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Research Article

Heavy metals content in sweet potato (*Ipomoea batatas* L.) grown on soil contaminated by gold mine tailings with composted cow manure amendment

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Abstract

Artisanal gold miners usually dispose of gold mine tailings in storage ponds or agricultural land used for farming. However, the gold mine tailings still contain heavy metals such as cadmium, copper, lead, and zinc and can lead to bioaccumulation in food chains. This study investigated the influence of composted cow manure as organic fertilizer on heavy metals (Cd, Cu, Pb and Zn) content in sweet potatoes grown on soil contaminated by gold mine tailing. The MZ119 clone sweet potato plants were grown on soils added with mixtures of gold mine tailings at ratios of 0% (control), 30%, 50%, 70%, and 100% (w/w), and composted cow manure (0, 250, 500, and 750 g/10 kg of soil). The results showed that the higher the ratio of gold mine tailings to the soil, the higher the accumulation of metals in sweet potatoes. According to the translocation factor (TF) value, heavy metals (Cd, Cu, Pb and Zn) accumulated higher in the shoots than in the roots of sweet potatoes. Accumulation of heavy metals in sweet potato occurred in the following order: Zn>Cu>Pb>Cd. This study recommends that sweet potatoes could be used for the phytoremediation of heavy metals (Cd, Cu, Pb and Zn) in polluted soils, but the plants may not be used for consumption.

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Introduction

Artisanal and small-scale gold mining (ASGM) is gold mining carried out by individual miners or small businesses with limited capital investment and production. Indonesia has many gold mining locations carried out by ASGM, including in Kertajaya Village, Sukabumi Regency, West Java, Indonesia. Artisanal gold miners in Kertajaya village commonly use the mercury amalgamation method to extract gold ore mines, a simple process that requires only a small investment. This process generates tailings or solid waste, typically disposed of in storage ponds or agricultural land used for food crops such as sweet potatoes, maize and cassava. Gold mine tailings contamination can reduce soil productivity, plant growth, and yield. According to Roy et al. (2005), high concentrations of heavy metals in soils inhibit plant growth and agricultural productivity.

The gold mine tailing still contains hazardous heavy metals such as cadmium, copper, lead, and zinc. According to Ghosh (2010), the most dangerous heavy metals in terms of toxicity are Hg, Cd, Pb, As, Cu, Zn, Sn, and Cr. In various studies, plants of the

Convolvulaceae family, like sweet potatoes, were metal accumulators. Heavy metal content in gold mine tailings can accumulate in sweet potatoes and harm human or animal consumption through the food chain. Plant and animal cells have mechanisms for bioaccumulation that allow them to accumulate nutrients and essential minerals, absorb nutrients, and store harmful substances such as heavy metals (Antonious et al., 2011). According to Zhou et al. (2016), sweet potatoes absorb more metals (Pb, Cd, and As) from polluted soil than white radishes and carrots. Nenman et al. (2022) found that sweet potatoes grown on abandoned mined accumulated Zn (up to 4,012.35 mg/kg), Cu (up to 14,377.36 mg/kg), Cr (up to 5,268.42 mg/kg), Mn (up to 6,429.58 mg/kg), Ni (up to 4,562.67 mg/kg) and Fe (up to 71,633.35 mg/kg). Heavy metals are not biodegradable and, therefore, can accumulate in vital human organs (Demirezen and Aksoy, 2006). Heavy metals risk living organisms and the environment due to their carcinogenic and mutagenic properties (Wu et al., 2018). Heavy metal's permissible limit in vegetables is 0.2 mg/kg (Cd), 0.3 mg/kg (Pb), 73.3 mg/kg (Cu), and 99.4 mg/kg (Zn) (FAO/WHO, 2001).

Cow manure is an organic application that farmers use because it is low-cost and easily obtained. Utilization of such organic application is beneficial for soil health as it improves soil physicochemical properties and modifies the degree of heavy metal availability. Organic applications have a high humified organic matter content, decrease the bioavailability of metals in soil via adsorption, and form stable complexes with humic substances (Shuman, 1999). Organic fertilizers like animal dung and compost have improved soil physical and chemical qualities, increased biological biodiversity, and lowered metal bioavailability (Montiel-Rozas et al., 2015). Total N, available P, exchangeable K, Ca, Mg, accessible S, Zn, and B, and the amount of organic matter in the soil, were all significantly boosted with the addition of composted cow manure (Zaman et al., 2017).

This study aimed to investigate the effect of the soil level contaminated by gold mine tailing in combination with composted cow manure application on heavy metals accumulation in sweet potatoes.

Materials and Methods

Sampling location

This study was conducted at the greenhouse of the Faculty of Agriculture, Padjadjaran University, Jatinangor, Sumedang Regency, West Java. Gold mine tailings and soil (0-25 cm depth) used in this study were collected from gold mining locations in Kertajaya Village, Sukabumi District, West Java, Indonesia, with coordinates of -7.102817 latitude and 106.588848 east longitudes (Figure 1). The origin soil used type in Kertajaya village was an Inceptisol (Fluvaquentic subgroup).

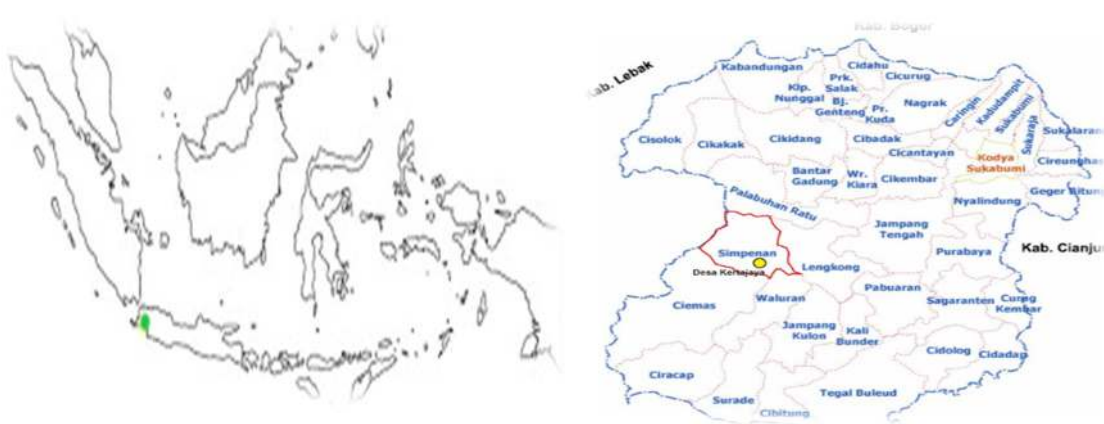


Figure 1. Sampling locations in Kertajaya Village, Simpenan District, Sukabumi Regency, West Java, Indonesia.

Materials

The gold mine tailings and soil were air-dried for seven days before sieving through a 2 mm sieve and air-dried before being analyzed for characteristics and SEM (gold mine tailing). The air-dried samples were analyzed to determine pH by the H_2O method (Environmental Protection Agency (EPA) U.S, 2004), organic C (Walkley and Black, 1934), total N (Bremner, 1960), total P (Bray and Kurtz, 1945), and cation exchange capacity (CEC) (Chapman, 1965). The cow manure was obtained from the waste treatment plant of the Faculty of Animal Husbandry, Padjadjaran University. The characteristics of the gold mine tailing, soil, and cow manure used in this experiment are shown in Table 1. The result of the SEM analysis of gold mine tailings is shown in Figure 2. The sweet potato used in this experiment was the orange-fleshed sweet potato MZ119 clone (Karuniawan et al., 2021). The sweet potato MZ119 was among the genotypes with stability and high yield (Maulana et al., 2020).

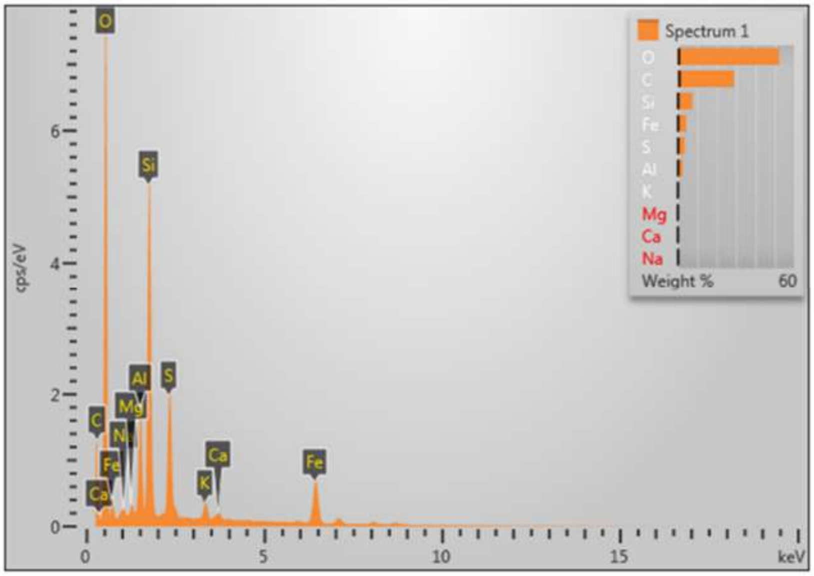


Figure 2. SEM analysis results of gold mine tailings from Kertajaya Village, Sukabumi, West Java.

Table 1. Characteristics of gold mine tailing, soil and cow manure used for the study.

Characteristics	Gold mine Tailing	Soil	Cow manure
pH	3.65	5.44	7.5
Organic C (%)	0.87	2.47	30.45
N (%)	0.09	0.18	2.18
P_2O_5 (ppm)	11.97	2.87	10.19
K_2O (mg/100 g)	17.19	48.13	0.91%
CEC cmol/kg	21.92	19.27	
Texture		Clay loam	
Pb (mg/kg)	368.18	11.04	
Cd (mg/kg)	52.04	0.86	
Cu (mg/kg)	6,142.23	23.62	
Zn (mg/kg)	11,506.77	71.96	

Pot experiment design

A pot experiment was conducted in a greenhouse at Ciparanje Experimental Farm, Faculty of Agriculture, Padjadjaran University, Indonesia, from August to December 2020. The first treatment factor was the gold mine tailing (T) ratio consisting of five levels, i.e., 0% (without tailing), 30% (w/w), 50% (w/w), 70% (w/w), 100% tailing. The second treatment factor was cow manure (C) doses consisting of four rates (0, 250, 500, and 750 g/pot) once applied in the beginning. In each pot, 10 kg of gold mine tailings was mixed with soil (first treatments factor) as growing media of sweet potatoes. All treatments were arranged in a completely randomized factorial design with three replications. The planting media was watered often to keep its moisture level at 60% of its water field capacity. Six weeks following planting, all plants received a fertilizer (NPK) application at a rate of 5 g/pot. The plants were harvested 18 weeks after being sown.

Heavy metals analysis

The total amount of metals in the dry weight of harvested plants was used to calculate the concentrations of metals (Cd, Cu, Pb and Zn). All plants were divided into shoots and roots, rinsed with water, and weighed (fresh and dry weights). The harvested plants were reduced in size and oven-dried for 48 hours at 80 °C. The dried sweet potato shoots and root samples were ground to a powder using a mortar and pestle and a mixer grinder for metals analysis. The heavy metals in plants were analyzed using the approach given by Bokhari et al. (2016). Plant samples were washed with distilled water, dried in the oven for 48 hours at 70 °C, milled, and sieved. Plant material (0.25 g) was digested on a hot plate with 10 mL of double acid (HNO_3-$HClO_4$ in a 2:1 ratio) and diluted in deionized water to 50 mL. The concentration of heavy metals (Cd, Cu, Pb, and Zn) in plant samples was measured using a Flame Atomic Absorption Spectrometer (Shimadzu AA 7000 series).

The capacity of the plants to accumulate and transport heavy metals was determined using the Translocation Factor (TF), which demonstrates plants' ability to transfer metals from roots to stems and leaves (Arnot and Gobas, 2006). Translocation Factor (TF) can be calculated as follows (Majid et al., 2012):

$$TF = \frac{\text{Metal concentration in aerial parts (mg/kg dry weight)}}{\text{Metal concentration in the root (mg/kg dry weight)}}$$

Statistical Analysis

All data were analyzed using SPSS 26.0 to calculate the mean and standard deviation of all the data and conduct a statistical analysis of variance (ANOVA). Significant differences in metal accumulation in different plant sections were calculated using Duncan Multiple Range Test (DMRT).

Results

Dry biomass of plants

The gold mine tailing and cow manure amendment on soil interact significantly ($p<0.05$) with sweet potatoes' roots and shoots dry weight biomass (Table 3). As a result, applying cow manure to the soil without gold mine tailing contamination increased plant dry-weight biomass by 24.3-125.9% (roots) and 51.9-76% (shoots) over the control. Otherwise, contamination of gold mine tailing on soil without cow manure amendment decreased by 60-98.5% (roots) and 82.1-94.9% (shoots) over the control.

Table 3. Gold mine tailing and cow manure effect on sweet potatoes dry weight biomass.

Treatment	Plants dry weight (g)	
	Roots	Shoots
T0C0 (Control)	31.20 bc	41.46 b
T0C1	70.50 a	62.98 a
T0C2	67.27 a	72.99 a
T0C3	38.79 bc	72.84 a
T1C0	12.46 def	7.38 fg
T1C1	24.48 cde	17.69 de
T1C2	29.34 bcd	24.23 cd
T1C3	39.30 bc	38.65 b
T2C0	2.76 f	6.15 fgh
T2C1	10.23 ef	19.83 de
T2C2	44.43 b	36.88 bc
T2C3	44.71 b	43.44 b
T3C0	1.33 f	3.62 gh
T3C1	1.02 f	6.52 fgh
T3C2	3.08 f	13.32 def
T3C3	2.38 f	12.06 ef
T4C0	0.44 f	2.08 gh
T4C1	0.83 f	2.45 gh
T4C2	0.68 f	1.38 h
T4C3	0.61 f	1.40 h

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA.

The dry weight biomass of sweet potato roots cultivated in soil without contamination of gold mine tailing (w/w), with cow manure rate of 250 g/pot and 500 g/pot, was significantly ($p<0.05$) higher than the other treatments. Meanwhile, soil without contamination of gold mine tailing (w/w) was not significantly different in combination with all treatment cow manure rates on the dry weight of shoots parts of sweet potato.

Heavy metals content

Cadmium (Cd)

This study revealed a significant interaction effect ($p<0.05$) between gold mine tailing ratio and cow manure application on Cd content in sweet potato roots and shoots (Table 4). Contamination of gold mine tailing on soil without cow manure application increased by 29.41-47.38 mg/kg (roots) and 24.27-65.76 (shoots) over the control. Meanwhile, cow manure application to the soil without gold mine tailing contamination increased Cd content in sweet potato by 57.78-73.33% (roots) and 8.47-55.48% (shoots) over the control. The highest Cd accumulation in the sweet potato showed in soil with the 30% gold tailing (w/w) ratio combined without cow manure application (0 g/pot) but no significant difference ($p<0.05$) with 250 g/pot cow manure application. The combination of a 30% gold mine tailing ratio (w/w) and 250 g/pot cow manure application showed increments of Cd content 41.84 mg/kg (roots) and 60.7 mg/kg (shoots) over the control (Table 4).

Table 4. Effect of gold mine tailing and cow manure on Cd content in sweet potato (roots and shoots).

Treatment	Cd content (mg/kg dry weight)	
	Root	Shoot
T0C0 (Control)	0.90 h	6.02 h
T0C1	0.24 h	5.51 h
T0C2	0.27 h	2.68 h
T0C3	0.38 h	2.77 h
T1C0	48.28 a	71.78 a
T1C1	42.74 ab	66.72 a
T1C2	36.00 bc	49.88 b
T1C3	24.01 ef	40.65 bcd
T2C0	29.46 cde	46.47 bc
T2C1	28.82 cde	33.50 def
T2C2	31.59 cde	26.80 fg
T2C3	34.69 bcd	27.81 f
T3C0	36.57 bc	38.15 cde
T3C1	33.89 bcd	28.30 f
T3C2	31.89 cde	30.86 ef
T3C3	25.20 def	26.34 fg
T4C0	30.31 cde	30.29 ef
T4C1	23.58 ef	31.20 ef
T4C2	19.55 fg	27.33 f
T4C3	15.22 g	20.13 g

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA.

Copper (Cu)

The study showed no significant interaction ($p<0.05$) between the gold mine tailing ratio and cow manure application in their effect on Cu content in sweet potato root but neither in the part of the shoots. Otherwise, gold mine tailing contamination on soil and cow manure application independently affect Cu accumulation in sweet potato roots (Table 5). Data presented in Table 5 show that sweet potatoes grown on 100% gold tailing had the highest Cu content in roots and increased 346.25 mg/kg compared to those without gold mine tailing contamination. Meanwhile, the treatment without cow manure application (0 g/pot) had the highest Cu accumulation on sweet potato roots, 201.48 mg/kg. Cu content in sweet potato roots increased by 152.54-553.77 mg/kg over the control after gold mine tailing contamination of soil without cow manure application. Meanwhile, adding cow manure to the soil without contaminating it with gold mine tailings increased Cu content in shoots by up to 14.8% over the control.

Table 5. Gold mine tailing and cow manure effect independently on Cu content in roots.

Treatment	Cu content (mg/kg dry weight)
Gold Tailing (% w/w)	
T0	11.58 d
T1	99.77 c
T2	108.25 c
T3	272.42 b
T4	357.83 a
Cow manure (g/pot)	
C0	201.48 a
C1	178.92 b
C2	160.98 bc
C3	138.51 c

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA.

The study results in Table 6 show that 100% gold tailing (w/w) combined without cow manure application (0 g/pot) results in the highest Cu in shoots.

Lead (Pb)

The result of this study revealed a significant interaction ($p<0.05$) between gold mine tailing contamination and cow manure application to Pb accumulation in sweet potatoes (roots and shoots). The effects of a combination of gold mine tailing and cow manure application on the content of Pb in sweet potatoes is shown in Table 7. Contamination of gold mine tailing on soil without cow manure application increased Pb content in roots of sweet potatoes by 8.04-144.71 mg/kg and 36.86-87.07 mg/kg over the control. Meanwhile, cow manure application to the soil without gold mine tailing contamination decreased Pb content in sweet potato roots by 1.1-2.0 mg/kg (roots) and 5.41-24.32 mg/kg (shoots) over the control. The highest Pb content in the sweet potato showed in the 100% gold mine tailing (w/w) ratio combined without cow manure application (750 g/pot) but no significant difference ($p<0.05$) with 250 g/pot cow manure application.

Table 6. Gold mine tailing and cow manure interaction on Cu content in sweet potato shoots.

Treatment	Cu content (mg/kg dry weight)
T0C0 (Control)	58.20 ij
T0C1	38.49 j
T0C2	60.23 ij
T0C3	66.86 hij
T1C0	210.74 cd
T1C1	161.26 cdef
T1C2	130.13 efg
T1C3	88.09 ghi
T2C0	339.45 b
T2C1	199.47 cde
T2C2	138.09 defg
T2C3	117.58 fgh
T3C0	358.32 b
T3C1	327.34 b
T3C2	191.54 cdef
T3C3	175.14 cdef
T4C0	611.97 a
T4C1	584.69 a
T4C2	362.17 b
T4C3	221.94 c

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA.

Zinc (Zn)

This study resulted in no significant interaction ($p<0.05$) between gold mine tailing and cow manure application on Zn content in sweet potato (roots and shoots). However, there was an independent effect of gold mine tailing and cow manure application on Zn content in the roots and shoots of sweet potatoes (Table 8). The results showed that sweet potato soil contaminated with 100% gold mine tailing had the highest Zn content in roots and increased by 4,423.50 mg/kg to those without gold mine tailing contamination (control). The treatment without cow manure application (0 g/pot) and 250 g/pot did not significantly ($p<0.05$) differ in Zn content in the roots part of sweet potatoes. Soil contaminated by gold mine tailing increased Zn content in shoots of sweet potato 1,050.03-2,936.12 mg/kg over control (without gold mine tailing). However, cow manure application decreased Zn accumulation in sweet potato shoots by 826.29-1,677.52 mg/kg compared to the control (without cow manure).

Table 7. Gold tailing and cow manure effect independently on Pb content in roots and shoots.

Treatment	Pb content (mg/kg dry weight)	
	Roots	Shoots
T0C0 (Control)	3.59 h	7.38 g
T0C1	1.82 h	12.79 g
T0C2	1.59 h	27.63 f
T0C3	2.43 h	31.70 f
T1C0	11.63 h	44.24 f
T1C1	31.33 g	42.40 f
T1C2	45.28 fg	39.76 f
T1C3	50.26 efg	69.75 e
T2C0	44.73 def	74.66 e
T2C1	97.94 cd	89.24 de
T2C2	78.34 cde	115.94 cd
T2C3	87.82 cd	128.96 c
T3C0	148.30 c	79.16 e
T3C1	103.18 c	125.40 c
T3C2	200.12 ab	118.46 cd
T3C3	223.55 ab	142.47 bc
T4C0	84.93 cd	94.45 de
T4C1	96.22 cd	77.72 e
T4C2	173.24 b	179.23 ab
T4C3	251.32 a	180.80 a

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA.

Translocation Factor (TF)

Translocation Factor (TF) values of sweet potato on treatment growth media are described in Figure 3. Results of the study revealed that, generally, the TF value of heavy metals (Cd, Cu, Pb and Zn) in all treatments was higher than 1. These indicate that the metals accumulate higher in the shoots than in the roots of sweet potatoes. The TF value of heavy metals tended to decrease with increasing doses of cow manure application.

Discussion

According to the results of this study, an increase in the ratio of gold mine tailings contamination to soil causes poor growth and decreased dry biomass of sweet potatoes. The gold tailings' poor features influenced sweet potatoes' low growth and biomass. Heavy metals content, low acidity and poor physical-chemical properties of the gold mine tailing were indicative of causing low dry weight biomass of sweet potatoes. According to Vega et al. (2004) and Blight and Fourie (2005), gold mining tailings had poor aggregation, high hydraulic conductivity, fine-grained texture, and low cohesion capacity.

Table 8. Gold tailing and cow manure interaction on Zn content in sweet potato roots and shoots.

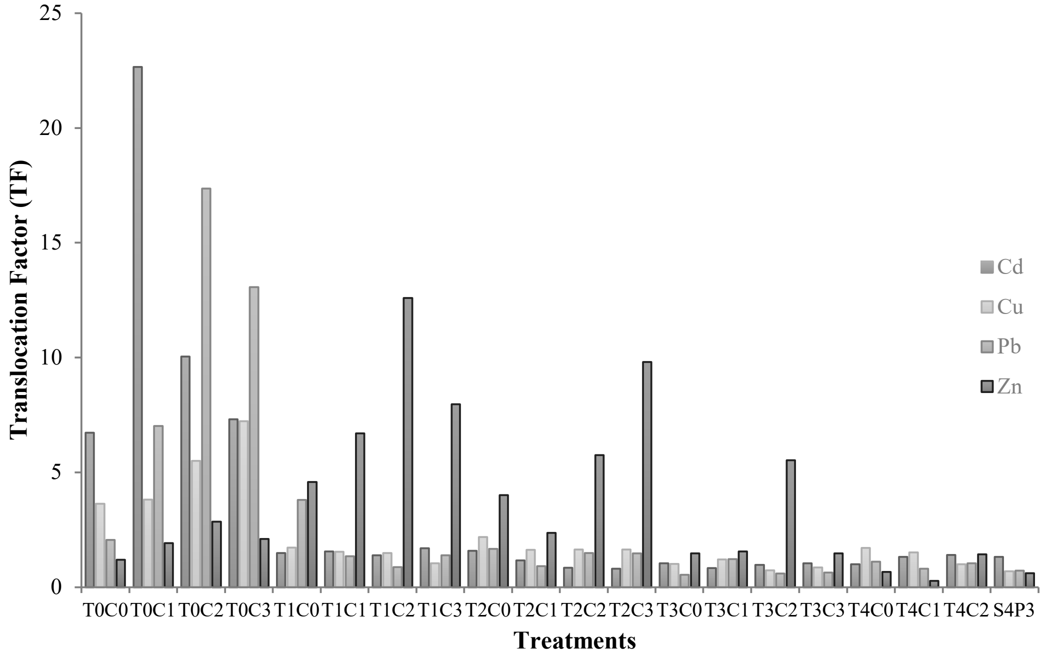
Treatment	Zn content (mg/kg dry weight)	
	Roots	Shoots
Tailing (% w/w)		
T0	156.24 d	282.24 c
T1	199.93 d	1332.27 b
T2	490.38 c	2107.59 ab
T3	1834.06 b	3218.36 a
T4	4579.74 a	2407.84 a
Cow manure (g/pot)		
C0	2311.33 a	2848.70 a
C1	2445.27 a	2022.41 ab
C2	396.49 b	1436.36 bc
C3	655.18 b	1171.18 c

Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot. Mean values followed by different lower letters (column) are significantly different ($p<0.05$). Data were square root (x + 0.5) transformed before analysis with ANOVA,

Chemically, tailings are nutrient deficient, with up to 6% pyrite content, high salinity, and low organic matter amounts (Vega et al., 2006). This study also revealed that adding the gold tailings contamination ratio (% w/w) increased the concentration of heavy metals in the soil, thereby reducing the growth and yield of sweet potatoes. According to Alaoui-Sossé et al. (2004), heavy metals increase the synthesis of carbohydrates and some amino acids while decreasing plant growth and crop production. The presence of heavy metals in gold mine tailings is a significant factor that can harm plants by influencing physiological and metabolic processes (Hossain et al., 2012). Heavy metals in soils may compete with essential nutrients, reducing their availability for uptake by roots and contributing to osmotic stress (Siyar et al., 2020). Gold tailing contamination decreases the pH of the soil because the negative charge on the soil can bind H^+ ions, and H^+ cations are one of the main factors causing soil acidity, and pH decreases. Based on SEM analysis (Figure 2), gold mine tailing had S content, which is a factor that could decrease soil pH. The chemical process by which sulfur (S) application results in decreased soil pH is shown below (Equation 1):

$$CO_2 + S + ½O_2 + 2H_2O \rightarrow CH_2O + SO_4^{2-} + 2H^+ \quad (1)$$

When mixed with soil, sulfur in gold-mined tailings will be oxidized (O_2) to produce SO_4 and hydrogen ions (H^+), causing soil pH to decrease.



Notes: T0 = without tailing or 100% soil, T1 = 30% tailing, T2 = 50% tailing, T4 = 70% tailing, C0 = without cow manure, C1 = 250 g cow manure/pot, C2 = 500 g cow manure/pot, C3 = 750 g cow manure/pot

Figure 3. Translocation Factor (TF) of heavy metal in sweet potato growth on gold mine tailing.

Root H^+ ion secretion can promote metal solubility by acidifying the rhizosphere. H^+ ions can substitute heavy metal cations bound to soil particles (Alford et al., 2010). Low soil pH raises the concentration of heavy metals in the soil solution (Thangavel and Subhuram, 2004) and plants and causes a decrease in growth or plant death (Handayanto et al., 2016). Otherwise, this study demonstrated that increasing the dose of cow manure increased sweet potatoes' dry biomass. Nutrient and organic matter content in cow manure increasing carbon content of gold tailing contaminated soil may lead to the increasing availability of nutrients for the sweet potatoes growth. According to Gupta et al. (2016), cow manure contains 24 minerals, including nitrogen, potassium, and trace amounts of sulfur, iron, magnesium, copper, cobalt, and manganese. The organic matter content (C and N) in the gold tailings and soil used in this study was low (Table 1), so adding cow dung increased the organic content. A study by Fernandes et al. (2020) showed that nitrogen application induced a more significant increase in storage root biomass and nutrient uptake in sweet potatoes. In addition, cow manure contains microorganisms and helps improve the physical properties of gold-tailing contaminated soil as sweet potato-grown media.

The results of this study showed that the heavy metal content in sweet potatoes could be profoundly affected by the amount of available heavy metals in the growing media. The higher the concentration of metals in the growing media (treatments), the greater the heavy metal content in sweet potatoes. This study showed that combining gold mine tailings and cow manure did not produce differences in Cu content (roots) and Zn (roots and shoots). This result suggests that Zn and Cu absorb by plants as ions Zn^{2+} and Cu^{2+} and bound into roots by sulfur as ZnS and CuS. According to Isaure et al. (2006), heavy metals bind with root tissue in the root zone, mainly associated with sulfur. It has been demonstrated that heavy metals like Cu, Pb, Cd, Zn, and Ni can be firmly bound by organic molecules. The concentration of dissolved organic matter in the soil solution, pH, and metal loading over soil sorbents are the critical determinants of metal solubility (Weng et al., 2002). Temperature, pressure, pH, redox, concentrations of elements, ions, or compounds that complex with zinc (such as Cl^-, HS^-, SO_4^{2+}, and more), and partial pressures of gases (such as O_2, CO_2, H_2S, S_2, NH_3) are the geochemical variables that directly affect solubility and sorption (Mcphail et al., 2003).

The results of this study showed cow manure application on gold tailing contaminated soil decreased the accumulation of metals in sweet potatoes except for lead (Pb). The organic application can decrease the bioavailability of heavy metals in soil due to changing their available forms to fractions associated with organic materials, carbonates, or metal oxides that are in unavailable form (Wei et al., 2010). Three categories can be used to categorize the bioavailability of heavy metals and metalloids in soil: readily bioavailable (Cd, Ni, Zn, As, Se, Cu), moderately bioavailable (Co, Mn, Fe), and least bioavailable (Pb, Cr, U) (Prasad, 2003). Cadmium accumulation in sweet potatoes shoots higher than in the root, and cadmium content reduced as cow manure application increased. Heavy metals strongly bonded to organic compounds when organic waste like cow manure was applied, making heavy metals like Cd inaccessible to the plant.

Referring to the TF value of this study, almost all treatments resulted in the TF value of heavy metals above 1, which indicated metals accumulated higher in the shoots part of the sweet potatoes than in the roots. Low mobility of metals from the root part to the shoot is a process by the plant for metal toxicity neutralization (Badr et al., 2012). The higher the level of gold tailing contamination, the higher the accumulation of metals in the roots than the shoots part of the sweet potato. Meanwhile, with the higher cow manure application, the content of Zn was decreased. Heavy metals in the soil can be transported and distributed to various parts of the plant along with the absorption and transportation of water (Hao et al., 2012). Heavy metal ions that enter root cells can form complexes with various chelators, including organic acids (Yan et al., 2020). Heavy metal complexes, such as carbonate, sulfate, and phosphate precipitate, are then immobilized in extracellular (apoplastic cellular walls) or intracellular spaces (symplastic compartments, such as vacuoles) (Ali et al., 2013). The results of this study were in line with Tamungang et al. (2016) findings that sweet potatoes accumulate Cd higher in leaf parts than roots planted in soil contaminated with different cadmium concentrations.

This study results revealed that the concentration of heavy metals (Cd, Cu, Pb and Zn) in all parts (root and shoots) of the samples were higher than the WHO/FAO permissible limits. The negative consequences of exposure to or consuming heavy metal in quantities more significant than the daily recommended limits are toxicity. Pb, Cd, and Ni are the heavy metals with the highest bioavailability and are most dangerous to human health because plants can absorb them and introduce them into the food chain. Heavy metals have an effect on the nervous system (Alzheimer's, Parkinson's, depression, dementia), the bone system (bone mineralization), and the reproductive system. These studies revealed that sweet potatoes could be used for the accumulator plant for remediation of heavy metals (Cd, Cu, Pb and Zn) in contaminated soil; however, the yields may not be used for animal feeds or human consumption.

Conclusion

Gold mine tailing contamination on soil could inhibit growth, decrease harvested biomass and accumulate heavy metals (Cd, Cu. Pb and Zn) of sweet potatoes. The results of this study have highlighted differences in the absorption level of heavy metals (Cd, Cu, Pb, and Zn) by different gold mine tailing mixtures and cow manure application doses. The order of accumulation of heavy metals in sweet potato plants is Zn>Cu>Pb>Cd. These studies revealed that sweet potatoes could be used for the phytoremediation of heavy metals (Cd, Cu, Pb and Zn) in polluted soil, but the plants may not be used for consumption.

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