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Analysis of Lead (PB) Metal Content in Soil and Peanut Seeds *Arachis hypogaea* With the Application of Coal Ash *Fly Ash* and *Bottom Ash* (FABA) in Post-Tin Mining Land

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Abstract

The increase of heavy metal content in post-mining land is one of the main challenges in using tin mine tailings for agricultural activities. This study aimed to determine lead changes (Pb) concentrations in tin mine tailings after the application of Faba (fly ash-bottom ash) and the cultivation of peanut (*Arachis hypogaea* L.), and to evaluate the potential for Pb accumulation in peanut seeds. The experiment was conducted using five levels of Faba application (0; 15; 30; 45; and 60 tons/ha) on tin mine tailings, followed by peanut cultivation for one growing season. The results showed that Faba application increased total soil Pb concentration from 0.09 mg/kg (without Faba) to 19.58 mg/kg (60 tons/ha). However, after peanut cultivation, soil Pb content in all treatments decreased to below the AAS detection limit (< 8.73 mg/kg). Analysis of peanut seeds revealed that Pb levels were also below the detection limit (< 0.165 mg/kg), indicating no significant Pb accumulation in the seeds. This study demonstrates that applying Faba at certain doses can modify the chemical characteristics of mine tailings, and that peanut cultivation has the potential to reduce soil Pb levels through absorption and immobilization mechanisms. The key finding of this study is that combining Faba application at 30-45 tons/ha with peanut cultivation effectively reduces soil Pb content without increasing contamination in harvested seeds. Furthermore, peanut seeds remain safe for consumption due to their very low Pb concentration. Therefore, integrating Faba-based amelioration with the cultivation of excluder or phytoremediation plants, such as peanuts, is recommended as an environmentally friendly tailings reclamation strategy that supports sustainable food security.

Keywords: Faba (fly ash-bottom ash), Lead (Pb), Peanut, Phytoremediation, Tin Mine Tailing

1. Introduction

The mining industry is one of the sectors that cause environmental damage, including deforestation, groundwater pollution, and air pollution (Saepudin et al., 2022). Various mining activities damage the structure, texture, porosity, and bulk density of soil, which are important physical characteristics for plant growth (Hirfan, 2018). (Yulieta et al., 2023). Former tin mining land is dominated by sand, has minimal capacity to retain and supply nutrients and water, has very low organic carbon and CEC (Central Crude Oil), and low pH and essential macronutrient content.

Innovative agricultural technology interventions are believed to improve the soil's physical, chemical, and biological properties, making it an ideal medium for crop cultivation. The use of ameliorants is one of the keys to utilizing ex-tin mining land for agriculture (Asmarhansyah et al., 2015 (Asmarhansyah, 2017a), (Badayos et al., 2017). The use of coal ash (FABA) as an ameliorant on ex-mining land is one effort to improve the physical and chemical properties of post-mining soil to support plant growth (Wiskandar, 2017) (Randrikasari, 2024). The use of coal as fuel for steam power plants (PLTU) produces fly ash and bottom ash/FABA (Ardi et al., 2020) (Ardi et al., 2021).

In general, FABA (Fly Ash and Bottom Ash) is composed of inorganic components such as rock fragments

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and quartz, Fe-bearing minerals, high-temperature silicate minerals, as well as follower minerals and non-fuel components (Jurnal, 2018) (Anggara & Ferian, 2021; Hower et al., 2017; Damayanti, 2018). Its chemical composition is dominated by silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and various other oxide compounds. Furthermore, FABA is alkaline with a high pH and contains high to very high levels of Ca, S, and Mg.

One of the main issues in tin mining is the presence of heavy metals. The tin mining process uses a hydraulic system, which separates tin minerals using hydropower. Therefore, the primary source of heavy metals in tin mining is in-situ rock. However, the heavy metal content of ex-tin mining areas is relatively low and still below the permissible tolerance threshold (Asmarhansyah, 2017b).

Heavy metal pollution can originate from coal combustion residues. This heavy metal pollution can harm health and ecosystems through direct contact with the soil. Contamination, food chains, contaminated water, decreased food quality, and decreased land use (Hamzah, A., Priyadarshini, R., & Astutik, 2021). Coal ash contains lead (Pb) (Nugroho & Lestari, 2021). Based on analysis conducted by (PLTU Air Anyir, 2024), Pb content reached 7.91% PPM. The application of Faba increased soil Pb content by 28% and positively affected plant Pb content.

The use of fly ash and bottom ash (FABA) has been widely studied as an ameliorant improve the chemical and physical properties of soil in ex-coal mining areas, for example, by increasing pH, cation exchange capacity, and nutrient availability (Faoziah & Djajakirana, 2022).

FABA has been reported to have high silica, alumina, and calcium oxide content, which is beneficial in neutralizing soil acidity and increasing fertility (Irawan & Andriani, 2025). On the other hand, another study by Cheng et al. (2015) showed that peanuts (Arachis hypogaea L.) can absorb the heavy metal lead (Pb) from contaminated soil, but the accumulation in the seeds is very low, making this plant a potential phytoremediation agent. The novelty of this study lies in combining FABA application on post-tin mining land in the Bangka Belitung Islands with peanut planting to evaluate changes in soil Pb content and seed safety within the FAO/WHO consumption threshold. This approach has not been previously reported and provides a scientific and practical contribution to the environmentally friendly reclamation of marginal land using industrial waste.

The application of FABA to post-tin mining land is expected to provide macro- and micronutrient enrichment, optimizing the growth of plants cultivated there. To determine the effect of FABA application on soil lead content and heavy metal absorption by peanut plants through peanut pods, as an indicator of food security on post-tin mining land, research is needed to assess heavy metal absorption across various FABA application compositions. This research is expected to provide valuable information for optimizing the use of FABA.

2. Material and Methods

The materials used in this study were coal *fly ash* and *bottom ash* (Faba). Faba was applied to tailings soil in a post-tin mining area located in Kulur Village, Lubukbesar District, Central Bangka Regency, at an altitude of 14.6 meters above sea level. The research area can be expressed as 42.42 ° N, 106.23 ° E. The tools used in this research were agricultural tools, stationery, meters, cameras, scissors, rope, analytical scales, buckets, plastic, hoes, watering cans, netting, and other supporting equipment.

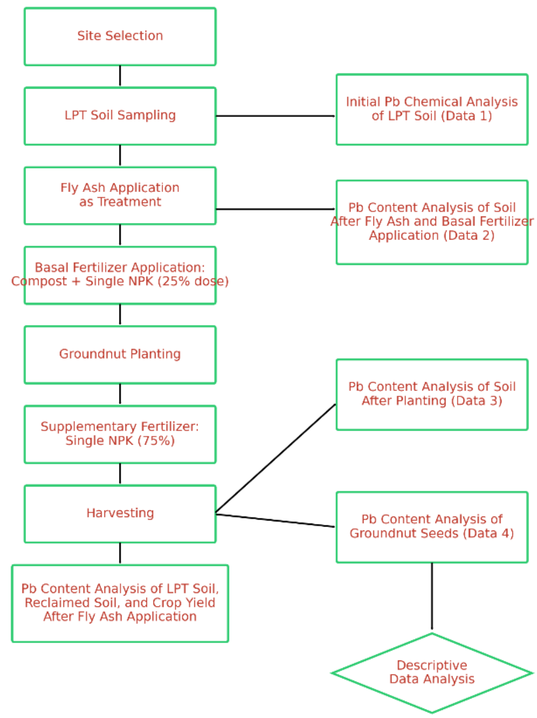

Figure 1. Research Flow Diagram

The research used an experimental method. A single treatment of various doses of *fly ash-bottom ash, bottom ash, and* coal ash (Faba) was applied to post-tin mining land tailings. There were 5 levels of single treatment with 3 replications, resulting in 15 experimental units. The experimental units were plots measuring 1 m x 2 m with a plot height of 30 cm. The compositions used were: without Faba; Faba at 15 tons/ha; Faba at 30 tons/ha; Faba at 45 tons/ha; and Faba at 60 tons/ha.

Land preparation was carried out in accordance with the research needs. The land was cleared of weeds, then cultivated until loose and leveled. 15 beds were made with a bed width of 100 cm, a length of 200 cm, and a height of 20 cm, with a spacing of 50 cm between beds. The prepared beds were then added with *Fly ash* - coal ash bottom ash (Faba) according to the treatment, and some were not given Faba as a comparison. Soil sampling was carried out in each treatment plot by taking soil samples diagonally at 5 points per plot, then stirring the samples to ensure homogeneity. The soil from each treatment plot was then composited within each treatment repetition, namely Repetition I, Repetition II, and Repetition III. The composited soil was then put into 5 kilogram plastic containers, labeled on each plastic, and then incubated for 1 (one) month. One kilogram of soil samples was taken per treatment, packed into plastic containers, and sent to the Testing Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB, Bogor, for analysis. The data analysis used descriptive methods to compare test results without faba treatment with those with faba treatment, focusing on changes in the physical and chemical characteristics of post-tin mining land.

Seeds of the local peanut variety Jongkong accession were planted in a bed plot with a spacing of 20 cm x 40 cm. Planting was done directly by making 2 (two) planting holes with a wooden digger, each hole 3 cm deep. 1 (one) seed was inserted into each hole, then covered with soil and watered. After 10 days of growth after planting, thinning was carried out. One bed plot consisted of 25 peanut plants and 5 plant samples were taken. Plant maintenance was carried out until harvest, including watering, fertilizing, and pest and disease control. Harvesting was carried out at around 85-90 days after planting. Peanut seed samples after drying were taken for testing the heavy metal lead (Pb) content at the KAN-accredited Laboratory at PT. Anugrah Analis Sempurna. The variables used in this study were the heavy metal lead (Pb) content in tailings, the lead content in tailings after faba application before planting, the lead content in tailings after planting, and the lead content in peanut seeds. The laboratory data were then analyzed descriptively.

3. Results and Discussion

3.1. Heavy Metal Pb (Lead) Content in Tailings and Tailings with Application of fly ash and bottom ash (Faba)

The content of heavy metal elements measured in changes in tailings without faba and with the application of additional faba composition can be seen in Table 1.

Table 1. Changes in Chemical Characteristics of Heavy Metal Pb (Lead) in Tailings with Faba Application

Dosage (ton/ha)	Content (mg/kg)	Compliance (20–40 mg/kg)	Compliance (⩽85 mg/kg)	Information
0	2.96	In accordance	In accordance	Very low category
15	3.57	In accordance	In accordance	Safe
30	3.77	In accordance	In accordance	Safe
45	6.53	In accordance	In accordance	Safe
60	19.58	In accordance	In accordance	Approach limit safe

The data in Table 1 show that increasing the FABA dose increases lead (Pb) content in the soil, from 2.96 mg/kg without FABA to 19.58 mg/kg at a dose of 60 tons/ha. Despite the increase, all Pb values remain below the safe thresholds set by SNI (20–40 mg/kg) and WHO (85 mg/kg). This result indicates that using FABA up to 60 tons/ha remains safe for the soil, but doses above this require caution because they may approach the pollution threshold. Post-tin mining land and tailings without FABA have a lead (Pb) heavy metal content of 2.96 mg/kg, classified as very low. Meanwhile, the lead content in the tailings soil after the addition of Faba composition of 15 tons/ha increased by 3.48 mg/kg, Faba composition of 30 tons/ha increased by 3.68 mg/kg, and Faba composition of 45 tons/ha increased by 6.44 mg/kg and the addition of Faba composition of 60 tons/ha increased the lead content by 19.49 mg/kg.

The addition of Faba composition to post-tin mining land tailings of 15 tons/ha, Faba composition of 30 tons/ha, and Faba composition of 45 tons/ha has a very low lead heavy metal content below the quality standard or limit value of lead content considered safe for human health and the environment of lead in the soil. Meanwhile, the addition of Faba composition to post-tin mining land tailings at 60 tons/ha is close to the quality standard or limit value for lead content considered safe for human health and the environment in soil, namely 20-40 mg/kg (Graph 1). The addition of Faba composition at more than 60 tons/ha has the potential to cause soil pollution and accumulation. Research results (Jayengswasono & Wicaksono, 2022) showed that a higher dose of coal fly ash increased soil Pb levels by 28% compared to the control. Meanwhile, the World Health Organization (WHO) sets a safe lead limit of 85 ppm (85 mg/kg).

The increase in Pb levels indicates that the Faba used contains a relatively high fraction of Pb metal, so that when applied to the tailings, there is an increase in the total Pb content of the soil. Fly ash can also be an effective amendment in neutralizing soil acidity. Many of the observed chemical and biological effects of fly ash application to soil are due to increased $Ca2+$ and $OH-$ ion activity. (Ahmed et al., 2020)

The heavy metal content in tailings soil increases significantly with increasing Faba composition. This result is due to Faba containing heavy metals, including lead (Pb), at 26-33% ppm (PT. Indonesia Power, 2024), with lead content ranging from 24-34% ppm (PT. Great Giant Pineapple, 2024), depending on the type of coal used. Although total Pb levels increase, the effect of Faba on Pb availability for plants can vary depending on changes in pH and Pb fixation reactions in the soil. Cui et al., (2023) stated that the increase in pH due to faba application can convert Pb into less soluble forms, such as $PbCO_3$ or $Pb(OH)_2$, thereby reducing the fraction of Pb that plants can absorb. Therefore, analysis of available Pb (e.g., via DTPA or $CaCl_2$ extraction) is needed to determine whether the increase in total Pb at the treatment level is accompanied by an increase in the fraction of Pb that plants readily absorb. The heavy metal content of Faba needs to be considered to avoid increasing secondary contaminants in the land where Faba is applied.

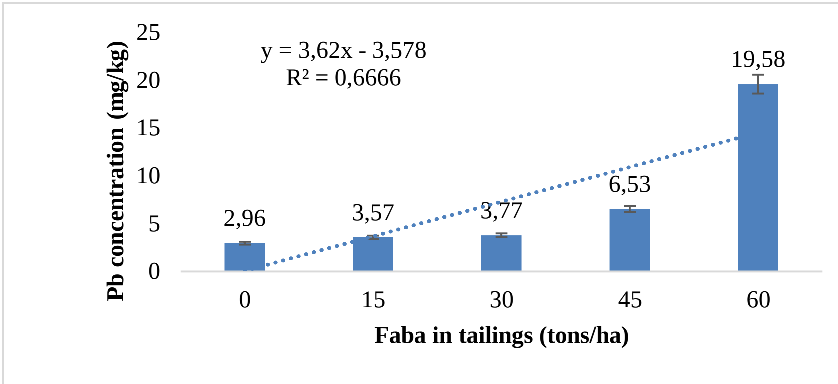

Figure 2. Heavy Metal Pb (Lead) Content in Tailings with Application of *fly ash* and *bottom ash* (Faba)

3.2. Heavy Metal Content of Pb (Lead) in Tailings and Tailings with Fly Ash and Bottom Ash (Faba) Application After Peanut Planting

The content of lead measured in soil after 3 months of peanut planting on post-tin mining tailings with the application of additional faba composition is shown in Table 2. Table 2 shows that all treatments exhibited very low soil Pb levels, below the detection limit (<8.73 mg/kg) and well below the safe threshold according to SNI and WHO standards. This result indicates that growing peanuts for 3 months effectively reduced or stabilized soil Pb levels, even at the highest FABA dose.

Table 2. Heavy Metal Content of Pb (Lead) in Tailings and Tailings after Faba Application Post-Planting 3 months

FABA dosage (ton/ha)	Soil Pb Content (mg/kg)	SNI Compliance (20–40 mg/kg)	WHO compliance (≤85 mg/kg)	Information
0	< 8.73	In accordance	In accordance	Very low
15	< 8.73	In accordance	In accordance	Very low
30	< 8.73	In accordance	In accordance	Very low
45	< 8.73	In accordance	In accordance	Very low
60	< 8.73	In accordance	In accordance	Very low

Measurement of heavy metals in soil after planting peanuts in post-tin mining tailings with the application of several faba compositions was carried out using the SNI 8910:2021 method at PT. Anugrah Analis Sempurna Laboratory in Bogor. The analysis results on post-tin mining tailings without faba after planting had a lead (Pb) heavy metal content of <8.73 mg/kg, classified as very low below the quality standard or limit value of lead content considered safe for human health and the environment of lead in the soil, which is 20-40 mg/kg, even the World Health Organization (WHO) sets a safe limit of lead at 85 ppm (85 mg/kg). Likewise, the lead content in the tailings soil after the addition of Faba compositions of 15 tons/ha, Faba compositions of 30 tons/ha, Faba compositions of 45 tons/ha, and Faba compositions of 60 tons/ha has a very low lead content below the lead heavy metal measurement standard set based on SNI 8910 2021 of <8.73 mg/kg. The low heavy metal lead content in the soil can be due to its low initial content. The decrease in lead metal in the soil can be caused by the transfer of heavy metals by diffusion and osmosis that occurs in the soil media to plants, through a phytoremediation process that is broken down by microorganisms in the soil that is strengthened by root exudates such as sugar, alcohol and acid (Darlis et al., 2023) . The decrease in soil Pb content after planting can be explained by several mechanisms. First, the absorption of heavy metals by peanut plants (Arachis hypogaea) likely reduces soil Pb levels, primarily through accumulation in roots and vegetative tissues.

Several previous studies (Lakshmi, 2014) have shown that peanuts can take up Pb from the soil and retain it in the roots and pods, although transfer to the seeds is relatively low. Second, changes in soil chemical conditions during plant growth, such as increased rhizosphere microbial activity, changes in local pH, and root exudates, can also alter the chemical form of Pb to less soluble or fixed forms, thereby reducing the fraction of Pb detectable in total extraction using the AAS method. Research by

Palansooriya *et al.* (2020) stated that the combination of ameliorants (such as Faba) and plant root activity can accelerate the process of Pb immobilization, either through precipitation (e.g., into $PbCO_3$, $PbSO_4$) or through strong adsorption on soil particles. (Niroshika et al., 2020) This amendment can reduce the bioavailability of toxic elements in soil through various mechanisms such as precipitation, complexation, redox reactions, ion exchange, and electrostatic interactions. However, soil properties such as soil pH, clay content, sesquioxides, and organic matter, as well as processes such as sorption/desorption and redox processes, are key factors that determine the efficacy of amendments in immobilizing toxic elements in soil.

3.3. Heavy Metal Pb (Lead) Content in Peanut Seeds Planted in Tailings with Application of Fly ash and Bottom ash (Faba)

The lead content, a heavy metal, measured in peanut seeds produced from peanut plants grown on post-tin mining tailings with the application of additional faba composition, is shown in Table 3.

Table 3. Content of Heavy Metal Pb (Lead) in Peanut Seeds Planted in Tailings with Faba Application

FABA dosage (ton/ha)	Pb content (mg/kg)	SNI Compliance	WHO Compliance
0	< 0.165	In accordance	In accordance
15	< 0.165	In accordance	In accordance
30	< 0.165	In accordance	In accordance
45	< 0.165	In accordance	In accordance
60	< 0.165	In accordance	In accordance

All treatments showed Pb levels in peanut seeds below the detection limit (<0.165 mg/kg) and in accordance with SNI and WHO food safety standards. This result confirms that planting peanuts in tailings land with FABA application remains safe for human consumption. The results of the analysis of lead (Pb) content in peanut seeds planted in post-tin mining tailings with various FABA doses showed that all treatments had very low Pb levels, namely below the instrument's detection limit (<0.165 mg/kg). This value is well below the food safety thresholds set by SNI and WHO, so it is considered safe for consumption.

Neither FABA nor doses of 15, 30, 45, and 60 tons per hectare showed significant Pb accumulation in peanut seeds. This result indicates that peanuts exhibit strong exclusion of heavy metals, with more Pb retained in roots and pods than transferred to the seeds. Therefore, the use of FABA as an ameliorant in post-mining areas does not pose a risk of heavy metal contamination in the crop, even at the highest doses.

Measurement of heavy metals in peanut seeds was carried out using the AOAC *Official Method 985 01 Metals and Other Elements in Plants and Pet Food* at the PT. Anugrah Analis Sempurna Laboratory in Bogor. The results of peanut seed production in post-tin mining tailings without faba have a lead (Pb) content of <0.165 mg/kg, which is classified as very low. The value is below the detection capability of the laboratory's measuring instruments, so the number cannot be determined with the method used. Meanwhile, the lead content in the tailings soil after the addition of Faba composition of 15 tons/ha, Faba composition of 30 tons/ha, Faba composition of 45 tons/ha, and Faba composition of 60 tons/ha has a very low lead content below the standard for measuring heavy metal lead contained in peanut seeds of <0.165 mg/kg. This result shows that planting peanuts in tailings with various Faba doses does not result in measurable Pb accumulation in the seeds. The application of Faba as an ameliorant can reduce Pb availability in soil by increasing pH, adsorption onto silicate/oxide minerals in Faba, and the formation of less soluble Pb compounds (Cheng et al., 2015). This result reduces the likelihood that Pb is in a form that can be absorbed by plants and translocated to seeds.

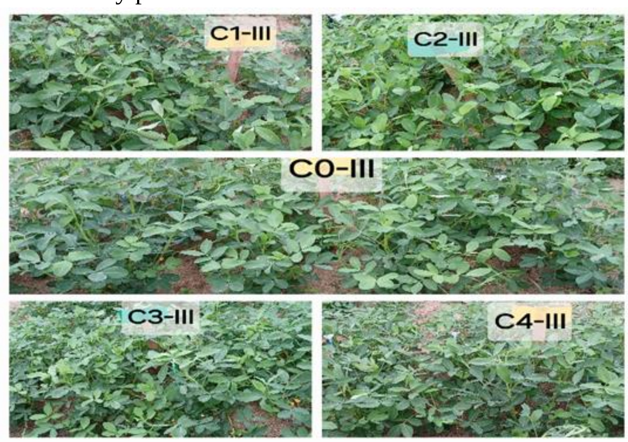

Figure 3. Growth conditions of peanuts in post-tin mining plots with various doses of FABA treatment.

Peanuts are excludable plants for Pb, with a general heavy-metal accumulation pattern: roots > pod skin > seeds (Lakshmi, 2014). Plant physiological mechanisms limit Pb translocation to reproductive tissues, including controlling Pb movement in the xylem, deposition in root cell walls, and Pb binding by compounds such as pectate and organic acids in root tissue.

Lead (Pb) does not easily accumulate in the fruiting parts of vegetable and fruit plants such as corn, beans, pumpkins, tomatoes, strawberries, and apples. High Pb concentrations are readily found in leafy vegetables such as lettuce and on the surface of tuber crops such as carrots

(Widyati, 2009). Pb levels in seeds below the detection limit are also well below the food safety threshold set by the FAO/WHO, which is 0.2 mg/kg for grains and similar products. Thus, under these experimental conditions, planting peanuts on tailings land with Faba application does not pose a risk of Pb contamination in consumer products (peanut seeds).

Table 4. Analysis of Changes in Soil Lead (Pb) Content and Peanut Transfer Factor (TF) Values at Various FABA Doses

Condition	FABA dosage (ton/ha)				
	0	15	30	45	60
Pb_before_planting (mg/kg)	3.0	3.6	3.8	6.5	19.6
Pb_after_planting (mg/kg)	8.7	8.7	8.7	8.7	8.7
Pb_seed (mg/kg)	0.2	0.2	0.2	0.2	0.2
?Pb (mg/kg)	-5.8	-5.2	-5.0	-2.2	10.9
% Pb Reduction	-194.9	-144.5	-131.6	-33.7	55.4
Transfer Factor (TF)	0.02	0.02	0.02	0.02	0.02

The analysis results in Table 4 show that changes in lead (Pb) content in soil after FABA application and peanut planting varied with the applied FABA dose. The Pb difference (ΔPb) at doses of 0 to 45 tons per hectare was negative, indicating a slight increase in soil Pb content after planting compared to before planting. This result is likely due to the release of Pb fractions from FABA into the soil or due to differences in the homogeneity of post-mining tailings media that still contain heavy metal residues. Conversely, at a dose of 60 tons per hectare, the ΔPb value was positive (10.85 mg/kg), indicating a decrease in soil Pb levels. This condition indicates that at high doses, FABA begins to function as a heavy metal stabilizer by forming less soluble Pb compounds, such as $PbCO_3$ or $Pb(OH)_2$, thereby reducing their availability in the soil.

The percentage reduction in soil Pb also showed a similar pattern, with negative values at low to medium doses (0–45 tons/ha) and a positive value of 55.41% at the highest dose (60 tons/ha). This result further supports the notion that high FABA doses can improve the chemical properties of tailings soil and reduce Pb mobility through adsorption and precipitation mechanisms.

Transfer Factor (TF) value of 0.019 across all treatments indicates a very low Pb content ratio between seeds and soil. This result indicates that peanuts have the potential to act as heavy metal exclusion plants, as more Pb is retained in the roots and pods rather than transferred to the seeds. Therefore, although FABA contains heavy metals, its use at optimal doses does not cause harmful Pb accumulation in peanut seeds.

Overall, these results confirm that the combination of FABA application and peanut planting has the potential to be an effective and safe phytoremediation approach in post-tin mining land.

4. Conclusion

The results indicated that applying FABA (fly ash and bottom ash) at doses up to 60 tons per hectare increased the total lead (Pb) content in the soil. However, after planting peanuts, Pb levels decreased significantly to below the detection limit (<8.73 mg/kg). The Pb content in peanut seeds was also very low (<0.165 mg/kg), well below the food safety thresholds established by the WHO and SNI.

The main advantage of this research is that it demonstrates how combining FABA application with peanut planting can improve the chemical properties of post-tin mining soil, reduce soil lead (Pb) levels through a natural phytoremediation process, and produce safe peanut seeds for consumption, free of heavy metal contamination.

Based on the results, it is recommended that FABA be used as an environmentally friendly ameliorant on post-tin mining land, with an optimal dose of no more than 45 tons per hectare. Peanuts are recommended as an effective phytoremediator and lead (Pb) excretory plant to support land reclamation. Furthermore, the use of FABA should be accompanied by regular monitoring of heavy metal levels to prevent potential long-term accumulation.

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