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# THE EFFECT OF MYCORRHIZA AND VERMICOMPOST ON PB-ABSORPTION, P-UPTAKE, AND YIELD OF CHILI PLANT (*Capsicum annuum* L.) ON TEXTILE WASTE CONTAMINATED SOIL

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***ABSTRACT.*** *The textile industry generates waste with elevated concentrations of heavy metals, dominated by lead (Pb). This waste can contaminate the surrounding agricultural land and be absorbed by plants, accumulating in their tissues. Applying mycorrhiza fungi is an effective strategy to prevent Pb accumulation and translocation in plant tissues. This study evaluates the effect of combining mycorrhiza with vermicompost in chili plants by analyzing Pb uptake, Pb translocation, phosphorus uptake, and harvest yield. We employed a randomized block design with two factors: the first factor was vermicompost dose (ranging from 0, 10, 15, 20, 30 t ha$^{-1}$), and the second factor was mycorrhiza application and non-mycorrhizal (with three repetitions per treatment). The results showed that vermicompost at a dose of 25 – 30 t ha-1 combined with mycorrhiza increased the Pb content in the root compared with the control treatment. Vermicompost at 0 and 10 t ha$^{-1}$ doses combined with mycorrhiza decreased significantly in Pb content in the shoot compared to the vermicompost treatment without mycorrhiza. Mycorrhiza did not increase the P-uptake and the yield of chili plants. Meanwhile, vermicompost at 25 -30 t ha$^{-1}$ increased significantly the plant chili yield. The mycorrhizal hyphae in the root tissue can bind Pb and suppress further Pb translocation to the plant's shoot. These research findings show that the chili plant is known as a Pb-accumulator plant. This research contributes to understanding the role of mycorrhiza and vermicompost in maintaining the safety of food crops cultivated around river areas contaminated with textile waste containing Pb.*

***KEYWORDS:*** *Capsicum annuum L., lead (Pb), mycorrhiza, vermicompost.*

## INTRODUCTION

Developing the industrial sector is crucial for improving a country's economy but severely harms the natural surroundings. Lead (Pb) poisoning can result in both acute and chronic damage to the kidneys, brain, reproductive organs, and central and peripheral nervous systems (Collin et al. 2022). One of the major issues is the generation of hazardous industrial waste, which can lead to severe consequences. The accumulation of heavy metals in soil and water bodies from industrial waste is a significant environmental problem. Pb exhibits a strong affinity for soil particles, leading to its predominant presence in the topsoil layer (Gupta et al. 2008). One example of such pollution is in the Rancaekek District of the Bandung Regency in West Java. Dumping textile industrial waste in this region has resulted in severe impacts. Our field survey indicates that plants impacted by lead (Pb) exhibit signs of retarded growth. Our soil analysis showed that the Pb content of the soil in that area had reached 39.61 ppm (unpublished personal data). These heavy metals are elements that are extensively used in the textile production process. Plants' absorption of Pb levels that exceed the permitted limits on agricultural land can be dangerous for consumption.

Heavy metals such as lead (Pb) can negatively impact plant photosynthesis, causing loss of biomass and fitness by disrupting physiological and biochemical responses (Emamverdian et al. 2015, Mateos-Naranjo et al. 2008, Windham et al. 2001). Previous research indicates that plant hyperaccumulators can tolerate heavy metal levels 10-500 times higher than other plants, without negative effects (Rascio & Navari-Izzo 2011, Skuza et al. 2022). However, plant metal uptake is influenced by factors such as soil pH and organic matter, which may have antagonistic effects (Herlina et al. 2020, Tibbett et al. 2021).

From the abovementioned problems, we explore the potential uses of vermicompost organic materials with mycorrhizal fungi to overcome and rehabilitate Pb-contaminated land. In Indonesia, vermicompost is an organic material that is still only used as an organic fertilizer because it contains the complete range of nutrients needed for plant growth, while its use as an alternative to reduce the harmful effects caused by heavy metals has yet to be widely used (Mahmud et al. 2020). Vermicompost facilitates plant growth and significantly mitigates abiotic stresses, particularly soil salinity and drought (Rehman et al. 2023). Vermicompost can be used as a material for rehabilitating land contaminated with heavy metals, if vermicompost has the characteristics of organic fertilizer (Rehman et al. 2023). According to Wan et al. (2018), organic materials can form heavy metal complex compounds called metal-organic complexes and play a crucial role in controlling the transformation of heavy metal fractionations in soils.

Besides that, vermicompost contains many microorganisms that are beneficial to plants. Wong et al. (2015) reported that the primary benefits of vermicompost application are attributed to the continuous availability of macro- and micronutrients and the biological effects associated with its enzymatic activities and plant hormones, leading to increased plant growth. Furthermore, Gadd (2001) stated that the microorganisms in organic materials can potentially be used as heavy metal biosorbed agents because soil organic matter plays a crucial role in regulating the conversion of heavy metals in the soil. Additionally, it helps to maintain the overall health and fertility of the soil (Zeng et al. 2011). The immobile fraction of heavy metals in the soil increases with increasing soil organic matter concentration (Sparks 2003). Furthermore, it is also known that the aging process of soil can cause heavy metals to transform from mobile forms to stable forms (Wan et al. 2018).

Mycorrhiza is a type of fungus that helps plants absorb nutrients like phosphorus while at the same time protecting their roots by colonized roots (Zhang et al. 2021). It can also act as a heavy metal binding agent. In soils contaminated with heavy metal, Arbuscula mycorrhizal fungi (AMF) contribute to the accumulation of soil organic carbon (SOC) by secreting glomalin-related soil protein (GRSP) and modulating plant carbon partitioning (Zhang et al. 2019). Mycorrhiza releases a glycoprotein (GRP) into the soil upon hyphal turnover or fungal death, and it can be measured in the soil as GRSP (Driver et al. 2005). More than 80% of land plants establish symbiosis with AMF in different ecosystems, including Pb-polluted areas (Davison et al. 2015, Faggioli et al. 2019, Parniske 2008, Zhang et al. 2021). AMF has been found to enhance plant growth by increasing nutrient uptake and tolerance to adverse environmental conditions (Liu et al. 2016). Moreover, AMF can also increase host plants' lead (Pb) tolerance by accumulating more Pb in the roots than non-mycorrhizal plants (Zhang et al. 2021). Plant roots may uptake Pb by following the water flow, facilitated by the aquaporin MtPIP2 (Zhang et al. 2021). It is possible to use a combination of vermicompost and mycorrhiza to rehabilitate land contaminated with Pb and suppress its translocation to affected plants. However, the effectiveness of vermicompost and mycorrhiza originating from inoculants in suppressing Pb ion content, translocation (Pb uptake), P uptake, and plant yields, as well as adequate vermicompost dosage levels, still have to be investigated.

This research aims to evaluate the potential of mycorrhiza combined with the application of organic vermicompost in chili pepper plants by suppressing Pb uptake and Pb ion translocation and its effect on P uptake and chili plant yield.

## MATERIAL AND METHODS

This research was conducted in a greenhouse at the Experimental Garden of the Faculty of Agriculture, Padjadjaran University, at 725 above sea level (a.s.l.). Laboratory analysis was conducted at the Biology and Biotechnology Laboratory, Faculty of Agriculture, Department of Soil Science and Land Resources Management, Padjadjaran University, in Jatinangor, Sumedang Regency, West Java Province.

### Research tools and materials

Mycorrhizal inoculant in zeolite carrier material with a spore density of 34 per g zeolite, consisting of 2 species (*Glomus* sp. and *Gigaspora* sp.). The inorganic fertilizer used is 50% of the recommended dose consisting of Urea 100 kg $ha^{-1}$ (0.5 g $pot^{-1)}$, Triple super phosphate (TSP) 50 kg $ha^{-1}$ (0.25 g $pot^{-1}$), KCl 25 kg ha-1 (0.125 g $pot^{-1}$), and cow dung compost at a dose of 5 tons $ha^{-1}$ (25g pot-$^{1}$). This was obtained from the Ciparamje experimental garden collection, Faculty of Agriculture, Padjadjaran University.

### Experimental design

A factorial randomized block design (RAK) with two factors was used.

Factor I: Variation in vermicompost dosage:

$v_0$ = without vermicompost
$v_1$ = vermicompost 10 t $ha^{-1}$
$v_2$ = vermicompost 15 t $ha^{-1}$
$v_3$ = vermicompost 20 t $ha^{-1}$
$v_4$= vermicompost 25 t $ha^{-1}$
$v_5$= vermicompost 30 t $ha^{-1}$

Factor II: ._Mycorrhizal inoculations:

$m_0$ = without mycorrhiza
$m_1$ = mycorrhizal inoculation

### Soil preparation

The research used soil from Jelegong Village in the Rancaekek District of Bandung Regency, contaminated with textile waste. Pb contaminated soil was taken in Jelegong Rancaekek village, using a purposive method by taking 10 sample points at a depth of 0 - 20 cm (the topsoil layer), then the soil samples were composited and then air-dried, pounded, passed through a sieve with a 2 mm diameter. For the initial analysis of soil characteristics, 0.5 kg of soil was used.

### Seeding chili seeds and mycorrhiza

We used the pre-inoculation method to sow chili seeds and apply mycorrhizal inoculation. The soil was pounded and sieved with a 2 mm sieve. The pre-inoculation method was used in 40 x 20 cm trays for the mycorrhiza treatment. During chili seeding, mycorrhizal inoculant was added. The media used in pre-inoculation was sterilized first, with a composition consisting of 3 layers (layering method), namely inceptisol soil (1645.2 g), 1.5 g mycorrhiza in zeolit (419.925 g) with a density of 34 spores per 1 g zeolite, and inceptisol soil (548.4 g), or the ratio of soil: inoculant mycorrhiza in zeolite: soil = 3: 12: 9. The seeds were sown in the top layer by slightly immersing them with a distance of 5 x 5 cm between the seeds. The humidity in the seedbed was maintained until the age of 30 days. Several plants were taken randomly every week to see the infectivity of mycofers and indigenous mycorrhizae. The acid fuchsin root staining method was used to examine root infections. Transplanting was carried out when the plants were 30 days after inoculation. Vermicompost was given at the time of transplanting according to the treatment dose.

### Planting chili seeds and application of vermicompost

The chili seeds, infected and sown at 30 days, were transplanted into a 5 kg pot-1 of Pb-contaminated soil and treated with vermicompost according to the dosage. Vermicompost application was carried out when planting seeds in a pot. As a starter, the soil was given essential fertilizers such as urea, phosphate, and potassium at 50% of the recommended dose. The plant media field capacity value was measured to determine the plant's water needs.

### Plant destruction and harvesting

Plant destruction was carried out during the final vegetative period (46 days after planting) to analyze soil dissolved Pb, Pb content in the root, plant Pb uptake, and P-uptake and. Soil Pb and plant Pb was analyzed by using the acid digestion method and measured using an AAS instrument. Harvesting was done at harvest time of 92 days after planting, followed by harvesting every week until the plants no longer bore fruit. *Observation parameters*: Pb content in roots, Pb content in the shoot, plant phosphorus uptake, and chili crop yield (gr plant$^{-1}$).

**Pb analysis in soil and plant**

The dry sample was crushed using a grinder and placed in a 50 mL digestion tube containing a 5 mL mixture of $HNO_3$ and $HClO_4$ in a 4:1 ratio. The mixture was gradually heated to 220°C for digestion. Lead concentrations were measured with flame atomic absorption spectrometry (PinAAcle 900F, PerkinElmer, USA). Lead content was calculated based on Pb concentration, fresh-to-dry mass ratio, and plant biomass.

**Phosphorus content in plant analysis**

Phosphorus content in plant analysis was using the wet destruction method. Equipment and materials: oven, analytical balance, grinder, 25 mL Kjeldahl flask, test tube, $HClO_4$, $HNO_3$, distilled water. The plant sample was dried in an oven at 75°C for 48 hours, then crushed using a grinder, leading the sample to a fineness of 0.5 mm. A 0.25 g portion of the sample was placed into a 25 mL Kjeldahl flask, and 5 mL of $HNO_3$ was added. Then, 0.5 mL of $HClO_4$ is added to the flask, shaken, and left overnight. The sample is digested by slowly heating to 350°C, producing a clear extract. The sample extract is mixed with 50 mL of distilled water, shaken, and transferred to a distillation flask. An additional 10 mL of reagent is added to measure P-concentration using a spectrophotometer at a wavelength of 889 nm.

**Statistical analysis**

Statistical Product and Service Solutions (SPSS) version 15.0 was used to analyze experimental data. Analysis of variance (ANOVA) was performed to assess significant differences at a level of 5% ($p < 0.05$).

## RESULTS

### Physical and chemical characteristics of experimental soil

The initial soil analysis of the experiment is shown in Table 1. The soil used in the experiment was from Jelegong Village, Ranacaekek District, where a river carries textile waste material and intrusion into agricultural land. Soil analysis of the experiment revealed that the soil was classified as slightly base, medium organic content (3.13%), total N was in the low category (0.22%), P ratio C/N was in the moderate category (14%), high base saturation (232%), cation exchange capacity (CEC) is high (27.75 meq/100g), base saturation is high and soil Pb content is above the permitted limit (39.61 ppm), and available P is very high (107.050 ppm). This soil is classified as highly contaminated with Pb and phosphate.

Table 1. The chemical and physical characteristics of experimental soil.

| No. | Parameters | Unit | Value | Criteria*) |
|---|---|---|---|---|
| 1. | pH $H_2O$ | | 7.80 | slightly base |
| 2. | pH KCl 1 N | | 6.42 | - |
| 3. | C-Organik | % | 3.13 | moderate |
| | Total-N | % | 0.22 | low |
| 4. | C/N ratio | % | 14 | moderate |
| 5. | $P_2O_5$Bray I | ppm | 107.05 | very high |
| 6. | CEC | meq 100 $g^{-1}$ | 27.75 | high |
| 7. | Base saturation | % | 232 | very high |
| 8. | Availability-Pb | ppm | 39.61 | above the threshold |

Source of criteria determination: *) Hardjowigeno (2007).

## Pb content in chili plant roots

Table 2 presents the analysis results of Pb content in chili plant roots due to treatment.

Table 2. Average Pb levels in plant roots resulting from treatment with and without mycorrhiza combined with various vermicompost doses.

| Treatment | m0<br>mg $g^{-}$ dry weight | m1<br>mg $g^{-1}$ dry weight |
|---|---|---|
| v0 | 21.192 a<br>A | 25.718 a<br>B |
| v1 | 24.352 b<br>A | 25.723 a<br>B |
| v2 | 25.040 b<br>A | 25.852 a<br>A |
| v3 | 26.107 b<br>A | 27.117 b<br>B |
| v4 | 27.613 b<br>A | 27.862 b<br>A |
| v5 | 29.129 c<br>A | 28.712 c<br>A |

Note: Numbers followed by identical lowercase and uppercase letters indicate no significantly different vertical differences between vermicompost dose treatments and horizontal differences between mycorrhizal treatments; m0= no mycorrhiza; m1= mycorrhiza. Codes v0 to v5 are variations in vermicompost dosage. The test is significantly different from the Ducan test by 5%.

The statistical analysis showed an interaction between mycorrhiza and vermicompost treatments. The lowest Pb levels were found in the control treatment (v0), at 21.192 mg $g^{-1}$ dry weight (Table 2). Vermicompost treatment in varying doses showed a significant increase in Pb levels in the roots ($p< 0.5$) compared to the control. Mycorrhiza treatment significantly increased Pb levels in the roots compared to the absence of mycorrhiza at vermicompost doses of 0, 10, and 20 t h-1 were 25.718, 25.723, and 27.117 (mg g-1 dry weight), respectively. Additionally, the application of mycorrhiza with vermicompost doses v2 increased significantly compared with vermicompost doses 20 t $h^{-1}$ and 30 t $h^{-1}$(v3 and v5 ), respectively, showed levels of 25.723, 27.117, 27.867, and 28.712 (mg $g^{-1}$ dry weight). The organic material from vermicompost produced the highest root Pb content, reaching 29.129 (mg $g^{-1}$ dry weight). (Table 2).

**Pb translocation in shoots**

Based on the variance analysis, Pb translocation in the upper part of the plant was influenced by mycorrhiza treatment and vermicompost (Table 3).

Table 3. Average Pb levels in the shoot of plants due to treatment with and without mycorrhiza, with variations in vermicompost doses.

| Treatment | m0 | m1 |
|---|---|---|
| | mg $g^{-1}$ dry weight | mg $g^{-1}$ dry weight |
| v0 | 14.500 a<br>A | 11.893 a<br>B |
| v1 | 13.394 a<br>A | 11.672 ab<br>B |
| v2 | 12.160 b<br>A | 10.721 ab<br>A |
| v3 | 11.140 bc<br>A | 10.558 ab<br>A |
| v4 | 10.578 c<br>A | 10.459 bc<br>A |
| v5 | 8.873 d<br>A | 8.858 c<br>A |

Note: Numbers followed by identical lowercase and uppercase letters indicate no significantly different vertical differences between vermicompost dose treatments and horizontal differences between mycorrhizal treatments; m0= no mycorrhiza; m1= mycorrhiza. Codes v0 to v5 are variations in vermicompost dosage. The test is significantly different from the Ducan test by 5%.

According to the investigation results, applying vermicompost alone decreases the shoots' Pb content. The study found that vermicompost doses ranging from 15 t $ha^{-1}$ to 30 t $ha^{-1}$ showed a significant decrease in Pb content in the shoot compared to the control treatment. The lowest Pb content was observed in the treatment with the application of 30 t $ha^{-1}$ vermicompost, which amounted to 8.873 mg $g^{-1}$ of dry weight. Furthermore, mycorrhiza application in the control treatment and mycorrhiza combined with vermicompost at 10 t ha-1 significantly decreased Pb content in the shoot. The study found that mycorrhiza inoculation resulted in a significant decrease in the Pb content of the shoot.

**Plant phosphorus uptake**

Based on analysis of variance, there was an interaction between mycorrhiza and vermicompost treatments on phosphorus uptake (Table 4).

Table 4. Average P-plant uptake due to treatment with and without mycorrhiza and variations in vermicompost doses

| Treatment | m0 | m1 |
|---|---|---|
| | mg $g^{-1}$ dry weight | mg $g^{-1}$ dry weight |
| v0 | 304.7117 a<br>A | 212.8983 a<br>B |
| v1 | 296.1533 a<br>A | 259.4583 a<br>A |
| v2 | 280.0117 a<br>A | 282.2000 a<br>A |
| v3 | 246.3167 a<br>A | 280.4733 a<br>A |
| v4 | 252.673 c<br>A | 278.7567 ab<br>A |
| v5 | 224.827 c<br>A | 288.5017 b<br>A |

Note: Numbers followed by identical lowercase and uppercase letters indicate no significantly different vertical differences between vermicompost dose treatments and horizontal differences between mycorrhizal treatments; m0 = no mycorrhiza; m1= mycorrhiza. Codes v0 to v5 are variations in vermicompost dosage. The test is different from the Ducan test by 5%.

According to the results of the analysis, there is an interaction between the different doses of vermicompost treatment and mycorrhiza inoculation treatment. The study reveals that the mycorrhiza inoculation treatment enhances the highest plant phosphorus (P) uptake when combined with 30 t $ha^{-1}$ vermicompost treatment compared to the other treatments, at 288.5017 mg $g^{-1}$ dry weight (Table 4). However, overall, the results suggest that the application of vermicompost and mycorrhiza results in lower phosphorus uptake than the control.

**Dry weight of chili yield**

Table 5 displays the impact of vermicompost and mycorrhiza application on chili plant yield. The study shows no interaction between the vermicompost application and mycorrhiza. Furthermore, there is a significant difference between the various doses of vermicompost provided and the yield of chili plants.

Table 5. Average chili yield due to treatment with and without mycorrhiza combined with varying vermicompost doses.

| Vermicompost (v) treatment | Weight of chili yield (g $plant^{-1}$) |
|---|---|
| v0 | 58.80 a |
| v1 | 52.08 a |
| v2 | 61.71 a |
| v3 | 49.05 a |
| v4 | 68.14 b |
| v5 | 70.12 b |
| Mycorrhiza (m) treatment | |
| m0 | 60.15 a |
| m1 | 49.50 b |

Note: Numbers followed by identical lowercase and uppercase letters indicate no significantly different vertical differences between vermicompost dose treatments and horizontal differences between mycorrhizal treatments; m0 = no mycorrhiza; m1= mycorrhiza. Codes v0 to v5 are variations in vermicompost dosage. The test is significantly different from the Ducan test by 5%.

The statistical analysis results indicate independent effects between the application of vermicompost and mycorrhiza inoculation. The application of vermicompost at doses of 25 t $ha^{-1}$ and 30 t $ha^{-1}$ significantly increased chili fruit yield compared to the other treatment. Meanwhile, the chili yield using mycorrhiza is considerably lower than without mycorrhiza, at 49.50 g·plant$^{-1}$. Increased chili yield requires a high dose of vermicompost.

## DISCUSSION

### The role of vermicompost and mycorrhiza to Pb content in chili plant roots

This research found that vermicompost and mycorrhiza played a role in increasing Pb translocation to the roots. As has been explored by Sparks (2003) and Zeng et al. (2011), organic matter plays a critical role in regulating the conversion of heavy metals in soil. As such, vermicompost helps Pb uptake in chili roots by binding the functional group of the vermicompost's organic compound to the heavy metal in the soil. Functional groups such as Protonated hydroxyl (-OH), carboxyl (-COOH), and amino (-NH2) can form intra- and intermolecular hydrogen bonds, limiting metal ion complexation (Liu et al. 2020). Liu et al. (2020) demonstrated that the adsorption performance of sugar cane waste was superior in a similar adsorbent-adsorbate system. The carboxyl groups of organic materials contribute to superior adsorption performance; most probably, the reason is their functional groups, like hydroxyl and carboxy, and benzene rings bind the heavy metal (Liu et al. 2020).

The research revealed that mycorrhiza plays a significant role in assisting the uptake of Pb in roots. It was found that mycorrhiza can act as a potential chelating agent that binds Pb in the roots of chili plants that are infected with mycorrhizal hyphae. This statement aligns with the conclusions drawn from the research of Zhang et al. (2021) which suggests that AM fungi can increase the concentration and content of Pb in plant roots. The uptake of Pb by plant roots is believed to occur through water flow (Zhang et al. 2021).

### The effect of vermicompost and mycorrhizal inoculation on Pb translocation in shoots

The application of vermicompost and mycorrhiza showed a tendency to suppress the translocation of Pb to the plant's shoot. Applying a vermicompost dose of 10 tons$^{-1}$ha (v1) showed a significant difference in suppressing Pb uptake between treatments with and without mycorrhiza. The higher the dose of vermicompost used, the lower the Pb levels absorbed by the plant. Thus, the results of this study illustrate that vermicompost plays a crucial role in preventing Pb translocation from continuing to the top of the plant. This happens because Pb is bound to the roots with the help of vermicompost to form stable organic Pb, so it is challenging to be translocated further to plant parts. According to Zhang et al. (2021), organic materials from the bagasse structure can increase the absorption capacity of Pb into a strong and stable biochemical bond (Huang et al. 2019, Wu et al. 2018). According to Liu et al. (2020), using organic materials based on sugar cane waste (Bagas) shows effective Pb adsorption performance. Mycorrhiza treatment showed significantly lower Pb uptake ($p< 0.5$) compared to the independent application of vermicompost, namely 11.893 ppm. Likewise, using vermicompost at a dose of 10 $t^{-1}$ha using mycorrhiza showed a decrease.

Mycorrhizae are known to bind heavy metals to carboxyl groups in pectic or hemicellulose compounds, in the matrix between the contact surfaces of mycorrhizae and host plants, in polysaccharide sheaths and hyphae cell walls (Zhang et al. 2021). The decomposition of organic material influences AM mycelia by releasing secondary metabolites produced by microorganisms during the decomposition process of organic material (Gryndler et al. 2009).

Lead uptake has decreased due to the binding of dissolved lead in the soil, caused by the humic acid in organic materials such as vermicompost (Wan et al. 2018).

Increasing the ability to accumulate Pb in roots colonized by AM fungi can occur through two pathways, namely nutrient and water uptake (Ferrol et al. 2016, Smith & Smith 2011). Hypothesis according to Zhang et al. (2021) AM increases Pb uptake in colonized root segments through (1) increasing plant transpiration; (2) AM fungi translocating Pb to segment of colonized root; and (3) Pb uptake by plant involves the participation of plant aquaporins. The results showed that the Pb content at the plant's shoot was lower than the Pb content in the roots (Tables 2 and 3). This indicates that translocation has obstacles due to mycorrhiza and vermicompost treatment. According to Zhang et al. (2021), Pb uptake through mycorrhiza-colonized root segments has low mobility when moving from roots to shoots and is likely accumulated by AM fungi in the roots. In line with previous studies, mycorrhizal plants accumulated higher Pb in roots than in shoots compared to non-mycorrhizal plants (Yang et al. 2016, Zhang et al. 2021).

**The effect of the application of vermicompost combined mycorrhiza to plant phosphorus uptake**

Mycorrhiza treatment resulted in a significantly lower phosphorus uptake due to the physiological disruption caused by the accumulation of Pb in the roots. From the investigation results, it is evident that there is a high accumulation of Pb in the roots, resulting in a disrupted process of P transfer and uptake to the shoots. Mycorrhiza must first acclimate to its environment when exposed to high levels of heavy metal stress. The first phase of adaptation involves the ability of the mycorrhiza to bind heavy metals to its matrix and hyphae walls, which reduces its ability to absorb phosphorus. The application of vermicompost and treatment with mycorrhiza inoculation showed a tendency to increase P uptake, although this increase was not significant. Vermicompost can create conditions supporting mycorrhizal activity and adaptation, increasing plant P uptake. Meanwhile, as Mahmud et al. (2020) reported, the application of vermicompost significantly increased P uptake by the plant. In this research, the soil phosphate available is relatively high, causing the role of vermicompost and mycorrhiza to have no significant effects on the P-uptake of chili plants. However, vermicompost can help mycorrhiza adapt to Pb stress conditions by maintaining moisture and reducing dissolved Pb ions. According to research by Coria-Coyupaan et al. (2009), vermicompost (VC) is recognized as an effective plant growth promoter. After Goutam et al. (2011), because of microbial activities, micronutrients, nitrogen (N), phosphorus (P), and others will become more available. These micronutrients are necessary for plant growth, and their averages were reported by Adhikary et al. (2012). Moreover, these macro and micronutrients are readily available from vermicompost to plants (Atiyeh et al. 2000).

**Dry weight of chili yield due to the treatment of vermicompost and mycorrhiza variations**

The comparison between mycorrhizal and non-mycorrhizal treatments revealed significant differences in chili yield. It was observed that the application of mycorrhizal resulted in decreased yields of chili plants. The negative effect of mycorrhiza treatment can be attributed to the nature of mycorrhiza, which accumulates lead (Pb) in the roots at higher concentrations than in plant shoots (see Tables 2 and 3). This, in turn, disrupts the nutrient uptake and translocation process during the growth and fruiting of chili plants. Although mycorrhiza can potentially suppress Pb uptake, it fails to increase chili plant yields. The reason behind the ineffectiveness of mycorrhiza in increasing chili yields could be the availability of phosphorus (P) in the soil at very high levels. This high level of P inhibits mycorrhizal activity; therefore, heavy metal pollution is an important environmental issue. Collin et al. (2022) reported that lead uptake by primary producers (plants) adversely affects their metabolism, growth, and photosynthesis, with excessive lead accumulation reducing root growth by up to 42%. Plants absorb free $Pb^{2+}$ ions through capillary action from the soil or via cellular respiration from the air (Sharma & Dubey 2005). Once absorbed, lead enters the plant system, with the roots passively taking up divalent $Pb^{2+}$ cations and other nutrients from contaminated soil (Engwa et al. 2019). These ions are then transported through xylem vessels, moving upward with other dissolved nutrients, and ultimately reach the endodermis, where they bind to the cell wall and plasma membrane (Sharma & Dubey 2005). This can harm agricultural yields, ecosystem health, and global-scale biodiversity, as shown in studies conducted by He et al. (2013) and Paini et al. (2016).

Heavy metals can inhibit plant growth and productivity (Chowdhury & Maiti 2016, Tovar-Sánchez et al. 2018, Yang et al. 2016). Additionally, Pb can adversely affect photosynthetic activity and lead to loss of plant biomass and fitness by interfering with physiological and biochemical responses, including photosynthesis processes (Emamverdian et al. 2015, Mateos-Naranjo et al. 2008, Windham et al. 2001). It is, therefore, not surprising that the production of chili plants in this study was low.

Several researchers have documented the adverse effects of lead (Pb) on plants. Lead accumulation significantly impairs photosynthesis by reducing the photosynthetic rate, inhibiting chlorophyll synthesis, disrupting the Calvin cycle, and causing stomatal closure (Khan et al. 2015). In Ceratophyllum demersum, $Pb(NO_3)_2$ alters chlorophyll structure, decreasing its photocatalytic activity (Seregin & Kozhevnikova 2023). Lead also changes lipid composition, affecting chlorophyll B more than chlorophyll A, and these disruptions in photosynthesis negatively impact fruit and flower growth (Opeolu et al. 2010). Additionally, lead contamination reduces flower production, especially at 600 and 1800 ppm Pb levels (Hadi & Aziz 2015). High levels of lead inhibit ATP synthase/ATPase activity and decrease respiration rates in plant cells, which is crucial for mitochondrial function (Seregin & Kozhevnikova 2023). Higher lead concentrations diminish sunflower plant height, leaf number, and dry matter (Hung et al. 2014). This study found that applying vermicompost at 25-30 t $ha^{-1}$ significantly increased chili yield compared to the control treatment, indicating that vermicompost can mitigate the adverse effects of Pb on chili plants.

## CONCLUSIONS

Vermicompost application at a dose of 25 – 30 t ha-1 combined with mycorrhiza increased the Pb content in the root compared with the control treatment. At the same time, treatment of 0 and 10 t $ha^{-1}$ vermicompost combined with mycorrhiza decreased significantly in Pb content in the shoot compared to the vermicompost treatment without mycorrhiza. Overall, we found that mycorrhiza can inhibit the Pb translocation to the upper part of the plant, so the roots of chili plants accumulate Pb more than the shoot parts. The findings of this study revealed that the chili plant is a Pb-accumulator plant. Mycorrhiza did not increase the P-uptake and the yield of chili plants. Meanwhile, vermicompost application at 25 -30 t $ha^{-1}$ increased significantly the plant chili yield. However, the application of vermicompost combined with mycorrhiza can suppress the uptake of Pb into the shoot area, thereby reducing its translocation to the upper parts of the plant. It has a positive impact in preventing Pb pollutants from being translocated to the top of the plant or fruit consumed by animals or humans so that it will prevent the accumulation of Pb in the upper or fruit of chilies from increasing food safety.

### REFERENCES

Adhikary, S. (2012): Vermicompost, the story of organic gold: A review. Agricultural Sciences 3: 905–917.

Atiyeh, R., Arancon, N., Edwards, C., Metzger, J. (2000): Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresource Technology 75: 175–180.

Chowdhury, A., Maiti, S.K. (2016): Identification of metal tolerant plant species in mangrove ecosystem by using community study and multivariate analysis: A case study from Indian Sunderban. Environmental Earth Sciences 75: 744.

Collin, B.S., Baskar, A., Deepthi Mariam Geevarghese, D.M.G., Ali, M.N.V.S., Bahubali, P., Rajan Choudhary, R., Lvove, V., Tovar, G.I., Fedor Senatov, F., Koppala, S., Swamiappan, S. (2022): Bioaccumulation of lead (Pb) and its effects in plants: A review**.** Journal of

Hazardous Materials Letters 3: 100064.

Coria-Cayupaán, Y.S.; de Pinto, M.A.I.S.; Nazareno, M.A. (2009): Variations in bioactive substance contents and crop yields of lettuce (*Lactuca sativa* L.) cultivated in soils with different fertilization treatments. Journal of Agricultural and Food Chemistry 57: 10122–10129.

Davison, J., Moora, M., Öpik, M., Adholeya, A., Ainsaar, L., Bâ, A., Burla, S., Diedhiou, A. G., Hiiesalu, I., Jairus, T., Johnson, N. C., Kane, A., Koorem, K., Kochar, M., Ndiaye, C., Pärtel, M., Reier, Ü., Saks, Ü., Singh, R., Zobel, M. (2015): Global assessment of arbuscular mycorrhizal fungus diversity reveals very low endemism. Science 349 (6251): 970-973.

Driver, J.D., Holben, W.E., Rillig, M.C. (2005): Characterization of glomalin as a hyphal wall component of arbuscular mycorrhizal fungi. Soil Biology and Biochemistry 37 (1): 101-106.

Emamverdian, A., Ding, Y., Mokhberdoran, F., Xie, Y. (2015): Heavy metal stress and some mechanisms of plant defense response. Scientific World Journal 2015: 756120.

Engwa, G.A., Ferdinand, P.U., Nwalo, F.N., Unachukwu, M.N. (2019): Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the modern world - New tricks for an old dog? IntechOpen, http://dx.doi.org/10.5772/intechopen.82511.

Faggioli, V., Menoyo, E., Geml, J., Kemppainen, M., Pardo, A., Salazar, M.J., Becerra, A.G. (2019): Soil lead pollution modifies the structure of arbuscular mycorrhizal fungal communities. Mycorrhiza 29 (4): 363-373.

Ferrol, N., Tamayo, E., Vargas, P. (2016): The heavy metal paradox in arbuscular mycorrhizas: From mechanisms to biotechnological applications. Journal of Experimental Botany 67 (22): 6253-6265.

Gadd, G.M. (2001): Accumulation and transformation of metals by microorganisms. pp. 225-264. In: Rehm, H.J., Reed, G. (eds.), Biotechnology, John Wiley & Sons, Ltd.

Goutam, K.C., Goutam, B., Susanta, K.C. (2011): The effect of vermicompost and other fertilizers on cultivation of tomato plants. Journal of Horticulture and Forestry 3: 42-45.

Gryndler, M., Hršelová, H., Cajthaml, T., Havránková, M., Řezáčová, V., Gryndlerová, H., Larsen, J. (2009): Influence of soil organic matter decomposition on arbuscular mycorrhizal fungi in terms of asymbiotic hyphal growth and root colonization. Mycorrhiza 19 (4): 255-266.

Gupta, N., Khan, D.K., Santra, S.C. (2008): An assessment of heavy metal contamination in vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. Bulletin of Environmental Contamination and Toxicology 80 (2): 115-118.

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

He, B., Yun, Z., Shi, J., Jiang, G. (2013): Research progress of heavy metal pollution in China: Sources, analytical methods, status, and toxicity. Chinese Science Bulletin 58 (2): 134-140.

Herlina, L., Purnaweni, H., Sudarno, S., Widianarko, B., Sunoko, H.R. (2020): Phytoremediation of lead-contaminated soil by ornament plant *Codiaeum variegatum*. Journal of Physics: Conference Series 1567 (3): 032043.

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

Huang, D., Wu, J., Wang, L., Liu, X., Meng, J., Tang, X., Tang, C., Xu, J. (2019): Novel insight into adsorption and co-adsorption of heavy metal ions and an organic pollutant by magnetic graphene nanomaterials in water. Chemical Engineering Journal 358: 1399-1409.

Khan, A., Khan, S., Khan, M.A., Qamar, Z.M. (2015): The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. Environmental Science and Pollution Research 22 (18): 13772-13799.

Liu, T., Li, Z., Hui, C., Tang, M., Zhang, H. (2016): Effect of *Rhizophagus irregularis* on osmotic adjustment, antioxidation and aquaporin PIP genes expression of *Populus* × *canadensis* 'Neva' under drought stress. Acta Physiologiae Plantarum 38 (8): 191.

Liu, G., Liao, L., Dai, Z., Qi, Q., Wu, J., Ma, L. Q., Tang, C., Xu, J. (2020): Organic adsorbents modified with citric acid and Fe3O4 enhance the removal of Cd and Pb in contaminated solutions. Chemical Engineering Journal 395: 125108.

Mateos-Naranjo, E., Redondo-Gómez, S., Cambrollé, J., Figueroa, M.E. (2008): Growth and photosynthetic responses to copper stress of an invasive cordgrass, Spartina densiflora. Marine Environmental Research 66 (4): 459-465.

Mahmud, M., Abdulla, R., Yaacob, J.S. (2020): Effect of vermicompost on growth, plant nutrient uptake and bioactivity of ex vitro pineapple (*Ananas comosus* var. MD2). Agronomy 10 (1333): 1-22.

Opeolu, B.O., Adenuga, O., Ndakidemi, P.A., Olujimi, O.O. (2010): Assessment of phyto-toxicity potential of lead on tomato (*Lycopersicon esculentum* L) planted on contaminated soils. International Journal of Physical Sciences 5 (2): 68-73.

Paini, D.R., Sheppard, A.W., Cook, D.C., Barro, P.J.D., Worner, S.P., Thomas, M.B. (2016): Global threat to agriculture from invasive species. Proceedings of the National Academy of Sciences 113 (27): 7575–7579.

Parniske, M. (2008): Arbuscular mycorrhiza: The mother of plant root endosymbioses. Nature Reviews Microbiology 6 (10): 763-775.

Rascio, N., Navari-Izzo, F. (2011): Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? Plant Science 180 (2): 169-181.

Rehman, S., Castro, F.D., Aprile, S., Benedetti, M., Fanizz, F.P. (2023): Vermicompost: enhancing plant growth and combating abiotic and biotic stress. Agronomy 13: 1-25.

Seregin, I.V., Kozhevnikova, A.D. (2023): Phytochelatins: Sulfur-Containing Metal(loid)-Chelating Ligands in Plants. International Journal of Molecular Sciences 24 (3): 2430.

Sharma, P., Dubey, R.S. (2005): Lead toxicity in plants Braz. Journal of Plant Physiology 17 (1): 35-52.

Skuza, L., Szućko-Kociuba, I., Filip, E., Bożek, I. (2022): Natural molecular mechanisms of plant hyperaccumulation and hypertolerance towards heavy metals. International Journal of Molecular Sciences 23 (16): 9335.

Smith, S.E., Smith, F.A. (2011): Roles of arbuscular mycorrhizas in plant nutrition and growth: new paradigms from cellular to ecosystem scales. Annual Review of Plant Biology 62 (1): 227-250.

Sparks, D.L. (2003): 3-Chemistry of Soil Organic Matter. pp. 75–113. In: Sparks, D.L. (ed.), Environmental Soil Chemistry (Second Edition), Academic Press.

Tibbett, M., Green, I., Rate, A., Oliveira, V.H.D., Whitaker, J. (2021): The transfer of trace metals in the soil-plant-arthropod system. Science of The Total Environment 779: 146260.

Tovar-Sánchez, E., Hernández-Plata, I., Martínez, M.S., Valencia-Cuevas, L., Galante, P.M. (2018): Heavy metal pollution as a biodiversity threat. In: Saleh H.E.D.M., Aglan, R.F. (eds.), Heavy Metals, IntechOpen, doi: 10.5772/intechopen.74052.

Wan, D., Zhang, N., Chen, W., Cai, P., Zheng, L., Huang, Q. (2018): Organic matter facilitates the binding of Pb to iron oxides in a subtropical contaminated soil. Environmental Science and Pollution Research 25 (32): 32130-32139.

Wong, W., Tan, S., Ge, L., Chen, X., Letham, D., Yong, J. (2015): The importance of phytohormones and microbes in biostimulants: Mass spectrometric evidence and their positive effects on plant growth. pp. 49-60. In: Proceedings of the II World Congress on the Use of Biostimulants in Agriculture 1148, Florence, Italy.

Windham, L., Weis, J.S., Weis, P. (2001): Lead uptake, distribution, and effects in two dominant salt marsh macrophytes, *Spartina alterniflora* (Cordgrass) and *Phragmites australis* (Common Reed). Marine Pollution Bulletin 42 (10): 811-816.

Wu, J., Huang, D., Liu, X., Meng, J., Tang, C., Xu, J. (2018): Remediation of As(III) and Cd(II) co-contamination and its mechanism in aqueous systems by a novel calcium-based magnetic biochar. Journal of Hazardous Materials 348: 10-19.

Yang, Y., Liang, Y., Han, X., Chiu, T.-Y., Ghosh, A., Chen, H., Tang, M. (2016): The roles of arbuscular mycorrhizal fungi (AMF) in phytoremediation and tree-herb interactions in Pb contaminated soil. Scientific Reports 6 (1): 20469.

Zeng, F., Ali, S., Zhang, H., Ouyang, Y., Qiu, B., Wu, F., Zhang, G. (2011): The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environmental Pollution 159 (1): 84-91.

Zhang, H., Liu, T., Wang, Y., Tang, M. (2019): Exogenous arbuscular mycorrhizal fungi increase soil organic carbon and change microbial community in poplar rhizosphere. Plant, Soil and Environment 65 (3): 152-158.

Zhang, H., Ren, W., Zheng, Y., Li, Y., Zhu, M., Tang, M. (2021): Arbuscular mycorrhizal fungi increase Pb uptake of colonized and non-colonized *Medicago truncatula* root and deliver extra Pb to colonized root segment. Microorganisms 9 (6): 1203.