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Research Article

Identification of Metal Content in Arabica Coffee Plants (*Coffea arabica*), Robusta Coffee (*Coffea canephora*) and Liberica Coffee (*Coffea liberica*) Based on Differences in Growing Places

Identificação do teor de metais em plantas de café arábica (Coffea arabica), café robusta (Coffea canephora) e café liberica (Coffea liberica) com base nas diferenças nos locais de cultivo

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ABSTRACT

There have been many cases of poisoning when consuming coffee. One possible factor is the presence of metal content that exceeds the standard limit in the coffee. Plant metals enter through root absorption by carrying metals around the roots. The metals are then translocated to other plant organs (stems, leaves, and fruit) through xylem and phloem, where they are processed and consumed by humans. So, it is necessary to identify metals in Arabica, Robusta, and Liberica coffee plants, which are generally known in Indonesia, such as Jambi Province. Identification of metals in coffee was carried out using X-Ray Fluorescence (XRF) to determine the metal content in plants and coffee grounds, then morphological analysis was carried out using Scanning Electron Microscopy (SEM). Furthermore, identification of bioactive compounds using the Liquid Chromatography Mass Spectrometry (LC-MS) method was conducted on coffee grounds to determine the components of its bioactive compounds. The study results showed Fe, Si, Ca and K metal contents in Arabica, Robusta, and Liberica coffee plants. The three types of coffee plants show that in the soil there is a content of Fe > Si > Ca > K, in the stem part K > Ca > Fe, followed by the leaf part having a metal content of Ca > K > Fe, and the seed part is known to have K > Ca > Fe. After roasting coffee beans, the metal content increases due to the high temperature, resulting in the formation of new compounds.

KEYWORDS: Arabica coffee. Liberica coffee. Metal identification. Profile sensory and robusta coffee.

RESUMO

Houve muitos casos de intoxicação ao consumir café. Um possível fator é a presença de conteúdo metálico que excede o limite padrão no café. Os elementos metálicos são absorvidos através das raízes. Os metais são então translocados para outros órgãos da planta (caules, folhas e frutos) através do xilema e do floema, onde são processados e acumulados e, quando do consumo humano, podem causar problemas de saúde. Portanto, é necessário identificar metais em plantas de café Arábica, Robusta e Libérica, que são geralmente conhecidas na Indonésia, uma das quais é a província de Jambi. A identificação de metais no café é realizada usando Fluorescência de Raios X (XRF) para determinar o conteúdo de metais em plantas e borra de café, em seguida, a análise morfológica é realizada usando Microscopia Eletrônica de Varredura (MEV) e a identificação de compostos bioativos usando o método de Cromatografia Líquida por Espectrometria de Massas (LC-MS) contidos na borra de café para determinar os componentes de seus compostos bioativos. Os resultados do estudo mostraram os teores de metais Fe, Si, Ca e K em plantas de café Arábica, Robusta e Libérica. As três espécies de plantas de café apresentam teores de Fe > Si > Ca

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> K no solo, K > Ca > Fe na parte do caule, seguidas pela parte da folha, que apresenta teores de Ca > K > Fe, e pela parte da semente, que apresenta K > Ca > Fe. Após a torrefação dos grãos de café, o teor de metais aumenta devido à alta temperatura, formando novos compostos.
PALAVRAS-CHAVE: Café arábica. Café libérica. Identificação de metais. Perfil sensorial e café robusta.

INTRODUCTION

Coffee *(Coffea sp)* is one of the second most traded food commodities worldwide, making coffee have a high selling value (HARUM, 2022). Coffee belongs to the genus *Coffea, which* has 70 species. Still, only a few species are grown worldwide, including 70% for Arabica coffee (*Coffea Arabica*), 24% Robusta coffee (*Coffea canephora*) and only 2% for Liberica coffee (*Coffea liberica*) (DAVIS et al., 2022). In Indonesia, coffee plantations reach 1.24 million hectares (WIBOWO, 2021).

Based on statistical data, Jambi Province has a coffee plantation area of 17,000 hectares, featuring three different coffee variants. Liberica coffee is the mainstay in West Tanjung Jabung, Jambi, which grows on peat plants at 20 meters above sea level (SAIDI & SURYANI, 2021). Arabica coffee can grow at an altitude of 500-1,700 meters above sea level, and Kerinci is one of the Arabica coffee plantation commodities in Jambi Province (LAMEFA et al. , 2020). Merangin Regency is one of the areas producing robusta coffee in Jambi Province, which has brought economic changes to the surrounding community (RAMADHAN et al ., 2022).

Generally, coffee beans contain various volatile compounds such as caffeine, acetic acid, phosphoric acid, ketones, alcohol, minerals, and terpenoids that can increase cholesterol (KITZBERGER et al. 2014). Coffee beans contain nutritional compounds in the form of fat, protein and carbohydrates to strengthen coffee's body (thickness) and play a role in forming volatile compounds (LEE et al., 2015; TARIGAN et al., 2022). All plants, including coffee plants, require essential nutrients for optimal growth and development. These nutrients are absorbed in ionic form, such as iron (Fe), silicon (Si), calcium (Ca), and potassium (K), each playing a distinct physiological role in supporting plant function, growth, and development. These four elements are among the most commonly occurring metals in plant tissues and are critical for processes such as photosynthesis, cell wall formation, and water regulation in coffee plants (WHITE & BROWN, 2010).

Plant metals enter through root absorption, which carries metals around the roots. The metals are then translocated to other parts of the plant organs (stems, leaves, and fruit) through xylem and phloem (RAI et al. 2019). Another factor in the entry of heavy metals into the human body is contamination by cooking utensils, such as *roasting machines,* during coffee processing (GUADALUPE et al. 2023). Based on the results of the previous study, Pb metal was found in Arabica coffee soil with a concentration exceeding the 0.5 mg/kg standard (PIGOZZI et al. 2018).

According to SNI (2004), the quality standard for heavy metals in soil is 0.04 mg/kg for Cu, 0.03 mg/kg for Hg, 0.07 mg/kg for Pb. and 0.06 mg/kg for Zn. Based on another study, there is also high Fe in the soil, which affects the health and availability of nutrients for plants and causes the soil to become toxic (soil poisoning) (HARISH et al. 2023). Similarly, the presence of calcium (Ca), silicon (Si), and potassium (K) in coffee plants plays a crucial role in supporting plant growth and development.

Therefore, it is essential to analyze the metal content in coffee plants to ensure that they receive adequate nutrients for optimal growth.

Additionally, monitoring the levels of metals such as iron (Fe), silicon (Si), calcium (Ca), and potassium (K) in both plants and coffee beans is important, as these elements can impact human health when the beans are consumed. Excessive intake of certain metals beyond recommended limits may lead to adverse health effects, including neurotoxicity, inhibition of hemoglobin function, and potential poisoning.

MATERIALS

Equipment and Chemicals

The tools used include analytical scales (Analytical Balance Kern), glass bottles, spatulas, vials, funnels (Pyrex), glassware (Pyrex), X-Ray Fluorescence (XRF) (S2 PUMA Bruker), Scanning Electron Miscroscope (SEM), Liquid Chromatographu Mass Spectrometry (LC-MS), soil drill, dry sieving shaker 5E-SSB200, Roasting Machine (ICCRI-tech), digital pH meter (Range 0-14 pH; Resolution 0.1 pH) and Coffee Grinder (Feima Royal). The materials used include soil samples, stems, leaves, Arabica coffee beans (Pelompek Village, Gunung Tujuh District, Kerinci Regency, Jambi), Robusta (Sungai Lalang, Kec. Lembah Masurai, Merangin Regency, Jambi), Liberica (Betara District, West Tanjung Jabung, Jambi), and distilled water.

METHODS

Determining Sample Location

The sampling in this study was carried out at three different coffee plantation sites, each representing a distinct coffee variety and environmental condition: Arabica coffee in Kerinci, Robusta coffee in Jangkat, and Liberica coffee in East Tanjung Jabung. These locations were deliberately selected to capture variation in altitude, climate, and soil characteristics, ranging from highland to lowland ecosystems. A purposive random sampling technique was employed. This approach involved the intentional selection of sampling locations based on specific criteria—such as coffee type and plantation region—while incorporating random elements in choosing individual trees within each location to ensure representative sampling.

At each site, samples were collected from three different coffee trees, totaling nine trees across the three plantations. From each tree, four types of samples were taken: soil, stem, leaf, and coffee beans. For instance, in the Arabica plantation in Kerinci, samples were collected from three trees located in Pelompek Village, Gunung Tujuh District, at elevations ranging from 1,400 to 1,800 meters above sea level. The precise GPS coordinates of each tree were recorded to ensure reproducibility and accurate spatial reference (Figure 1). The robusta coffee samples were taken at the location (Sungai Lalang, Kec. Lembah Masurai, Merangin Regency, Jambi) at three different points, namely tree I (2 º34'99”S 101º73'53.2”E), tree II (2 º34'92”S 101º73'39.1”E), and tree III (2 º3'51”S 101º73'82'.3”E) at an altitude of 900-1200 meters above sea level (Figure 2). All collected samples were then analyzed for heavy metal content to assess potential contamination across different plant parts and soil.



Figure 1. Arabica Coffee Sampling Location Points.



Figure 2. Robusta Coffee Sampling Location Points.

Meanwhile, the location for taking samples of Liberica coffee was (Jati Mulyo, Kec. Dendang, Tanjung Jabung Timur Regency, Jambi) at three different points tree I (1º27'9"S 103 º98'24.2"E), tree II ((1º27'7"S 103 º99'23.3"E) and tree III (1º28'2"S 103 º98'13.0"E) at an altitude of 400-600 meters above sea level were taken diagonally (Figure 3).



Figure 3. Liberica Coffee Sampling Location Points.

Sample Preparation

Land: Soil samples were collected using a soil auger at two depth intervals: 0–25 cm and 25–50 cm below the surface. For each tree, two soil subsamples—one from

each depth—were taken and composited to form a representative sample. The collected soil was cleaned of impurities, placed into labeled plastic bags, and air-dried to reduce moisture content. Once dried, the samples were ground and sieved using a 250-mesh sieve shaker until they became fine powder (SUSTAWAN et al. 2016).

Stem: Samples were taken from the first primary branch of each tree. One stem segment was collected per tree. The sample was cleaned, dried, and then ground until a uniform particle size and constant weight were obtained (GAMA et al. 2018).

Leaf: samples were collected from each tree by taking leaves from **four cardinal directions** (north, south, east, and west) and from **two vertical positions** (upper and lower canopy). This resulted in a total of **eight leaf subsamples per tree**, which were combined into a single representative sample. All leaves were washed with running water, air-dried, and then ground using a blender until fine and homogeneous, following the procedure described by pre vious study (GAMA et al. 2018). In total, for each of the nine sampled coffee trees, two soil subsamples, one stem sample, and eight leaf subsamples were collected and processed for further analysis of heavy metal content.

Fruit: Coffee beans (Arabica, Robusta, and Liberica) are picked when ripe (red). Coffee beans are processed using the full wash method by soaking the coffee beans in water to obtain good quality coffee beans, then separating the skin from the coffee beans. Then, the coffee beans, which still contain mucus, are soaked. The coffee beans are soaked in water for 10 hours for the fermentation process to help remove the remaining mucus on the coffee beans. Then, the coffee beans are washed to remove the remaining mucus from the fermentation and the beans are dried by drying them in the sun. The dried coffee beans are ground using a Coffee Grinder machine until coffee powder is obtained (TARIGAN et al. 2024).

Measuring pH of Coffee Plant Soil

Each soil sample (5g) was placed into an Erlenmeyer flask, followed by the addition of 12.5 mL of distilled water (Aquadest). The mixture was stirred for 20 min and then allowed to stand for 24 hours at room temperature. Afterward, the mixture was stirred once more, left to settle for 10 min, and the pH was measured using a calibrated pH meter (SUSTAWAN et al. 2016).

Metal Content Testing in Soil, Leaves, Stems and *Green Beans* of Arabica, Robusta and Liberica Coffee

Testing of metal content of samples (soil, stems, leaves and *green beans*) of Arabica, Robusta and Liberica coffee that have been powdered using *X-Ray Fluorescense* (XRF) with the brand (*S2 PUMA Bruker*). Before the analysis is carried out, first weigh 10 g of each sample then the sample is placed in *the sample holder* on the XRF tool to be tested for metal (NGUGI et al. 2016).

Metal Content Testing in Arabica, Robusta and Liberica Coffee Beans After *Roasting*

Roasting process on coffee beans is carried out at a *medium roast level* until the color of the coffee beans changes from green to dark brown for 9-10 min at a temperature of 180 ºC. After that, the coffee beans are aired for 2-3 min to avoid *over-roasting* (HARUN et al. 2021). Then, the coffee beans are ground using a coffee

grinding machine until they are in the form of a fine powder. After obtaining the coffee powder, its metal content was analyzed using XRF.

Arabica, Robusta and Liberica Coffee Sensory Test (*Cupping Test*)

The *cupping test* on coffee refers to SCAA (*Specialty Coffee Association of America*) with several trained panelists (*roasters* or baristas). *The roasted* coffee powder is evaluated for its dry and wet aromas by brewing it with water at 93 °C. The brewed coffee powder is left for 3-5 min to evaluate its wet aroma. Sensory testing of coffee is done by taking 1 spoon of brewed coffee, inhaling it, and analyzing *the flavor, aftertaste, fragrance, acidity, and body* of each coffee. Panelists are asked to fill in the weight of the coffee flavor parameter criteria, modified from SCAA (2012), a value range of 6-10, with good-outstanding criteria. The weighting assessment aims to determine the importance of the criteria used in assessing coffee taste (TARIGAN et al. 2024).

Morphological Analysis of Coffee Powder

Each ground Arabica, Robusta, and Liberica coffee powder was then weighed as much as 10 grams and put into a small container for the morphological structure testing process using Scanning Electron Microscopy (SEM) integrated with Energy Dispersive X-ray spectroscopy (EDX) (Pawarangan et al, 2023).

Analysis of Bioactive Compounds in Coffee Powder

Identification of bioactive compound components was carried out using LCMS Shimadzu 2020. The identification procedure was carried out by taking a sample extract of 2 ppm and injecting it into the instrument. The LCMS conditions were C-18 water column with a temperature of 40 ºC, mobile phase A (40% water/0.1% formic acid) and mobile phase B (60% acetonitrile with a flow rate of 0.2 mL/min). Identification of each peak in the chromatogram was carried out by matching the MS spectrum of each peak obtained with the Wiley database to determine the type of compound contained in the sample (TARIGAN et al. 2024).

RESULTS AND DISCUSSION

Measuring the pH of Coffee Plant Soil

Plant fertility is influenced by the plant's ability to absorb nutrients from the soil, with soil acidity (pH) being a key factor affecting nutrient availability. Measuring soil pH is essential to assess the extent to which plants can absorb nutrients and to identify the possible presence of toxic elements in the soil. In this study, soil pH was measured using a digital pH meter. The pH values of soil samples taken from a depth of 0–25 cm under Arabica coffee (*Coffea arabica*), Robusta coffee (*Coffea canephora*), and Liberica coffee (*Coffea liberica*) plants are presented in Table 1.

Table 1. Results of Soil pH Measurement at Depth 0-25 cm.

Soil Depth	Sample	pH
0-25 cm	Arabica Coffee	3.5
	Robusta Coffee	3.1
	Liberica Coffee	1.0

Based on the data presented in Table 1, the soil pH values under Arabica, Robusta, and Liberica coffee plants are classified as low, with values below 5, indicating a highly acidic environment. Soil pH is a crucial factor influencing the mobility, solubility, and availability of metal elements essential for plant growth. ANAM ET AL. (2023) reported that the optimal pH range for Arabica coffee (*Coffea arabica*) cultivation is 5.6–7.3, while Robusta coffee (*Coffea canephora*) thrives in soils with a pH between 5.3–6.5. In comparison, *Coffea liberica* (Liberica coffee) prefers a slightly wider range, with an ideal pH of 4.5–6.5.

The discrepancy between the observed pH values and those reported in the literature may be attributed to several environmental and geological factors, including differences in soil composition, temperature, rainfall, and intrinsic soil properties such as texture and mineral content. For instance, clay soils generally exhibit a more acidic pH compared to sandy soils due to their higher cation exchange capacity and organic matter content. The results of soil pH measurements at a depth of 25–50 cm are presented in Table 2.

Table 2. Results of Soil pH Measurement at a Depth of 25-50 cm.

Soil Depth	Sample	pH
25-50 cm	Arabica Coffee	2.8
	Robusta Coffee	2.9
	Liberica Coffee	1.8

The soil pH plays a critical role in determining the availability of nutrients and, consequently, the productivity of coffee plants. According to agronomic references in Indonesia, the optimal pH range for most crops, including coffee, is between 5.5 and 6.5, which is considered slightly acidic. Within this range, the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) is maximized. At the same time, the solubility of potentially toxic metals, including aluminum (Al) and iron (Fe), remains low.

However, soil pH measurements at a depth of 25–50 cm, as reported in Table 2, show that the soils from Arabica, Robusta, and Liberica coffee plantations tend to become very acidic at greater depths. This condition aligns with findings by ALAM et al. (2023) who explain that deeper soils are more acidic due to poor drainage and high rainfall. These factors cause the leaching of basic cations, such as magnesium (Mg) and calcium (Ca), while increasing the concentration of acid cations, including Fe, Al, and manganese (Mn). In areas with poor water infiltration, water stagnation exacerbates acidification.

Soil acidity at these levels negatively affects nutrient uptake, especially for phosphorus (P) and potassium (K), which are essential for plant growth. Low soil pH leads to inefficient nutrient absorption, directly reducing the growth and productivity of coffee plants. Moreover, when the soil pH drops below pH 4.0, the solubility of heavy metals such as Fe and Al increases significantly. At high concentrations, these metals become toxic, damaging plant roots and further inhibiting the development of the coffee plant (QUISPE et al. 2025). In summary, while coffee plants are naturally adapted to slightly acidic soils, very acidic conditions (pH <5)—particularly in deeper layers—can

lead to nutrient deficiencies and heavy metal toxicity. This condition limits coffee productivity, especially if soil amendments or drainage improvements are not implemented.

Identification of Metals in Arabica, Robusta, and Liberica Coffee Plants

Identifying metals in coffee plants by testing the metal levels in the soil, stems, leaves, and coffee beans. Based on the results of the XRF test, the presence of 12 (twelve) metals is found in Arabica, Robusta, and Liberica coffee plants. However, only four metals have a fairly high percentage, namely iron (Fe), silicon (Si), calcium (Ca), and potassium (K). The following is a discussion of the four metals in Arabica, Robusta, and Liberica coffee plants.

Fe Metal Content in Arabica, Robusta and Liberica Coffee Plants

Iron (Fe) plays a vital role in various physiological processes essential for plant growth and development. It is involved in protein synthesis, acts as a catalyst in chlorophyll formation, and contributes to root development. Iron deficiency can lead to stunted plant growth, while excessive iron levels may negatively affect soil microbial activity. Therefore, it is essential to evaluate the availability of iron from the soil to the coffee beans, ensuring adequate nutritional support for the coffee plants. The distribution and availability of Fe in Arabica (*Coffea arabica/AC*), Robusta (*Coffea canephora/RC*), and Liberica (*Coffea liberica/CL*) coffee plants—from soil to beans—are presented in Table 3.

Table 3. Fe Metal Levels in Arabica, Robusta, and Liberica Coffee Plants.

Samples Code	Soil Type	Mean Metal Content (%) ± SD					
		Land 1	Land 2	Stem	Leaf	Bean 1	Bean 2
AC	Andosol	34.13±3.07	38.32±4.20	3.96± 2.16	0.68± 0.13	0.40± 0.17	0.49± 0.09
RC	Clay	42.61±5.26	39.95± 4.58	0.89± 0.15	0.38± 0.04	0.29± 0.1	0.36± 0.05
LC	Peat	22.7± 8.48	15.41 ±7.11	1.48± 1.16	0.39± 0.06	0.47± 0.39	0.59± 0.25

Information: Land 1: Depth 0-25 cm. Bean 1: Coffee beans before *roasting.* Land 2: Depth 25-50 cm. Bean 2: Coffee beans after *roasting.*

Our findings reveal notable variations in iron (Fe) content across different parts of the coffee plant and its associated soil profiles. In Arabica coffee (*Coffea arabica*), the Fe concentration in soil at a depth of 0–25 cm was found to be 34.13%, increasing to 38.32% at a depth of 25–50 cm (Table 3, Figure 4). However, a decrease in Fe content was observed in the stems and leaves, with values of 3.96% and 0.68%, respectively. In the coffee beans, Fe content was relatively low, with a slight increase from 0.40% in green beans to 0.49% after roasting.

For Robusta coffee (*Coffea canephora*), the Fe content in the topsoil (0–25 cm) was recorded at 42.61%, slightly decreasing to 39.95% at 25–50 cm. The Fe content in stems and leaves was low, measured at 0.89% and 0.38%, respectively. In Robusta beans, there was a modest increase in Fe content from 0.29% in green beans to 0.36% post-roasting.

In contrast, the Fe concentration in Liberica coffee (*Coffea liberica*) soil was lower, with 22.7% at a depth of 0–25 cm, decreasing further to 15.41% at a depth of 25–50 cm. The Fe content in the stem and leaf was measured at 1.48% and 0.39%, respectively. Interestingly, the Fe concentration in Liberica beans increased from 0.47% before roasting to 0.59% after roasting.

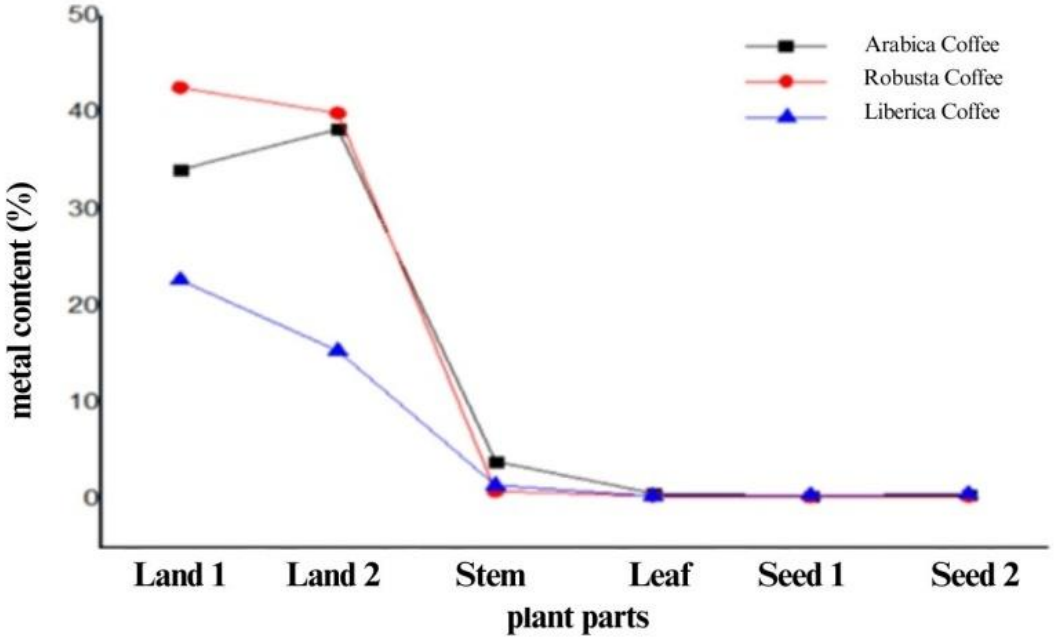


Figure 4. Fe Metal Graph Against Arabica, Robusta, and Liberica Coffee Plants.

According to Adler et al. (2019), the Fe content in green coffee powder can reach up to 60 mg/g, whereas roasted coffee powder contains approximately 41.1 mg/g. These differences in Fe content may be influenced by several factors, including soil composition, regional climatic variations, and variations in analytical methods used. Specifically, the sensitivity and selectivity of Atomic Absorption Spectroscopy (AAS) and X-Ray Fluorescence (XRF) can yield varying results, contributing to discrepancies in measured Fe levels.

The results of elemental analysis using X-Ray Fluorescence (XRF) revealed that the soil contains various essential and trace elements, including magnesium (Mg), phosphorus (P), sulfur (S), chlorine (Cl), titanium (Ti), strontium (Sr), zirconium (Zr), calcium (Ca), silicon (Si), aluminium (Al), iron (Fe), and potassium (K), each present in varying concentrations. The soil types analyzed—namely, andosol, clay, and peat—exhibited acidic characteristics, with pH values below 4.

The high concentrations of Fe and Al in these soils contribute significantly to their acidity. This is supported by the observation that elevated Fe and Al levels are present in all three soil types. These metals tend to bind with phosphorus (P), forming insoluble complexes that reduce the availability of P for plant uptake. Consequently, phosphorus deficiency may occur despite the presence of phosphorus in the soil. Furthermore, the elevated Fe content is strongly associated with the low pH conditions.

Under such acidic conditions, Fe in the soil may enter irrigation water and undergo biological reduction. In this process, ferric ions (Fe^{3+}) are reduced to ferrous ions (Fe^{2+}), which are more soluble in water. This can lead to the accumulation of Fe^{2+} in the root zone, resulting in iron toxicity or "iron poisoning" in plants (AUNG & MASUDA, 2020). Soils with a pH below 5 are particularly prone to this condition, as described by Equation 1.

$$Fe(OH)_3 + e^- \rightarrow Fe(OH)_2 + OH^- \quad (1)$$

Toxic (poisoning) iron in the soil can inhibit plant growth, excess Fe metal is influenced by acidic pH, poor water flow *(drainage) and high rainfall resulting in leaching of nutrients in the soil.* Higher Fe levels in the soil are also caused by the soil being a planting medium that is in direct contact with Fe, which is then absorbed and ready to be translocated to the seeds. The content of Arabica, Robusta.

There is an increase after Arabica, Robusta, and Liberica coffee beans before roasting contains Fe levels of 0.40%, 0.29% and 0.47% respectively. There is an increase after Arabica, Robusta, and Liberica coffee beans are *roasted* to 0.49%, 0.36%, and 0.59%, respectively. Figure 5 shows a comparison graph of Fe levels in coffee beans before and after roasting.

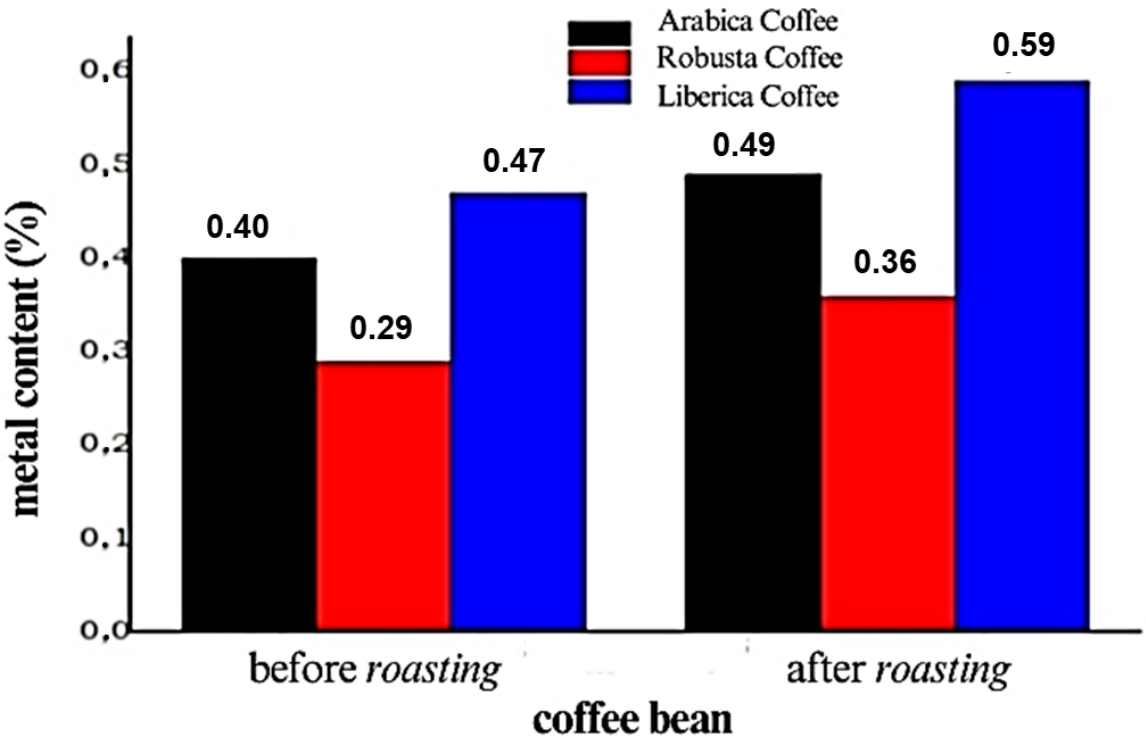


Figure 5. Comparison Chart of Fe Metal in Coffee Beans Before and After *Roasting.*

Generally, iron in coffee drinks is in the form of Fe^{2+} and is an iron ion that can dissolve in water, in addition, in the coffee content there is a chemical compound chlorogenic acid which gives a sour taste to coffee and when it reacts with Fe^{2+}, chlorogenic acid will undergo oxidation to produce a quinine hydroxide product that has a sweet taste so that the coffee will taste sweet.

Si Metal Content in Arabica, Robusta, and Liberica Coffee Plants

Silicon (Si) is a beneficial element found in significant quantities in the soil. Although not classified as an essential nutrient, silicon (Si) plays a crucial role in enhancing plant physiological functions. In coffee plants, Si contributes to increased photosynthetic efficiency and strengthens resistance against biotic stresses (such as pest and disease attacks) and abiotic stresses (such as drought and salinity). Table 4 presents data on the Si content in soils associated with Arabica, Robusta, and Liberica coffee plantations.

Table 4. Si Metal Content in Arabica, Robusta and Liberica Coffee Plants.

Sample	Soil Type	Mean Metal Content (%) ± SD					
		Land 1	Land 2	Stem	Leaf	Bean 1	Bean 2
AC	Andosol	31.24±2.06	26.47± 2.52	-	-	-	-
RC	Clay	20.20± 2.30	23.2± 3.27	-	-	-	-
LC	Peat	24.45± 8.80	10.32± 4.59	-	-	-	-

Information : Land 1: Depth 0-25 cm. Seed 1: Coffee beans before *roasting.* Land 2: Depth 25-50 cm. Seed 2: Coffee beans after *roasting*

In Figure 6, it can be seen that Si in andosol soil at a depth of 0-25 cm is 31.24% and there is a decrease at a depth of 25-50 cm, which is 26.47%. In addition, it is also known that there is an increase in Si levels in clay soil from 20.20% to 23.2% and finally, in peat soil types, there is a Si content of 24.45% at a depth of 0-25 cm, and there is a decrease to 10.32%. While in the stems, leaves, and seeds, there is no Si content in them.

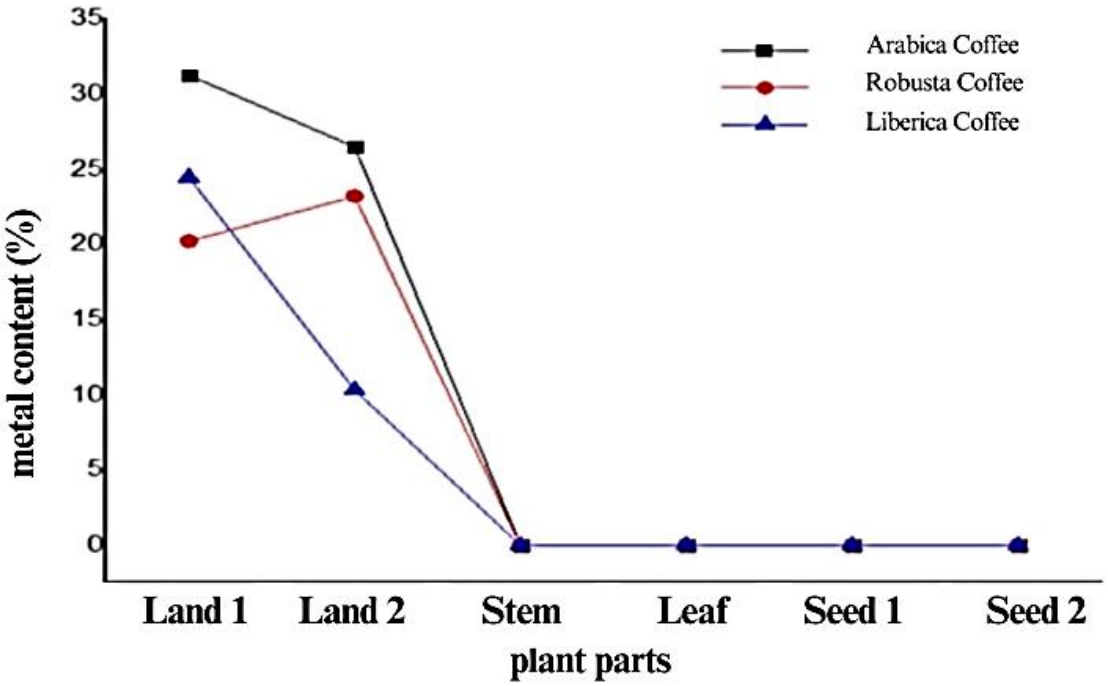


Figure 6. Si Metal Graph Against Arabica, Robusta and Liberica Coffee Plants.

The availability of Si in the soil is lower than the Fe content in the soil, due to the desiccation process, namely high *leaching,* as a result of which Si in the upper layer will be washed to the lower layer, so that the Si content in the soil becomes lower. At the same time, Fe and Al accumulate on the soil surface. This is in line with the previous research; the higher the Fe and Al in the soil, the lower the dissolved Si (KHAN et al., 2021). Silicon (Si) is absorbed by plants in the form of monosilicic acid [$Si(OH)_4$] through the xylem and is translocated to the leaves along with water.

During transpiration, water evaporates and silica is deposited in the epidermal layers of the leaves as amorphous silica. In the present study, no detectable levels of Si were found in the stems, leaves, or seeds. This finding aligns with previous studies, which suggest that although silicon is abundantly available in the soil, it is

predominantly present in the form of silica (SiO_2), a compound that is insoluble and therefore not readily absorbed by plants (KHAN, 2024).

Ca Metal Content in Arabica, Robusta and Liberica Coffee Plants

Calcium (Ca) in plants is a macronutrient required for plant growth and development as cell wall formation, enzyme activity and disease resistance. The Ca metal content found in Arabica, Robusta and Liberica coffee plants shown in Table 5.

Table 5. Ca Metal Levels in Arabica, Robusta and Liberica Coffee Plants.

Sample	Soil Type	Mean Metal Content (%) ± SD					
		Land 1	Land 2	Stem	Leaf	Bean 1	Bean 2
AC	Andosol	7.65± 0.77	5.24 ± 2.48	22.59± 1.82	35.78 ±2.39	9.43±1.85	9.70±0.67
RC	Clay	2.21 ± 1.03	2.15± 2.57	17.21± 5.28	40.75 ±5.43	7.83±1.53	14.02±6.07
LC	Peat	13.19 ± 0.92	16.9± 1.81	17.39 ±4.18	51.92 ±1.47	16.9±8.97	19.1±4.07

Information : Land 1: Depth 0-25 cm. Bean 1: Coffee beans before *roasting.* Land 2: Depth 25-50 cm . Bean 2: Coffee beans after *roasting*

The highest Ca content in the leaves from the highest to the lowest, namely 51.92% in liberica coffee leaves, 40.72% in robusta coffee leaves and the lowest in arabica coffee at 35.78% (Figure 7). Then, followed by arabica, liberica and robusta coffee stems respectively by 22.59 %, 17.39% and 17.21%. Coffee beans before and after *roasting* Ca increased from 9.43 % to 9.70%. Of the three plant organs (leaves, stems and seeds), soil has the lowest Ca content.

The Ca content from highest to lowest is 2.21%, 7.65% and 13.19% respectively in clay, andosol and peat soils in soil 1, namely a depth of 0-25 cm. Meanwhile, in soil with a 25-50 cm depth, the Ca content of clay, andosol and peat soil types is 2.15%, 2.54% and 16.9%. The Ca content before and after *roasting* was 789 mg/g and 869 mg/g, respectively, because plant varieties vary in their ability to absorb calcium. Varieties that are more efficient at absorbing calcium have a higher calcium content (RONGPIPI et al. 2023).

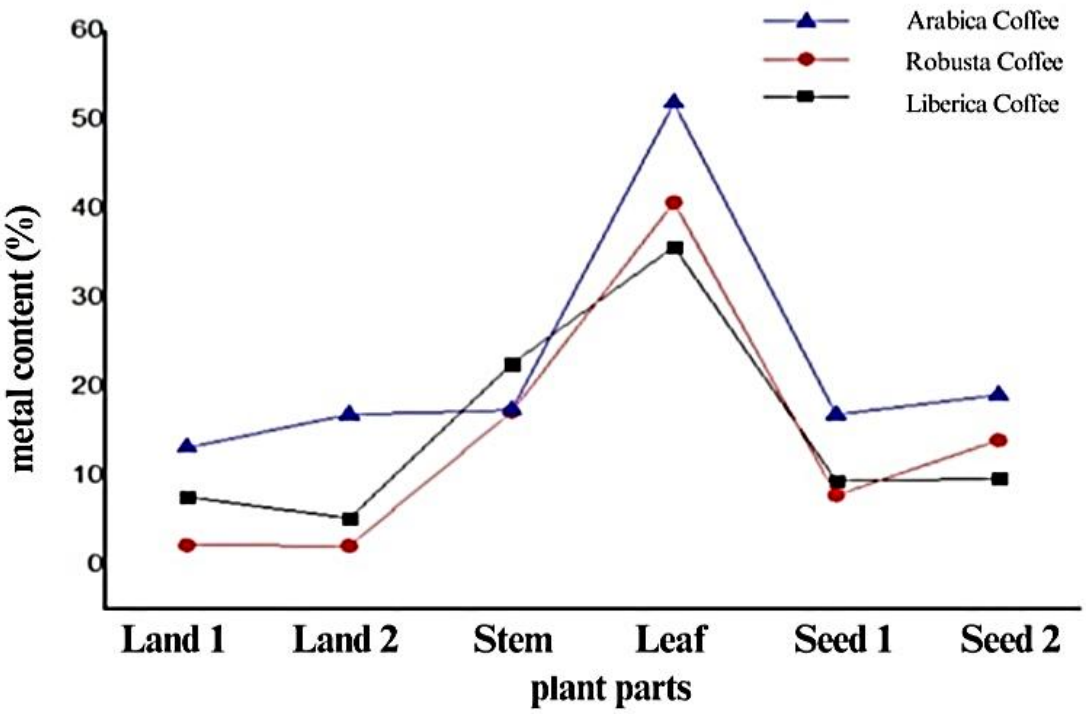


Figure 7. Ca Metal Graph Against Arabica, Robusta and Liberica Coffee Plants.

The acidic soil pH (pH<4) influences the low availability of Ca in the soil. In addition, the availability of Ca is related to the percentage of base saturation. If base saturation is low, it reflects low Ca availability. Base saturation is related to pH, soil with low pH has low base saturation and vice versa. Soil with low base saturation indicates that the soil experiences a lot of leaching of basic cations such as Ca^{2+} , K^{+} and Mg^{2+} and *the sorption* is more filled with acid cations such as Al and Fe, causing low levels of Ca in the soil. In acidic soil, toxic Fe and Al inhibits calcium uptake by blocking Ca^{2+} from entering the plasma membrane. Plants need basic cations such as Ca, but Ca in acidic soil and flooded with basic cations will be more easily leached to reduce Ca uptake in the soil.

Ca in Arabica, Robusta and Liberica coffee beans before and after roasting increased from 9.43%, 7.83% and 16.9% to 9.70%, 14.02% and 19.1%. The comparison graph of Ca before and after *roasting* in Arabica, Robusta and Liberica coffee beans is presented in Figure 8.

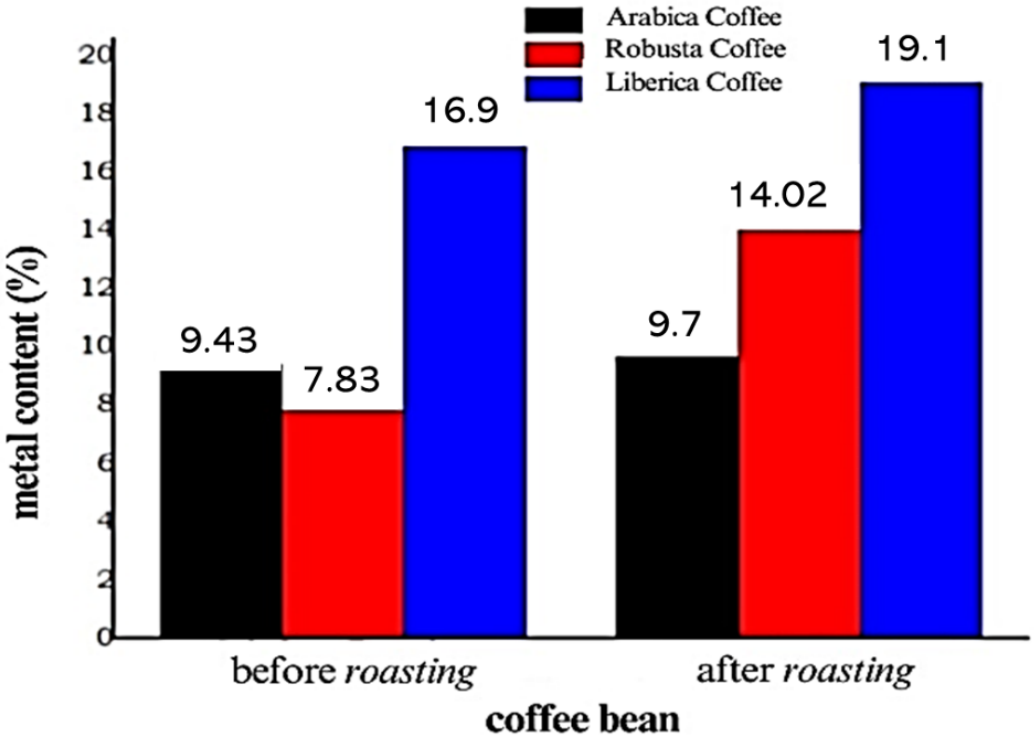


Figure 8. Comparison Chart of Ca Metal in Coffee Beans Before and After Roasting.

The findings indicate an increase in calcium (Ca) content in coffee beans after the roasting process (Figure 8). However, the presence of calcium generally does not impart a distinct taste or significantly affect the sensory characteristics of coffee beverages.

Calcium plays a crucial role in plant growth and development by regulating cell permeability, maintaining membrane function, facilitating ion exchange, and supporting ion transport within plant tissues. Plants absorb calcium primarily in the form of Ca^{2+} ions; however, not all calcium present in the soil is bioavailable. Acid precipitation and ion exchange processes can reduce the availability of Ca^{2+} in the soil. Calcium uptake by plant roots occurs through mechanisms such as root interception and mass flow, after which it is translocated to other parts of the plant.

Calcium typically constitutes around 0.5% of the total plant biomass. It is predominantly stored in the leaves, where it may precipitate as calcium oxalate within plant cells. As the plant matures, the concentration of calcium tends to increase, particularly in tissues such as the middle lamella and the outer surface of the cytoplasm.

In this study, Ca content was found to be highest in the leaves compared to other plant tissues, consistent with the previously research who reported that in spinach (*Spinacia oleracea*), the calcium content was significantly higher in leaves (48.5%) than in stems (25.29%). This distribution is attributed to the relatively small atomic mass of Ca, which facilitates its upward translocation with the aid of energy-driven processes that mobilize nutrients from roots to aerial plant parts (SEMENOVA et al. 2023).

K Metal Content in Arabica, Robusta and Liberica Coffee Plants

Potassium (K) is an essential macronutrient that plays a significant role in various physiological and biochemical processes in plants, including enzyme activation, osmoregulation, and the synthesis of proteins and carbohydrates (HASANUZZAMAN et al. 2018). In coffee plants, adequate potassium levels are crucial for improving bean quality, disease resistance, and overall yield. The distribution of potassium in different plant tissues, such as soil, stems, leaves, and beans, varies depending on the species and environmental conditions. The K metal content in Arabica, Robusta, and Liberica coffee plants is presented and compared to assess its availability and accumulation patterns across species (Table 6).

Table 6. K Metal Levels in Arabica, Robusta and Liberica Coffee Plants.

Samples	Soil Type	Mean Metal Content (%) ± SD					
		Land 1	Land 2	Stem	Leaf	Bean 1	Bean 2
A	Andosol	2.25±0.85	1.48 ± 0.09	25.12± 2.81	33.45 ±0.30	51.9±2.18	55.76±5.25
B	Clay	1.77 ± 0.35	1.23± 0.46	32.64±13.58	23.31 ±6.89	50.27±5.69	64.56±1.19
C	Peat	1.43 ± 0.32	2.12± 0.25	26.93 ±0.91	10.1 ±3.51	40.71±12.7	51.76±3.58

Information : Land 1: Depth 0-25 cm. Bean 1: Coffee beans before *roasting.* Land 2: Depth 25-50 cm. Bean 2: Coffee beans after *roasting.*

Figure 9 illustrates the potassium (K) content in soils and plant tissues across different coffee species. In andosol soil planted with Arabica coffee, the K content was 2.25%, which decreased to 1.48% at a soil depth of 25-50 cm. The potassium content in the stems and leaves of Arabica coffee was recorded at 32.64% and 23.31%, respectively. In Robusta coffee plants grown in clay soil, the K content at the surface was 1.77%, decreasing to 1.23% at a depth of 25-50 cm. The potassium content in the stems and leaves of Robusta coffee was consistent with Arabica, at 32.64% and 23.31%, respectively. For Liberica coffee plants grown in peat soil, the K content at a depth of 0-25 cm was 1.43%, increasing to 2.12% at 25-50 cm. The potassium content in the stems and leaves of Liberica coffee was 26.93% and 10.1%, respectively.

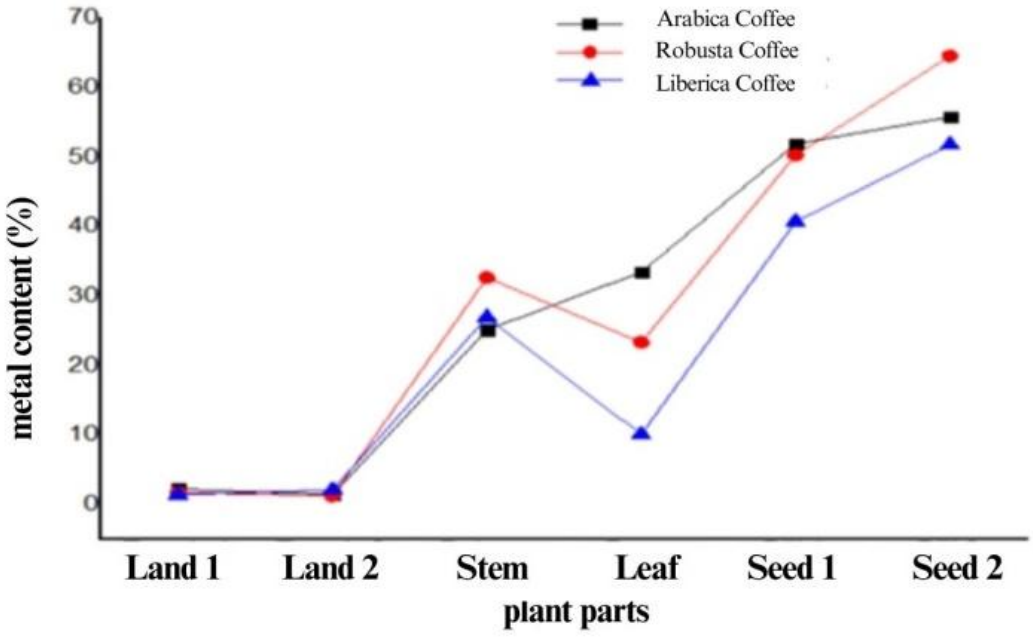


Figure 9. K Metal Graph Against Arabica, Robusta and Liberica Coffee Plants.

Potassium in the soil originates from both natural and anthropogenic sources. Natural sources include plant residues, plant ash, and minerals such as mica and feldspar, while non-natural sources primarily involve the addition of fertilizers. Despite its abundance in the soil, only a small fraction of potassium is dissolved in water and available for absorption by plants. The solubility and toxicity of potassium in the soil are influenced by soil pH. Lower pH levels increase the solubility of elements like iron (Fe), which can lead to higher iron toxicity. Furthermore, the leaching process of base cations, including potassium, is facilitated by acidification and high rainfall, both of which contribute to the depletion of potassium in the soil. Adler et al. (2019) reported potassium levels in green and roasted coffee beans ranging from 19.898 mg/g to 23.817 mg/g, respectively, indicating that coffee beans grown in different geographical regions exhibit distinct chemical composition characteristics.

There was an increase in Arabica, Robusta and Liberica coffee beans before and after *roasting*, namely the percentages obtained respectively were 51,9%, 50,27% and 40,71% increasing after *roasting* to 55,76%, 64,56% and 51,76%. The comparison of K metal in Arabica, Robusta and Liberica coffee beans before and after roasting was presented in Figure 10.

The high potassium content in coffee beans after *roasting* affects the taste of the coffee to become saltier, this is proven in *cupping tests* on Arabica, Robusta and Liberica coffee beans. The presence of K^+ ions cause the salty taste, the higher the potassium content , the saltier the taste. Minerals or cation ions can cause the salty taste, which is felt by the tongue through simple diffusion of ions from certain inorganic ions and the presence of receptors that provide a salty taste.

Potassium (K) in plants plays a role in maintaining water balance in plant cells, regulating osmotic pressure and strengthening the strength of the upright stem. Based on the results obtained in this study, it is known that the highest potassium content is found in coffee stems and beans *(green beans)* in line with other studies on bean plants showing that the highest potassium content is found in green bean pods, *the*second highest content in the stem and the lowest potassium content is found in the leaves. Potassium plays a role in several physiological processes such as protein formation, carbohydrate metabolism and osmosis regulation. At the beginning of growth such as seed formation, plants prioritize potassium to supporting parts such as reproduction and seed development so that the potassium content in the stem and seeds is higher in potassium. In the stem, potassium plays a role in maintaining cell strength and ensuring a strong structure, especially in forming cell walls. In contrast, in seeds potassium is needed to regulate water balance and maintain the integrity of embryo cells.

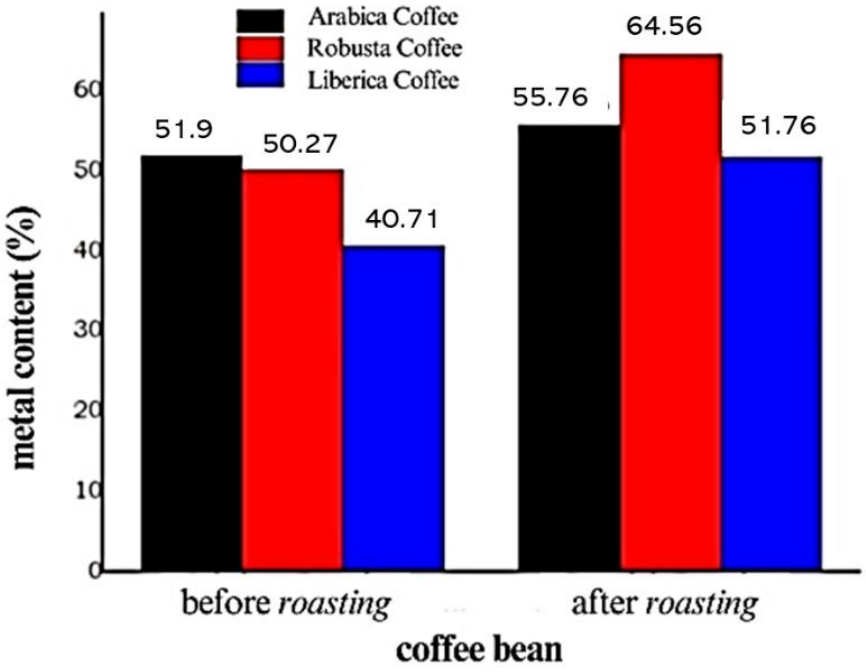


Figure 10. Comparison chart of K Metal in coffee beans before and after roasting.

Based on the results obtained, there is an observed increase in the concentrations of Fe, Ca, and K in coffee beans after the roasting process compared to green beans. This increase is primarily attributed to the loss of water and volatile organic compounds during roasting, which leads to a concentration effect of non-volatile elements such as metals. Roasting typically involves high temperatures (180–250 °C), causing significant moisture evaporation. As a result, although the absolute amount of metals remains relatively stable, their concentration per unit mass increases (BITTER et al. 2020).

In addition, the thermal degradation of organic matter during roasting may break down complex compounds that bind metals, making them more detectable in roasted beans. Furthermore, chemical changes during roasting, such as the degradation of chlorogenic acids and phenolic compounds, along with the formation of Maillard reaction products, may alter the chemical matrix of the beans, affecting metal bioavailability and possibly contributing to the formation or release of metal-associated complexes (HUSNIATI & OKTIANI, 2019; LIU et al. 2019). Together, these mechanisms explain the observed increase in mineral content after roasting.

Sensory Test of Arabica, Robusta and Liberica Coffee

Sensory tests were analysed based on SCAA (Specialty Coffee Association of America) standards. As shown in Table 7, Arabica coffee received the highest average sensory score (8.2), followed by Robusta (8.0), both of which are categorized as excellent. Liberica coffee scored slightly lower (7.9) and is categorized as very good. These differences in sensory quality can be influenced by several factors, including growing altitude and metal content in the beans.

Generally, Arabica, grown at higher altitudes, exhibits more acidity and complexity, contributing to higher preference in cupping scores. In contrast, Liberica, which is typically grown in lowland areas, presents lower acidity and a more earthy,

woody, and uneven flavour profile. Interestingly, the saltiness attribute was high across all coffee types, with Robusta scoring highest (8.1) in this category. This is in line with its high potassium (K) content, as potassium ions (K^+) are known to enhance salt perception.

The order of potassium levels was Robusta > Arabica > Liberica, which correlates directly with the saltiness scores (Robusta 8.1, Liberica 7.85, Arabica 7.9). The sweetness attribute, often less emphasized in coffee, showed variation among the samples. Arabica and Liberica had the same sweetness score (7.75 and 7.8 respectively), with Robusta slightly higher (7.9). This may seem inconsistent at first, but considering iron (Fe) content—known to influence perceived sweetness—the ranking aligns with Liberica > Arabica > Robusta in Fe levels, which mirrors the sweetness trend to some extent.

In terms of mouthfeel, Arabica scored the highest (10), which may be attributed to its lower calcium content. Higher calcium concentrations can sometimes create a more astringent or heavy mouthfeel. In this context, Liberica, with the highest calcium content, had a slightly lower mouthfeel score (7.5), suggesting a possible inverse relationship between Ca levels and desirable mouthfeel. In summary, sensory attributes like saltiness, sweetness, and mouthfeel show observable correlations with potassium, iron, and calcium content, respectively. These findings highlight the role of mineral composition in shaping the sensory profile of different coffee varieties.

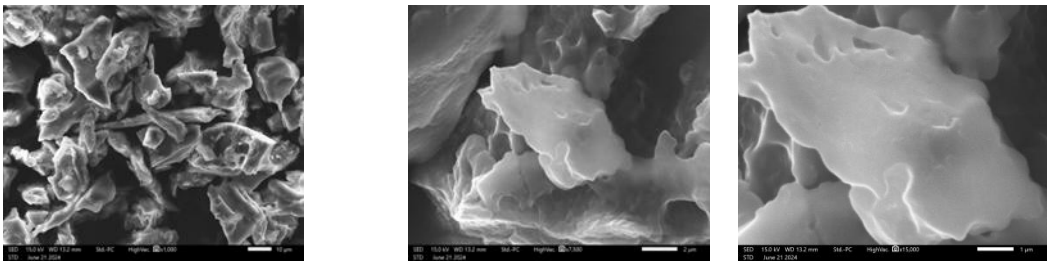
Table 7. Average Sensory Test of Arabica, Robusta and Liberica Coffee.

Types of Coffee	Fragrance	Flavor	Salt	Sweet	Mouthfell	Balance	Overall	Aftertest	Uniform cup	Clean cup	Total
Arabica	7.3	7.3	7.9	7.75	10	7.4	7.3	7.4	10	10	8.2
Robusta	7.5	7.5	8.1	7.5	7.6	7.25	7.5	6.9	10	10	8.0
Liberica	7.4	7.4	7.85	7.8	7.5	7.5	7.5	7	10	10	7.9

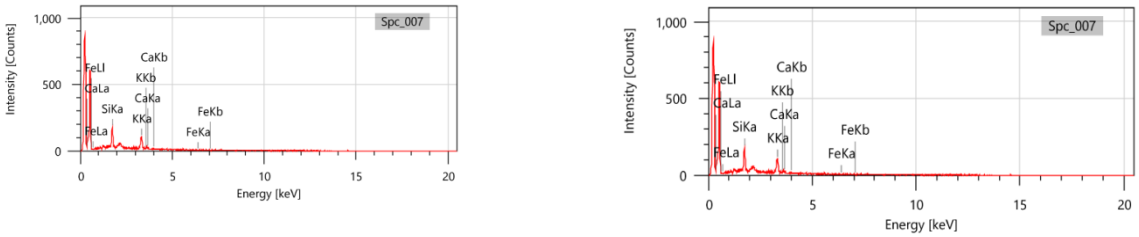
Arabica coffee has a taste note of brown sugar, lemony , fruity and nutty . Robusta coffee has a nutty , buttery and milky taste character. Meanwhile, Liberica coffee has a taste of jack fruit, brown sugar, rubbery, and nutty. The character of the flavor is produced due to the presence of volatile and aromatic compounds in coffee. In addition, the resulting flavor is also influenced by the height of planting, post-harvest process and mineral content in coffee. The height of planting affects the taste of coffee; the higher the place of growth, the quality of the coffee flavor will increase. The height of the place of growth affects the content of ethanol and acetone, both of which contribute to the fruity aroma. This is particularly evident in Arabica coffee, which has a taste that tends to be fruity. In addition to the height of the planting site, the mineral content also influences the resulting coffee flavor, such as in the types of coffee (arabica, robusta, and liberica) analyzed, all three tend to have a salty taste caused by the high potassium (K) mineral content, which exceeds the standard in coffee grounds.

Morphological Analysis of Coffee Powder

The morphological structure of Arabica, Robusta, and Liberica coffee powder was analyzed using Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX) integrated with SEM. Based on the morphological structure of Arabica, Robusta, and Liberica coffee powder, it is shown in Figures 11, 12, and 13.

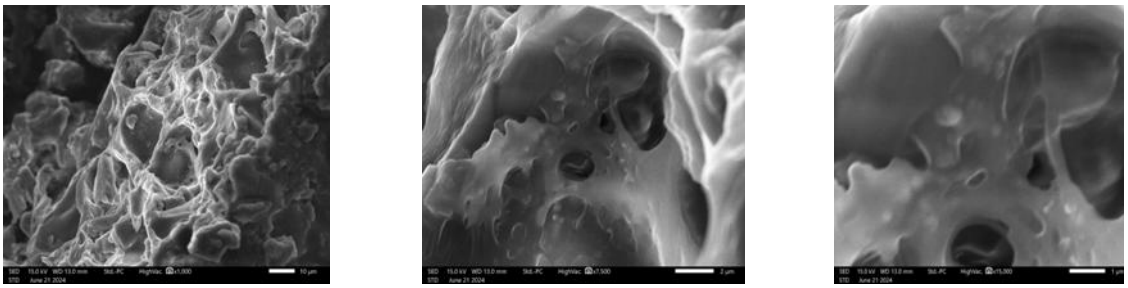


[A]

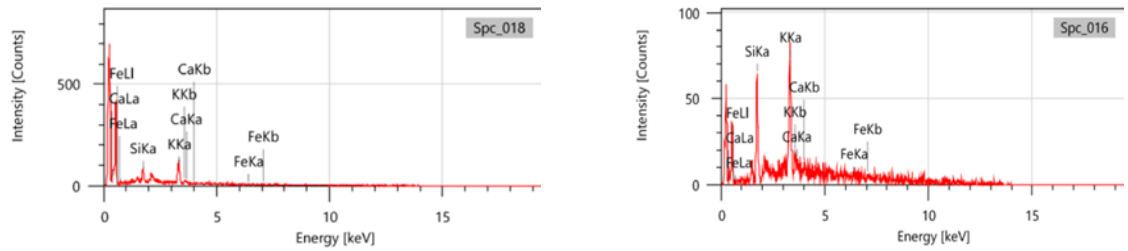


[B]

Figure 11. Morphological structure and chemical composition of Arabica coffee powder, [A] Morphological structure with magnification of 1000x; 7500X and 15000X; [B]. Ion composition.



[A]



[B]

Figure 12. [A] Morphological structure and chemical composition of robusta coffee powder with magnification of 1000x; 7500X and 15000X.

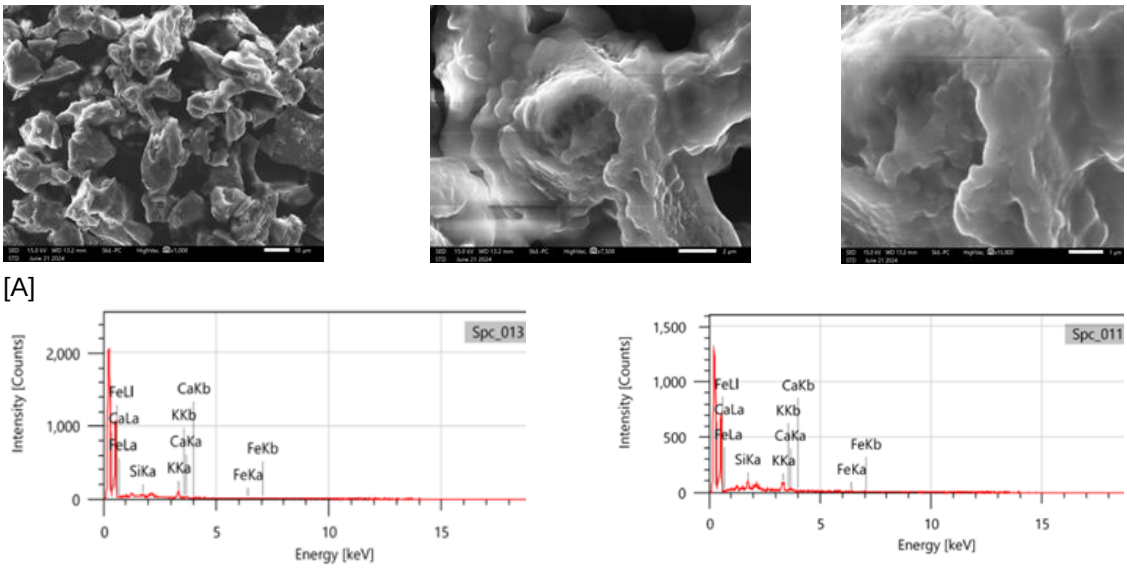


Figure 13. [A] Morphological structure and chemical composition of liberica coffee powder with magnification of 1000x; 7500X and 15000X.

Scanning Electron Microscope (SEM) analysis revealed distinct morphological differences among roasted Liberica, Robusta, and Arabica coffee powders (from left to right), which correlate strongly with their respective metal content profiles, as confirmed by SEM-EDX and XRF analyses. The surface morphology of Liberica coffee (Figure 13) demonstrated a crystalline, angular, and highly compact structure, indicative of strong internal bonding and minimal structural degradation during roasting.

The high concentrations of calcium (Ca: 14.75%) and iron (Fe: 12.81%) in Liberica are likely responsible for this rigidity. Calcium fortifies plant cell walls, while iron participates in catalytic oxidation and binding with polyphenolic compounds, promoting the formation of stable protein–mineral networks that resist breakdown at elevated temperatures. However, the relatively lower potassium (K: 56.96%) content may reduce osmotic elasticity and limit water retention, resulting in reduced expansion of the bean matrix during roasting. These structural features are consistent with literature reports that associate high Ca and Fe concentrations with more compact and crystalline morphologies in thermally treated plant powders (LISCIANI et al. 2025).

In comparison, Robusta coffee (Figure 12) displayed a denser and more fibrous morphology, with evident signs of layered matrix formation and particle aggregation. This intermediate microstructure reflects its moderate Ca content (5.79%) and high K content (68.09%), the latter being the highest among the three varieties. Potassium enhances intracellular turgor pressure and promotes moisture retention before roasting, which likely contributes to the formation of a cohesive structure upon dehydration. Meanwhile, its lower Fe level (3.64%) may reduce the extent of cross-linking with phenolic compounds, resulting in a relatively smoother, less rigid particle surface. Overall, mineral balance influences roasting behaviour and structural cohesion (VÁRADY et al. 2021).

On the other hand, Arabica coffee (Figure 11) exhibited a more open, fragmented, and irregular surface morphology, characterized by visible cracks and loosely bound particles. This disrupted structure may be attributed to lower levels of Ca (4.39%) and

Fe (4.43%), both essential in reinforcing cellular frameworks during thermal stress. The high K content (66.87%) in Arabica, however, likely enhances osmotic regulation and cell expansion during heat exposure, contributing to its porous texture. These observations align with previous findings that potassium content significantly impacts the thermal and structural properties of roasted coffee (SCHENKER et al. 2000; HU et al., 2020).

The SEM-EDX elemental mapping further supports these trends, confirming potassium (K) as the most abundant element in all three coffee types, followed by variable levels of Ca, Si, and Fe. Notably, Robusta exhibited the highest K content, while Liberica contained the highest Ca and Fe levels, and Arabica presented a more balanced but overall lower mineral composition. These findings are corroborated by X-ray fluorescence (XRF) analysis, which consistently identified potassium as the dominant element across all varieties. The correlation between mineral composition and microstructural integrity provides valuable insight into the sensory characteristics, such as texture and mouthfeel, of each coffee type.

Analysis of Bioactive Compounds in Coffee Powder

Liquid Chromatography Mass Spectrometry (LC-MS) analysis results In the Arabica, Robusta and Liberica coffee samples shown in the Table 8. Table 8 presents chromatographic data, which show several peaks with varying retention times, indicating the presence of distinct bioactive compounds in Arabica, Robusta, and Liberica coffees. Based on LC-MS analysis, nine major compounds were identified across the three types of coffee.

Among them, *n*-O-caffeoylquinic acid and *n*-O-feruloylquinic acid are classified as phenolic compounds with similar structural frameworks. The primary distinction lies in their precursor acids: *n*-O-caffeoylquinic acid is derived from caffeic acid, while *n*-O-feruloylquinic acid is synthesized from ferulic acid. Both are conjugated to quinic acid. These compounds influence the sensory characteristics of coffee, with *n*-O-caffeoylquinic acid imparting a more bitter taste compared to *n*-O-feruloylquinic acid.

Table 8. LC-MS Analysis Results on Arabica, Robusta and Liberica Coffee.

Compounds	Peak Max	MW (gr/mol)	Area		
			Arabica	Liberica	Robusta
n-O-Caffeoylquinic acid (1)	320	345.31	11,810,653	10,056,267	18,577,429
n-O-Caffeoylquinic acid (2)	320	354.31	3,555,053	3,587,369	1,336,093
n-O-Caffeoylquinic acid (3)	320	354.31	38.168.302	42,988,342	55,894,738
Caffeine	270	194.19	25,214,609	26.152.174	49,533,104
n-O-feruloyquinic acid (1)	320	368.3	432,057	187,843	681,357
n-O-feruloyquinic acid (2)	320	368.3	1,714,040	4,183,340	5,520,629
N-O-feruloyquinic acid (3)	320	368.3	7,861,111	8,890,272	11,104,008
n-Caffeoyl-1,5-quinolactone	320	336.29	7,796,599	10,581,897	2,043,260
trans-cinnamic acid	270	148.15	13,858,870	14,405,917	7,707,561

Beyond their contribution to flavour, these phenolic acids are capable of forming complexes with metal ions, potentially altering the bioavailability of minerals such as calcium (Ca) and iron (Fe) during digestion. Additionally, their antioxidant properties can protect metal ions from oxidative degradation, thereby enhancing the stability of minerals within the coffee matrix.

Another prominent compound detected was caffeine ($C_8H_{10}N_4O_2$), a well-known alkaloid abundant in coffee. Caffeine has been identified as a contributor to the potassium (K) content in coffee due to its molecular composition. This is supported by the observed trend in potassium concentrations across the varieties—Robusta > Arabica > Liberica—which aligns with Robusta's typically higher caffeine content. Potassium plays a vital role not only in cellular osmotic regulation but also in influencing the solubility and extraction dynamics of caffeine and other phenolic compounds during brewing and metabolism.

In terms of calcium and iron, the mineral analysis revealed the following trends: Ca: Liberica > Robusta > Arabica and Fe: Liberica > Arabica > Robusta. The higher concentrations of Ca and Fe in Liberica coffee may be attributed to interactions with phenolic acids such as *n*-O-caffeoylquinic acid and *n*-O-feruloylquinic acid, which possess metal-chelating capabilities. These interactions can enhance metal retention during processing and influence their bioavailability post-ingestion. Notably, *n*-O-caffeoylquinic acid has a stronger binding affinity due to its catechol group, potentially forming more stable complexes with divalent metal ions like Ca^{2+} and Fe^{2+}. This could help explain the elevated mineral levels observed in Liberica coffee, which also displayed a more crystalline morphology under SEM imaging.

Furthermore, n-caffeoyl-1,5-quinolactone, another identified compound, may regulate mineral bioavailability by promoting or inhibiting the gastrointestinal absorption of Ca and Fe. Although it does not directly contribute to the flavor of coffee, it can influence the overall sensory profile through its interactions with other bioactive compounds. Lastly, trans-cinnamic acid ($C_9H_8O_2$), an aromatic compound and derivative of cinnamic acid, imparts a sweet flavor and distinctive aroma to coffee. It may also modulate taste by balancing the bitterness of caffeine and enhancing overall flavor harmony, particularly in mineral-rich coffee types, such as Liberica.

In conclusion, the combined use of LC-MS and mineral analysis provides valuable insights into the biochemical interactions between bioactive compounds and essential metals in coffee. These interactions influence both the sensory characteristics and nutritional properties of each variety. The findings suggest that variations in mineral content among Arabica, Robusta, and Liberica are shaped not only by environmental and genetic factors but also by the specific profile of organic compounds inherently present in the coffee beans.

CONCLUSION

Based on the research results, no heavy metals were found in the coffee content of Arabica, Robusta, and Liberica coffee plants and powder in Jambi Province. The results show that the three types of coffee plants show that in the soil there is a content of Fe > Si > Ca > K, in the stem part K > Ca > Fe, followed by the leaf part having a metal content of Ca > K > Fe, and the seed part is known to have K > Ca > Fe. After

roasting, the metal content of coffee beans increases due to the high temperature, which results in the formation of new compounds. In the content of Arabica, Robusta, and Liberica coffee powder that has been studied, 9 bioactive compound components play a role in the absorption of minerals and influence the resulting taste.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, ML, SS and ILT; software and validation, ML and SS; investigation, PNS and YY; resources and data curation, ML and PNS; writing-original draft preparation, ML and PNS; writing-review and editing, SS and ILT; visualization, ML, PNS and ILT; supervision, SS and YY; project administration, ML and SS; funding acquisition, ML, YY, and SS. All authors have read and agreed to the published version of the manuscript.

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INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable, as this study did not involve humans or animals.

INFORMED CONSENT STATEMENT

Not applicable, as this study did not involve human participants.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in this published article.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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