. Eng. Res.* **28** 0–2
[22] Yan A, Wang Y, Tan S N, Mohd Yusof M L, Ghosh S and Chen Z. 2020. *Front. Plant Sci.* **11** 1–15
[23] Egendorf S P, Groffman P, Moore G and Cheng Z. 2020. *Int. J. Phytoremediation* **0** 916–30
[24] Bielczynski L W, Łaçki M K, Hoefnagels I, Gambin A and Croce R. 2017. *Plant Physiol.* **175** 1634–48
[25] Long A, Zhang J, Yang L T, Ye X, Lai N W, Tan L L, Lin D and Chen L S. 2017. *Front. Plant Sci.* **8** 1–22
[26] Hatamian M, Rezaei Nejad A, Kafi M, Souri M K and Shahbazi K. 2020. *Chem. Biol. Technol. Agric.* **7** 1–8
[27] Khan A, Khan S, Khan M A, Qamar Z and Waqas M. 2015. *Environ. Sci. Pollut. Res.* **22** 13772–99
[28] Santos L R, Batista B L and Lobato A K S. 2018. *Photosynthetica* **56** 591–605
[29] Collin S, Baskar A, Geevarghese D M, Ali M N V S, Bahubali P, Choudhary R, Lvov V, Tovar G I, Senatov F, Koppala S and Swamiappan S. 2022. *J. Hazard. Mater. Lett.* **3** 100064
[30] Gul I, Manzoor M, Hashmi I, Bhatti M F, Kallerhoff J and Arshad M. 2019. *J. Environ. Manage.* **249**
[31] Manzoor M, Gul I, Silvestre J, Kallerhoff J and Arshad M. 2018. *Soil Sediment Contam.* **27** 439–53
[32] Gul I, Manzoor M, Kallerhoff J and Arshad M. 2020. *Chemosphere* **258** 127405
[33] Arshad M, Merlina G, Uzu G, Sobanska S, Sarret G, Dumat C, Silvestre J, Pinelli E and Kallerhoff J. 2016. *J. Soils Sediments* **16** 581–91
[34] Manzoor M, Gul I, Manzoor A, Kamboh U R, Hina K, Kallerhoff J and Arshad M. 2020. *Environ. Sci. Pollut. Res.* **27** 39753–62
[35] Bassegio C, Campagnolo M A, Schwantes D, Gonçalves Junior A C, Manfrin J, Schiller A da P and Bassegio D. 2020. *Int. J. Phytoremediation* **22** 134–9
[36] Amin H, Arain B A, Jahangir T M, Abbasi M S and Amin F. 2018. *Geol. Ecol. Landscapes* **2** 51–60
[37] Fahr M, Laplaze L, Bendaou N, Hocher V, El Mzibri M, Bogusz D and Smouni A. 2013. *Front. Plant Sci.* **4** 1–7
[38] Xue W, Jiang Y, Shang X and Zou J. 2020. *BMC Plant Biol.* **20** 1–15
[39] Mahar A, Wang P, Ali A, Awasthi M K, Lahori A H, Wang Q, Li R and Zhang Z. 2016. *Ecotoxicol. Environ. Saf.* **126** 111–21
[40] Qian Y, Gallagher F J, Feng H and Wu M. 2012. *Environ. Pollut.* **166** 23–30
[41] Kiran B R and Prasad M N V. 2017. *Selcuk J. Agric. Food Sci.* **31** 73–80