Potential of sweet potato (*Ipomoea batatas*) for gold phytomining from mercury amalgamation tailings

R Noviardi\(^1\), A Karuniawan\(^2\), E T Sofyan\(^3\) and P Suryatmana\(^3\)

\(^1\) Research Center for Geotechnology, Indonesian Institute of Sciences, Bandung 40135 Indonesia  
\(^2\) Department of Agronomy, Faculty of Agriculture, Padjadjaran University, Sumedang 45363 Indonesia  
\(^3\) Department of Soil Science and Land Resources, Faculty of Agriculture, Padjadjaran University, Sumedang 45363 Indonesia

*Corresponding author, e-mail: rhazista1972@gmail.com*

Abstract. Artisanal and small-scale gold mining (ASGM) generally use mercury amalgamation method to recover gold from the ores. The method leaves waste or tailing that still contain gold and other metals. The aim of this study was to determine the potential use of ten sweet potato clones to recover gold from mercury amalgamation tailing. The pot experiment was carried out at the experimental farm of Faculty of Agriculture, Padjadjaran University from February to May 2019. The Mercury amalgamation tailing that used in this study collected from ASGM in Sukabumi Regency, Indonesia. All experimental plants were harvested after 11 weeks, below-ground and above-ground part biomass were separated, washed and weighed. The results showed that there were no significant differences of gold concentration in 10 clones of sweet potato. According to a bioaccumulation factor (BCF) value, seven sweet potato clones have value above 1 and considered as potential gold accumulators, which is MZ332, MZ154, MZ119, Kriting Maja, 14 (84), Rancing and 44(41); meanwhile based on translocation factor (TF) value, only one sweet potato clone that is MZ119 has value above 1 so that classified as phytoextraction potential.

1. Introduction

Mercury amalgamation process is the common gold extraction method used in artisanal and small-scale gold mining (ASGM) because it is simple and affordable. Mercury amalgamation is carried out by 15 million artisanal and small-scale gold miners in more than 70 countries[1]. The process will leave waste or tailings that are material remains after the process of separating gold from the ore.

One of ASGM areas in Indonesia is in Sukabumi Regency, Province of West Java where miners recovering gold through mercury-amalgamation method by using river currents or dynamo as a driving force. The gold recovery by mercury amalgamation method of artisanal and small-scale gold mining at Sukabumi Regency, Indonesia is generally lower than 60% [2]. The process will leave waste or tailings which generally still contain gold and one or more hazardous metal elements such as Arsenic (As), Cadmium (Cd), Lead (Pb), Mercury (Hg).

The content of gold and other valuable metals in the tailings can be extracted (absorbed) using plants or known as phytomining technology. Phytomining is potential to applied for low-grade ores or mineralized soils exploitation that are not economical for conventional mining of metals [3].
Phytomining technology is the most feasible, economically acceptable, environmentally sound, and supplementary as well as an alternative plant-based technology for exploiting and recovering the precious metals from low-grade surface ores or mineralized soils [4,5]. Gold hyperaccumulation defined as plant tissue containing at least 1 mg of gold per kilogram of plant tissue [6].

Plants that used in phytomining are plants that absorb certain metals more than other plants, and are called hyperaccumulator. Phytoextraction of metals from contaminated sites using hyperaccumulator species is considered as a low-cost technique [7]. The mechanism of metals absorption by hyperaccumulator plants is through the roots and transport them to above-ground parts. Plant species that can withstand extremes of temperature, water stress, salinity, can grow in high mineral content, high biomass yield and fast-growing are appropriate for phytoextraction [6]. A similar statement was stated that fast-growing plants with high biomass, are tend to have better metal absorption and metal translocation [8]. Many plants were used for phytoextraction or phytomining of heavy metals. More than 45 families have been identified as hyperaccumulator plants, among them are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae, and Scrophulariaceae [8,9].

Plants from Convolvulaceae families reported that were to have the potential for phytoextraction of metals, one of them is sweet potato (Ipomoea batatas L.). Heavy metal accumulation (Pb, Cd, and As) in sweet potato is higher than other root crops (white radish and carrot) [10]. Besides that, sweet potato also has good adaptability to various environments [11] as drought tolerance [12]. Sweet potato has extensive widely branded fibrous root system results in a large root surface area per unit volume of surface soil [13].

Based on the above studies, this study aims to investigate the potential of gold phytomining by sweet potato (Ipomoea batatas L.) from mercury amalgamation tailings. This research is expected to contribute to obtaining environmentally friendly, simple and low-cost ways of extracting gold for mercury amalgamation tailing from ASGM.

2. Materials and methods

2.1. Tailings
Materials used for this study were mercury amalgamation tailings from ASGM in Simpenan District, Sukabumi Regency, West Java, Indonesia. The tailings' texture was silt loam, pH of KCl (1: 1) of 3.65 was classified as acidic, C – Org (%) of 0.87, total N (%) of 0.09, P-Olsen (mg/kg) of 88.80, K-content (m/100 g) of 17.19, Exchangeable K (cmol/kg) of 0.02, Ca (cmol/kg) of 5.49, Mg (cmol/kg) of 2.48, CEC (mol/kg) of 21.92. Meanwhile, the initial gold content in the tailings was 4.70 mg/kg.

2.2. Pot Experiment
The pot experiments were conducted from February to May 2019 at Ciparanje experimental farm, Faculty of Agriculture, Padjadjaran University, Sumedang Regency, Indonesia. Materials used for this study were mercury amalgamation tailings from artisanal and gold mining (ASGM) at Simpenan district, Sukabumi Regency, West Java, Indonesia and ten clones of sweet potato (Ipomoea batatas L.) that is Rancing, Kriting Maja, Biang, 14(84), MZ119, KMDK, MZ332, PR 49(412), MZ154 and 44(41). The gold amalgamation tailings collected were then air-dried for 7 days. The air-dried tailing sample was sieved to pass through a 2 mm sieve for physical and chemical analyses. The characterization of tailings that included texture, pH, organic C content, total-N, total P, exchangeable K, exchangeable Na, Ca available, exchangeable Mg, CEC, and Base Saturation was analyzed by Soil Laboratory, Padjadjaran University. Ten clones of sweet potato were arranged as a treatment in a randomized block design with three replicates. Sweet potato is grown for 11 weeks on 10 kg of growing media (mercury amalgamation tailings) in a polybag. To maximize plant growth, all tailings in pots were supplied with organic fertilizer (250 g/pot) and NPK fertilizer (5 g/pot).
2.3. Gold Determination
All experimental plants were harvested after 11 weeks, and then plant shoots and roots were separated, washed and weighed. The gold concentration in the tailings and harvested plants was determined following the methodology described by [14]. Harvested plants were dried in the oven for 48 hours at 70°C and ashed overnight at 550°C. For the analysis of Gold in plants, 0.2 g subsamples digested using 5 ml aqua regia (a mixture of nitric acid and hydrochloric acid, optimally in a molar ratio of 1:3) before determined by Flame Atomic Absorption Spectrophotometer (Shimadzu Instrument Company AA 7000 series).

2.4. Data Analysis
The ability of plants to tolerate and accumulate heavy metals can be quantified by calculating the bioaccumulation factor (BCF) and the translocation factor (TF). The plant BCF represents the efficiency of a plant in accumulating a metal into its tissues from the surrounding environment. The BCF is determined as the quotient of the content of a given metal of the plant to its total content of soil [15]. It is represented by the ratio:

$$\text{BCF} = \frac{[\text{Au}] \text{ plant}}{[\text{Au}] \text{ soil}}$$

[Au] plant, the total gold concentration in the plant biomass whereas [Au] soil is the total gold concentration in the soil

The translocation factor (TF) or mobilization ratio of metal was calculated to determine the translocation of metals from the rootto shoot of the plant species [16]. It is represented by the ratio:

$$\text{TF} = \frac{[\text{Au}] \text{ shoot}}{[\text{Au}] \text{ roots}}$$

[Au] shoot, the total Au concentration in the above-ground part biomass whereas [Au] roots is the total Au concentration in the below-ground biomass.

The translocation factor (TF) and the bioaccumulation factor (BCF) were defined and used to assess the amount of the metals accumulated in the plant and to evaluate heir potential for phytoextraction purpose [17].

2.5. Statistical Analysis
The data was subjected to Univariate analysis to see the effect of sweet potato clones on the observed variables. The difference between treatment means was determined by Duncan's multiple range test at 5% level (P = 0.05) using SPSS Ver. 26 software.

3. Results and discussion
3.1. Gold concentration in plant
Gold concentration in plants is the total amount of gold contained in sweet potato plants per unit weight of biomass. Concentrations of gold in the ten sweet potato clones have been described in Figure 1 and Figure 2. The result of this study showed that the sweet potato clones treatment did not significantly (p=0.05) affect the total concentration of gold in plants (Figure 1) and concentration of gold in the root (below-ground) and shoot (above-ground) parts of plants (Figure 2).
Gold accumulation in shoot part of plant has linear relation with gold uptake value by root [17]. Plants can minimize the adverse effects of excess heavy metals by regulating the distribution and translocation of heavy metals within their organs or cells [18]. The much higher amounts of heavy metals found in plant roots and reduced translocation to shoots is a widespread tolerance mechanism [19–21]. The plant might exclude metals from sensitive metabolism in the shoots, therefore tolerant genotypes have a lower heavy metal concentration in the shoot than sensitive genotypes [18]. The low metal mobility from the root to shoot is mechanism for neutralizing metal toxicity by plants [22].

The gold concentration in plant parts is related to the ability of plants to translocate and store gold in their biomass. Mechanism for transport of gold from root to the shoot is related with the evapotranspiration process [23]. It is similar with a statement that the transpiration stream is likely to be the main carrier of soluble chelated metal to the shoots, where water is transpired while metal accumulates [24]. Gold absorption and accumulation in plants will continue throughout evapotranspiration processes. Evapotranspiration process will decrease if the concentration of metal ions in plants achieve a toxic level [25].
3.2. Bioaccumulation Factor (BCF) and Translocation Factor (TF)

Bioaccumulation Factor (BCF) and Translocation Factor (TF) values of the ten sweet potato clones studied have been described in Figure 3. The results of this work indicated the gold concentrations in all of the plant shoots, except for MZ119 clones, were substantially lower than those in roots (Figure 2). However, these clones (MZ119) were highly efficient in taking up and translocating gold (TF of 1.35). The result showed that BCF values of seven sweet potato clones being higher than one that is MZ154 (WFSP), 14(84) (PFSP), MZ332 (YFSP), Kriting Maja (WFSP), MZ119 (OFSP), 44(41) (WFSP) and Rancing (YFSP). Sweet potato clones affecting gold accumulation by plant. Vegetable species differ widely in their ability to take up and accumulate heavy metals, even among cultivars and varieties within the same species [26,27]. Another factor that affects gold absorption by sweet potato is the tailing texture. The bioavailability of contaminants in various textures of soil in order are loam or sand > silt > clay loam > clay soils [28].

A previous study reported that TF > 1 indicates that the translocation of metals is made effectively to the shoot from the root. If the TF value is >1, the mechanism of gold transfer by plants is classified as phytoextraction [28]. For a classification viewpoint, TF > 1 indicates that the plant translocates metals effectively from root to shoots; BCF >10 infers the hyperaccumulator species, BCF > 1 shows the accumulator species, and BCF < 1 represents the excluder species [29]. Plant species with greater TF values were considered a good candidate for phytoextraction of metal from soils [30].

Solubility and bioavailability of metals are one of the main keys to phytomining [31]. Under normal conditions, plants do not accumulate Gold in an insoluble form. Therefore, gold must be in a dissolved form so that plants can absorb it. Metal accumulation in plants is influenced by plant type factors, metal element properties and soil characteristics (pH, cation exchange capacity, clay content and organic matter) [32]. Metals uptake by plant roots from soil occurs either passively with the mass flow of water or through active transport. High root to shoot translocation of these metals indicated that these plants have vital characteristics to be used in phytoextraction of these metals as indicated by [33,34]. Adequate soil nutrients are required to support the growth of plants and their associated microorganisms during phytoremediation when the plant/microbe community is under stress from the contaminants especially as petroleum hydrocarbons greatly reduce the availability of plant nutrient in soil [33]. It is recommended for future studies to induced biomass and accumulation of gold from mercury amalgamation tailing by sweet potatoes.
3.3. Dry Weight Biomass

Dry weight biomass of the ten sweet potato clones studied, are given in Figure 4 and Figure 5. Sweet potato clones treatment significantly affects the total dry weight biomass of plants (Figure 4) and dry weight biomass of shoot parts (Figure 5). The letters expressing the significant differences between various sweet potato clones in Duncan’s multiple range test (p = 0.05).

Sweet potato clone MZ332 (YFSP) had the highest biomass dry weight compared to other sweet potato clones (Figure 4). Meanwhile, the results of a variety of analysis show that the treatment of sweet potato clones significantly regulates the dry weight of biomass plants. Sweet potato clones MZ332 (YFSP) and MZ154 (WFSP) had a higher dry weight than other sweet potato clones, whereas sweet potato clone MZ332 (YFSP) had a higher dry weight of the canopy than other clones (Figure 5).

Figure 4. Dry weight biomass of ten sweet potato clones

Figure 5. Shoot and root dry weight biomass of ten sweet potato clones

Nevertheless, aboveground biomass of hyperaccumulating plants is easier to process than belowground biomass and is generally preferred. Metal uptake from growth media can be augmented by selecting correct plant species, modifying pH, using suitable chelating agents and genetically modifying plants [34].
4. Conclusion

The results of this research showed that based on Bioaccumulation Factor (BCF) value, seven clones of sweet potato categorized as accumulators of gold (BCF > 1) that is MZ154 (WFSP), 14(84) (PFSP), MZ332 (YFSP), Kriting Maja (WFSP), MZ119 (OFSP), 44(41) (WFSP) and Rancing (YFSP). Meanwhile, based on Translocation Factor (TF) value, sweet potato clones MZ119 (OFSP) had potential as phytoextraction of gold (TF > 1). Sweet potato clones MZ332 (YFSP) had the highest dry weight biomass that is 33.47 grams. The low weight of biomass caused by the incompatible environmental conditions of the planting media, among others: the pH of the tailing that is too acidic and low fertility causing the growth of sweet potatoes is inhibited.

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