

# AN OVERVIEW OF PHYTOMINING: A METAL EXTRACTION PROCESS FROM PLANT SPECIES

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## ABSTRACT

Metals are extracted from the hyper accumulated plant species having high biomass through the process of Phytomining. The phytomining process is a most liable, cheap and easy method to extract minerals from the soil. Many plant species works as hyper-accumulators which can accumulate a large number of minerals in it and helps to extract those minerals from the smelting process. Many plant species can accumulate a large amount of Nickel in it and does not even cause any damage to the plant as well. *Berkheya coddii* is one of the highest mineral accumulating plant species which favours in the accumulation of Nickel in it. This paper aims to do an overview of phytomining which shows the extraction of metals like Nickel (Ni), Cobalt (Co), Gold (Au). Advantages and disadvantages of this process are also discussed. These metals are important in human day to day life because of the increase in commercialization, industrialization process. Phytomining process is environmentally friendly which results an increasing demand for minerals now-a-days and further encourages to develop a preferred Phytomining process.

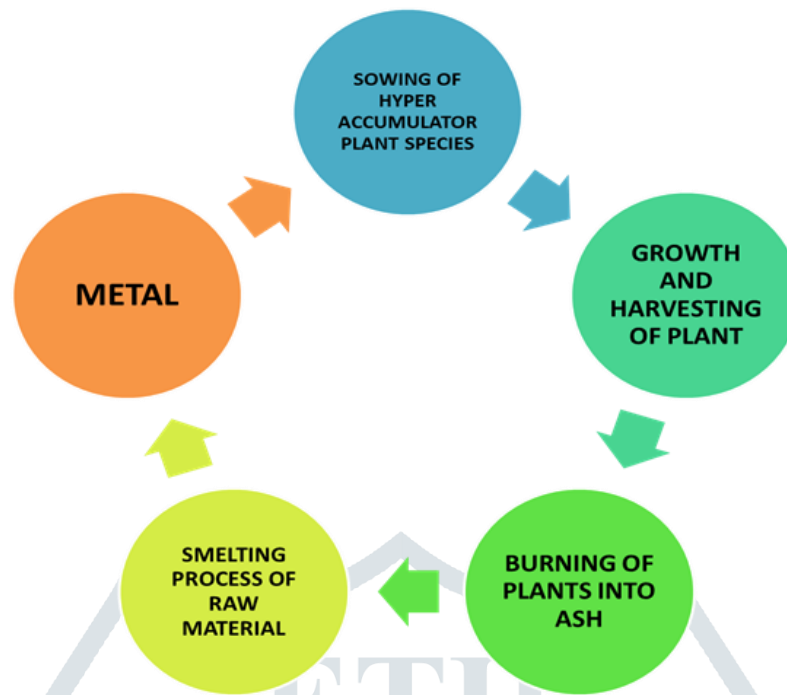
**Keywords:** Accumulators, Biotic, Crop, Density, Economy, Forage, Industrialization, Phytomining

## INTRODUCTION

A lot of big projects are working on the extraction of metals like arsenic, lead, gold, uranium, cadmium, chromium, thallium etc. These projects are working on a very large scale and extract a large number of minerals from the soil. Soil is a very big body and contains a huge amount of metals, microorganisms, acids and many more. Likewise, the soil contains a large number of metals which are important for human use. These metals are extracted through mining processes in which a large number of big pieces of machinery are used for their extraction. These metals or minerals are extracted from the soil by two methods one is through mining with big machinery and the second is through the natural process of planting plants that is Phytomining. Phytomining is the extraction of metals in which metals are recovered for their commercial purpose; minerals like gold, silver, lead, platinum, nickel, uranium, cobalt, palladium etc. are recovered for some commercial purposes (Rodriguer. E; Parsons. G.J et al., 2013). The plants can grow and take their nutrition by its own by roots or by light. Roots help the plants to absorb water, minerals and other things from soils. Roots have root hairs which help in the absorption of these essential materials.

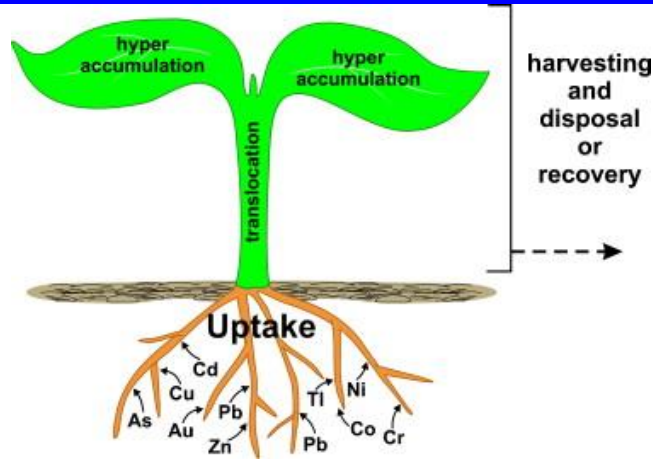
The vascular bundles present in plants help to translocate these absorbed materials to whole plant body with the help of xylem and phloem. The translocated material absorbed or collected in the leaves of the plants, that absorbed minerals are used in Phytomining process. Phytomining is the process in which plants are grown for the extraction of metals. It is the process which is used for the extraction of metals by various processes like cropping of hyperaccumulator plants, their harvesting, burning and collection of low ore metals (Rosenkranz et al., 2019). The plants which can grow in high minerals conditions or can absorb high metals in their tissues are known as hyperaccumulators (Brooks et al., 1998). Phytomining is a very cheap process which is used for the extraction of gold, cadmium, nickel, uranium, copper, cobalt etc (Eissa et al., 2017). In late seventy and eighties, these hyperaccumulator plants are used for the removal of heavy metals and minerals from the affected soil or contaminated soils (Boominathan et al., 2004). These hyperaccumulator crops are especially crops which can easily grow in toxic conditions but does not have any physiological toxicity to its own. Hyper accumulator plants like *Streptanthus polygaloides*, a Mediterranean plant, *Alyssum bertolonii*, *Berkheya coddii* are used for extraction of minerals in their tissues. They have the strong ability to accumulate minerals in their plant parts (Boominathan et al., 2004). The metalliferous soils are mainly used to accumulate metals. In this phytomining process first, the plant is planted and grown in toxic conditions. The plants are harvested after their proper growth and development. In the growing process, the roots of the plants absorb mineral or metals from the toxic soils and the vascular bundles i.e. the xylem and phloem help in the translocation of those metals from below-ground parts to the above-ground parts of the plants. These translocated minerals can accumulate mainly in the axil parts of the plants like a leaf. After the harvesting process, the whole plant is burnt. When the plant is burnt the carbon is reacting with the oxygen and carbon dioxide is formed, the ash is collected along with the carbon dioxide. Once the ash is collected the extraction process like roasting, smelting, electro-winning etc. of metals started. (Sheoran. et al., 2009). The hyperaccumulator plants are different from other normal plants because of their tolerance level. The tolerance level of those plants is 100 times more than other plants which are growing in normal soil conditions and environment. Even these plants contain more than 100mg to 10,000mg of heavy metals (Eissa et al., 2017). This type of hyperaccumulator plants is mainly grown in the ore mining areas. The phytomining process mainly depends upon two main points that are the harvested upper ground part of the plant and the presence of metals in the shoot portion. The amount of metal accumulates per hectare depending upon the agronomical practices and the selection of plant under the toxic area. It is necessary to maintain the agronomic practices like planting density, fertilization, irrigation, good quality seed etc. for the proper growth of the plant for the extraction of metals (Rosenkranz et al., 2019).

FIG. 1: CYCLIC REPRESENTATION OF PHYTOMINING PROCESS



Source: Prepared by Authors

**HYPERACCUMULATOR PLANTS:-** Hyperaccumulator plants are those plants which tend to absorb heavy toxic metals in very high concentrations without damaging to their plant parts (Fig 2). Every plant absorbs some metals along with water from roots, but after absorbing a small concentration of heavy metals the plant starts showing the toxicity symptoms. The plant can accumulate many more things along with metals, but the accumulation of metals from soils is known as metal accumulation. Mostly the soils which are used for the growth and development of these hyperaccumulator plants are serpentine. Serpentine soils are those soils which have a very low amount of nitrogen, potassium, phosphorus and other macronutrients. These type of soils are infertile soils having calcium-magnesium ratio at a very low rate. These soils are rich in nickel, cadmium, chromium, lead, thallium, uranium, gold and silver etc. These hyperaccumulator plants are also called as metallophytes. These hyperaccumulators or metallophytes helps in providing resistance against many fungal diseases and pathogens when grown in serpentine soils. But these hyperaccumulators shows very good results from fungal diseases in serpentine soils as compared to these grown in non-serpentine soils (Baker et al., 2016). Many families like Asteraceae, Brassicaceae, Caryophyllaceae, Crassulaceae, Euphorbiaceae, Fabaceae, Pteridaceae etc. are used for the extraction of metals from soils. The plant species like *Berkheya coddii*, *Helianthus annuus*, *Alyssum bertolonni*, *A. murale*, *A. halleri*, *Pteris vittata*, *Streptanthus polygalides*, *Nocca geosingensis*, *Odontarrhena muralis*, *Hylanthus floribundus* etc are extensively used and are best plant species for the phytomining process (Keeling et al., 1998).

**FIG 2: UPTAKE BY HYPERACCUMULATOR PLANTS**(Source: <https://www.sciencedirect.com/science/article/pii/S0168945210002402>)

The hyperaccumulator plant species are toxic for insect pests because they are rich in Zinc, Nickel and any other metal, which causes resistance from insects pests and reduces the growth rate of insects as well. Cadmium hyperaccumulation in plant species causes damage to the thrips, which provides resistance against Thrips and Aphids. These metals toxicity causes allelopathic effects to some plant species also (Chaney et al., 2007). Intercropping of different hyperaccumulators plant species increases the minerals and metals uptake in it. It also causes less competition between plant to plant for food, water and other nutrients as well as enhances the mineral uptake which is beneficial for Phytomining (Wiche et al., 2016). Phytomining is one of the environmentally friendly, mineral extraction technique which helps in the hyperaccumulator plant species at different areas of the globe. This technique helps in increasing the economic value of low-grade ores (Ha. Hoang et al., 2011).

**PHYTOMINING OF NICKLE:**

Nickel is mainly found in the galvanic sludge areas than conventional areas. These sludge areas contain a large number of metals and minerals other than Nickel also like Cadmium, Chromium, Arsenic, Gold, Silver etc. (Tongnacchini et al., 2019). The study of (Keeling et al., 2014) proves that the plant species of *Berkheya coddii* and *Streptanthus polygalides* are the nickel hyperaccumulator plants and helps in recovering the nickel at the rate 100Kg per hectare from the soil made from ultramafic rocks from the process of Phytomining. There are many more species of plants which accumulate Nickel given in Table.1.

One of the field experiment of (Rosenkranz et al., 2019) uses soil with good ploughing and fertilization with some liquid manures. The hyperaccumulator plants species of *Noccaea goesingensis* and *Odontarrhena muralis* is used for phytomining. These species of hyperaccumulator are used because they are high in biomass production. In this experiment, the seeds are grown in plastic trays for at least three months and then transplanted in the field with different treatments and intercropping systems. After the proper growth of plants, the harvesting is done from each plot and dry combustion process is crossed from each plant. In their research, the biomass production is higher in the high-density planting treatment and the nickel concentration is also high in the high-density planting treatment. In this research, the one noticeable thing is the growth of *Noccaea goesingensis* is increasing rapidly while the growth of *Odontarrhena*

*muralis* decreases during the whole performance. It was proved that in *Noccaea goesingensis* species of hyperaccumulator plants the accumulation of nickel is 36Kg per hectare as compared to the hyperaccumulator plant species *Odontarrhena muralis* that is it can accumulate about 4.2 Kg nickel per hectare. Harvesting time is also important for accumulating the higher yield of nickel, by harvesting the plant species at young age results in the higher production of nickel yield. The species *Noccaea goesingensis* is best for phytomining.

The serpentine soils have a huge amount of nickel present in different parts of the world. For proper mining of Nickel, the concentration needed in the soil is about more than 30,000mg per Kg which is extracted through many modern techniques of big machinery. In serpentine types of soils, nickel is present in the concentration of 700 to 7000 mg per Kg. But many researchers found that the hyperaccumulator plant species like *Hybanthus floribundus* contains about 1000mg per Kg of Nickel in the Australian fields (Sheoran et al., 2009).

The study of (Bani et al., 2015) showed the concentration of Nickel that is highest in the development stages of the hyperaccumulator plant species *Alyssum murale*, during its flowering stage. The leaves and flowers have much amount of Nickel concentration than roots and stem. In 1997, one research showed that the hyperaccumulator plant *Alyssum bertoloni* with proper doses of Nitrogen, Phosphorus, Potassium the biomass resulted is 9000Kg per hectare with the Nickel concentration of 8000 mg per Kg (72 Kg per ha) and the Ash concentration of 1,10,000mg per Kg (Robinson et al., 1997).

Another research was done by them on *Berkheya coddii* hyperaccumulator for the extraction of nickel through phytomining. This species provides up to 121 Kg nickel per hectare that is 5500mg per Kg nickel from the plant with the biomass of 22000 Kg per hectare. *Berkheya coddii* is regarded as one of the best plant species for the extraction of nickel which can provide a good amount of nickel as well as the biomass. This hyperaccumulator plant *Berkheya coddii* is a cheap, well grown in serpentine soils from the seeds. This plant is a perennial weed plant which is easily grown anywhere without any sowing. This plant has a weedy nature so that it can grow on any surface and can regrow year after year. The production of dry matter is also more than any other species of the hyperaccumulator plants. The production of dry matter is also more than any other species of hyperaccumulator plants. The main function of the plant *Berkheya coddii* is that it is the best accumulator for Phytomining of Nickel. This species is also resistant to many insects, pests, diseases as well as summers and winters as well. Even this plant species tolerate the chilling environment as well. The seeds produced from the plants can be used for future use and the flowers of the plants can be utilized by the honey bees for the production of honey. One thing that is observed during the research that the one year crop does not accumulate much nickel as compared to the young crop, it is found that the fully harvested crop at the right stage contains more amount of nickel in it (Brooks et al., 1998).

**TABLE.1:- HYPERACCUMULATED PLANT SPECIES OF NICKEL**

<b>S.No.</b>	<b>HYPER ACCUMULATED PLANT SPECIES</b>	<b>METAL</b>
1.	<i>Berkey coddii</i>	Nickel
2.	<i>Sebertia accuminata</i>	Nickel
3.	<i>Alyssum murale</i>	Nickel
4.	<i>Bornmuellera tymphaea</i>	Nickel
5.	<i>Thlaspi caerulescens</i>	Nickel
6.	<i>Alyssum markgraftii</i>	Nickel
7.	<i>Leptoplax emarginata</i>	Nickel
8.	<i>Alyssum bertoloni</i>	Nickel
9.	<i>Bornmuellera tymphaea</i>	Nickel

**Source:** Prepared by authors (Zhang et al., 2014)

### **PHYTOMINING OF GOLD**

In all around the world, the concentrations of gold are found in the waste rocks and dump yards of mining areas. The extraction of gold through the conventional method is very costly and time-consuming as well as it destroys a lot of natural habitats. So, without wasting these things, one of the best methods is Phytomining, which is natural as well as eco-friendly. Many plant species of hypo accumulator of gold are tested under many conditions like the field, greenhouse, glasshouses, laboratories etc. based on which species are determined for the extraction of gold through phytomining. Many technologies are recently used for the extraction of gold but they are not able to extract 100% of gold minerals. So, the leftover minerals in the mined ore areas can be extracted through Phytomining.

Gold can easily accumulate in plants of arid and semi-arid areas in plants per billions in the plant tissue. Even many plant species act as a bioindicator of gold in the soil. Their indication shows that in this area gold is present. These plant species are cheap, quick-growing, economical and gold can easily accumulate from this because gold is highly mobile. Scientists in their discovery showed that the use of various chemical increases the solubility of gold in the soil which results in the gold uptake into the plants. The chemicals which are added into the soil is also referred to as Chelating agents. In arid and semi-arid regions of West Africa, South America and Australia, the concentration of gold found in the soil is 1mg /Kg, which results to accumulation by plants is 0.01mg/Kg (Anderson et al., 2003).

The main aim of gold phytomining is that to get the economic profit from yield. With gold phytomining, other minerals like Nickel, Thallium and others are also extracted from waste ores. Nowadays, gold

phytomining becomes economically efficient and effective techniques. The chemicals which are used in the phytoextraction of gold to solubilise easily are Thiourea, Sodium cyanide, Ammonium thiosulphate, Ammonium thiocyanide etc. These chemicals are effective in alkaline soils or pH. The pH level can be maintained by the use of soil amendments (Correl et al., 2012).

Some reports on the hyperaccumulation of gold showed that the species *Brassica juncea*, when grown on silica sand having the concentration of gold that is 5mg/Kg, provides good yield biomass as well as a high concentration of gold in the leaf tissues that is 57mg/Kg. As well as many researchers are also researching various plant species like *Raphanus sativa*, *Daucus carota* etc. When they are cultivated in silica sand having a concentration of gold that is 3.8mg/Kg provides a good biomass yield and 200mg/Kg gold concentration in the plant tissue. Scientists had developed very technologies which are cheaper, eco-friendly and effective as well. Researchers had prepared some artificial gold-containing soils having 5mg/Kg concentration of gold. In these soils some crops are grown are *Berkheya coddii*, *Cichorium intybus*, *Brassica juncea* etc. provided with some treatments of chemicals as soil amendments. Chemicals like Ammonium thiosulphate, Potassium bromide, Potassium iodide were used in that soil. The results of that are the increase in the concentration of gold in plant leaves is 45-85mg/Kg, which gives a very good response in phytomining (Lamb et al., 2001).

### PHYTOEXTRACTION OF COBALT

Keeling et al. performed a trial on the phytoextraction of Nickel and Cobalt on *Berkheya coddii* hyperaccumulator species (Keeling et al., 2010). They proved that the mixed substrate of Nickel and Cobalt tends to decrease in the biomass production or accumulation of metals. The reduction in the accumulation of metals is 85% and 65% of Nickel and Cobalt which leads to poor results of Phytomining. The single substrate of metals get higher accumulation then mixed Nickel- Cobalt. When grown mixed Nickel-Cobalt, the accumulation of Cobalt increases, which leads to Phytotoxicity in the plant species. Yellowing of leaves at higher concentration and necrosis leads to a decrease in the total substrate concentration that is  $111\mu\text{g g}^{-1}$ .

In the process of Phytomining Robinson founded that the concentration of Cobalt increases in *Brassica coddii* crop up to 290mg/Kg. When the sulphur fertilizer is added at the concentration of 500g/Kg. Sulphur fertilizers are added to enhance the biomass production and yield of the plants. As well as it increases the uptake of Cobalt from the soil to the plant tissue (Sheron et al., 2009).

### ADVANTAGES OF PHYTOMINING:-

- Phytomining process helps to generate employment.
- In the smelting process, less Carbon dioxide is produced which causes a reduction in carbon dioxide emission.
- This process is environmentally friendly and does not cause any pollution to the environment.
- It can help in the extraction of more than one or two metals

- This process is cheaper than ore mining
- Phytomining helps in the increase of revenue and infrastructure as well.

### **DISADVANTAGES OF PHYTOMINING:-**

- Phytomining process extracts low-grade minerals.
- This process is very slow and time-consuming.
- Only 50% of metal is extracted through this process.
- High concentrations of toxic elements can pollute groundwater, which is poisonous to living beings.
- Toxic chemicals are produced during this process which causes a reduction in soil fertility.

### **FUTURE SCOPES**

As in the era of industrialization, commercialisation, the demand for minerals increases as the generation increases. The demand for gold, silver, platinum increases day by day which also causes an increase in the industrialization. The commercial use of these minerals is at the top due to the development of society. The extraction of these minerals through the mining process causes a lot of problems like the use of heavy machinery which is very costly, destruction of the environment, time-consuming and use of labour. So, to overcome these problems Phytomining process comes in a context which is time-saving, environmentally friendly and can help to secure future by causing very less environmental pollution. Nowadays many researchers are working on Phytomining process to improve its extraction process by making it more liable so that man can easily generate income through it. Phytomining process is open for future perspective.

### **CONCLUSION**

In phytomining process, various plant species are used to extract metals which gives good results in the extraction process. Plant species *Berkheya coddii* are used to accumulate Nickel, the single substrate can provide more amount of mineral than a mixed substrate, it demonstrated that the extraction of single elements can provide more amount of minerals than in combination with others (Keeling et al., 2010). Studies proved that the mid flowering stage of the plant can have more amount of minerals than other stages of plant development. As phytomining process is environmentally friendly, easy and provides a huge amount of low ore metal as well as the biomass production is also high which provides a good amount of mineral. The species used for this process is resistance to insect pest and diseases and also tolerate heavy metal stress.

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## AUTHOR CONTRIBUTION

The study was planned and written by P.K. , P.K., and T.K .

## CONFLICT OF INTEREST STATEMENT

The authors state that they have no interest in conflicts.

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