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# Translocation mechanism of heavy metal in plant roots: Concepts & conflicts: A review paper

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**Abstract**
Heavy metals (HM) pollute the soil environment & affect human, plant health. These heavy metals are continuously increasing in soil due to natural, anthropogenic activities. Mainly industrial waste & inorganic heavy metal contains pesticide. On the basis of their value for plant & essentiality these are divide into two group: (Mn, Fe, Zn, Cu, Mg, Ni & Mo) heavy metals are essential for the completing the physiological & biological growth of the plant & on the other hand non-essential for plant with unknown of their need are: Cd, Cr, Pb, As, Sb, Ag & Hg etc. In this review paper study of source of heavy metals, effect of on plant growth, uptake of heavy metal in plant means how its translocation of heavy metals particularly As. Rice uptake more As compared to other cereal crop. Translocation of As from root part to shoot part, shoot part to grains. As uptake by the silicon pathway & phosphate pathways in rice plant. In silicon pathway As transporter are Lsi1& Lsi 2 but in phosphate: osPT8, osPT4 etc. In sense of As toxicity West Bengal region is more affected as compared to Trans Indo-Gangetic Plain (TIGP): Haryana, Punjab, Delhi region (Average–196 µg $kg^{-1}$). As in plant in decreasing order root > shoot > grain but in grain hull> bran polish > brown rice > raw rice > polish rice.

**Keywords:** Heavy metals (HM), Essential, Non-essential, Toxicity, Silicon pathway, Phosphate pathway, Rice, Translocation, Arsenic (As)

## Introduction
Heavy metal are the inorganic containment or constraint present in the soil. These are the metal which has high densities & toxic in nature e.g. mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), &lead (Pb) etc. These heavy metals are previously present in low quantity in agriculture soil. But now a days their quantity increases in the agriculture soil due to natural process, anthropogenic activities (Akoto *et al*., 2018 & Parvin *et al*., 2019) [1, 2] & human activities. These activities lead to more toxicity of these compound in the soil & hinderance the plant activities in better way. Mainly industrial waste dumped in river or soil and heavy metal inorganic pesticide are major reason for the present of these heavy metal in the soil now days. Heavy metal contamination problem is not only in soil also in the water. Using of those contaminated river & ground water for irrigation or consumption purpose have hazards effect on the environment, human & animal health.

Increase in the concentration of these heavy metal elements in the soil is harmful to both plant and animals. Different type of mining activities, coming out of polluted industrial waste in river, use of more amount of heavy metal pesticide and fertilizer for crop production are some main source contamination by human activities (Juang *et al*., 2009 & Nouri *et al*., 2008). Using of heavy metal's polluted water cause soil degradation. They have major effect on the human health and the environment. Heavy metal (HM) are non-biodegradable and persistence in nature with high density more than 5g cm-3 have mutagenic effect on human and plants through affecting the food chain & atmosphere (Ding *et al*., 2015; Suman *et al*., 2018) [3, 4]. Continue addition of these heavy metalin excessive form in the soil lead to the reduction in the agriculture yield in the term of both quantity & quality (Chibuike & Obiora, 2014) [5].

On the basis of their value for plant & essentiality these are divide into two group: one is the under micro-nutrient (Mn, Fe, Zn, Cu, Mg, Ni & Mo) category & are essential for the completing the physiological & biological growth of the plant (Cempel & Nikel, 2006; Ding *et al*., 2015) [6, 3]. Other one is non-essential for plant with unknown of their need are: Cd, Cr, Pb, As, Sb, Ag & Hg etc. (Ding *et al*., 2015) [3]. The non-essential heavy metal is dangerous due to their long-term deposition in the soil & environment. For example- Lead (Pb) persistence in the soil is estimated in between 150-5000 years &Cadmium (Cd) average life in soil is around 18 years& 10 years in human body (Feng *et al*., 2005) [7].

The essential heavy metal plays an important role in the structure of many enzyme & protein. The essential heavy metals are act as co-factor for many enzymes. Deficiency of these essential lead to disruption in the growth of plant. Irrespective of their essentiality if they are present in excess amount in the soil. They become toxic in nature and have some harmful effect on the plant and cause environmental pollution (Clemens, 2006; Ding *et al*., 2015) [8, 3]. These metal present in the soil eitheras single element or in compound form with other soil component. They either are exchangeable ion, non- exchangeable ion or insoluble metal compound in nature (Chibuike & Obiora, 2014) [5].

Insertion of these heavy metal vary with places to place & time to time. Because at many places heavy metal contamination in soil is due to some parent rocks present in the soil. Their weathering take place slowly & naturally. But at many places human activities & industry place major role in their insertion. Presence of heavy metal in excessive amount means toxic level hinder the plant functioning and act as blockage in many metabolic activities of the plant. They may include: disturbing the structure many protein &enzymes, blocking activities of many functional group at cellular level, disturbing function of pigment and affecting cytoplasmic membrane. All this result in affecting many important processes like: photosynthesis, respiration etc. (Ding *et al*., 2015) [3].

The toxic condition of heavy metal leads to many disorders such as oxidation of protein & lipids, redox misbalancing, ion leakage &destroying the cell structure ultimately lead to the functioning of programmed cell death (PCD) pathways. Some heavy metals are emitting radiation (Sr, U, Pt etc.) in the environment which rises many health risks. Production of electricity in India from coal fired thermal power plant lead to deposition of heavy metal in environment. Fly- ash is by product of coal thermal plant industry dispersed in air & spread in the environment (Singh *et al*.., 2010) [9]. This fly ash has some toxic heavy metal Cd, Pb & Se etc. (Rautaray *et al*., 2003) [10] which polluted the environment.

Plant uptake these heavy metals & accumulate it. Those heavy metal heavy metal are essential they use for the various physiological & biological process. Other non-essential get accumulated in the plant. There are several mechanisms of the translocation of these heavy metal in the plant. Like translocation of heavy metal by plasma membrane of root cell & xylem loading & translocation etc. (Feng *et al*., 2005) [7]. Plant root produce some chelating compound that help heavy metal to absorb by plant.

Plant has several mechanisms for the tolerating the high toxic concentration of heavy metal. There are several methods for remediating heavy metal & they belong to physical to chemical or biological method (bioremediation). There are some: Phytoremediation, stabilization, rhizofiltration, phytovolatilization& soil washing etc. (Tangahu *et al*., 2011) [11]. Use of high dry matter plant help in remediation of heavy metal. There are several studies show that plant have ability to tolerate or resistance against high concertation heavy metal and only they vary with eco-physiological factor with in time & space (Antonovics *et al*.,1967; Ray *et al*., 1988) [12, 78]. One plant not show resistance for every heavy metal. Plant resistance for heavy metal depend upon the cyto-genetic makeup of that particular plant species (Singh *et al*., 2010) [9].

## Material and Methodology

### Heavy Metal Polluted Soils

Heavy metal show characteristics like ductility, conductivity & cation stability etc. They also feature high density in nature & have high atomic number mostly greater than 20 (Kumar *et al*., 1994) [13]. Their some heavy metal Zn, Ni, Fe, Mn, Cu & Mo are required in less amount for the plant growth. Other heavy metal like Cd, Pb, As etc. don't have any specific in contribution in the growth of the plant. They have toxic effect on the health ofsoil, animal & human. They available in various sometimes they are soluble &sometimesthey are fixed in the soil. These heavy available free & in compound form with other entities. Many heavy metals inbound with silicate mineral they don't cause contamination with respect to those heavy metal which present in the free form (Ramos *et al*., 1994) [14].

There are many soil factors which affect the availability of metal in soil to plant. Harter 1983 [15] stated that soil pH affects the availability of many metals in the soil. Wang *et al*., 2006 [16] reported that Cadmium (Cd) &Zinc (Zn) availability to the root of *Thlaspi carulescens* is decreased with increase in soil pH. Organic matter affects the availability of many metals by immobilizing of these heavy metals (Hong *et al*., 2007) [17]. Also, their positive relation of heavy metals reported by Sharma & Raju 2013 [18] with moisture content & water holding capacity. Mcbride & Martinez 2000 [19] described that application hydroxide containing things decreased the solubility of Cd, Mo, Pb & As but there is no effect on the solubility of Zn & Ni.

Heavy metal alters the soil physical, chemical & biological properties (Friedlova 2010) [20]. The toxic effect of these heavy metals on the plant & microorganisms influenced by the several factors like: pH, moisture, soil temp., chemical composition of metal organic matter, inorganic anion & cation (E. Bath 1989; Friedlova 2010) [21, 20].

Several studies show that availability of one heavy metal affect the availability of other heavy metal (Chibuike& Obiora 2014) [5]. A study by Rimmer & Luo, 1995 [22] stated that Cu lead to increase the toxicity of Zn in spring barley.

### Effect of Heavy Metal Polluted Soil on Plant Growth

Only those heavy metal are taken up by plant which are available in solubilize form in the soil solution (Blaylock & Huang 2000) [23]. Plant require only some heavy metal for the plant growth which come under essential category. Like Mn toxicity in the soil cause Crinkle leaf of the cotton. High concentration heavy metals caused inhibition of cytoplasmic enzyme & denaturation of cell structure due to oxidation stress (Jadia & Fulekar 2009; Assche & Clijisters 1990) [24, 25]. Heavy metals have antagonist effect on the soil microorganism. Reduction in the soil microorganism leads to reduction in the decomposition of organic matter & availability of the other nutrient in the soil.

The toxic effect of heavy metals on the plant vary with according to different heavy metals. Non-essential heavy metals like Pb, As, Cd etc. have toxic effect on the plant even at low concentration (Chibuike & Obiora 2014) [5]. In a study it was discovered that 1mg Hg/kg contaminated soil lead to the reduction of height of the rice plant& panicle formation (Kibra 2008) [26]. In another study it is reported that Cd concentration of 5ppm in soil solution leads to the reduction shoot & root growth of the wheat plant (Ahmad *et al*., 2012) [27].

For beneficial heavy metal like Cobalt (Co) Rajesh *et al*., 2013 reported that concentration of Co at 50mg/kg leads to increase in the nutrient content of tomato plant. But at the concentration of Co at 100mg/kg to 250mg/kg leads to the reduction of the nutrient in the tomato plant. Concentration Zn at 25ppm increase the growth of cluster bean but at Zn concentration of 50ppm in soil solution had adverse effect on the plant growth (Sekar *et al*., 2011). Some heavy metals inn combination causes more destruction to the plant. In a study conducted by Nicholls & Mal 2003 [30] reported that Cu & Pb cause complete death of leaves & stem of *Lythrium salicaria*at both high & low concentration. It is important to note the certain plant that have some mechanism to tolerate or show resistance to toxic concentration of heavy metals.

**Fig 1:** Toxic effect of Copper (Cu)

**Fig 2:** Toxic effect of Cadmium (Cd)

**Uptake & Translocation of Heavy metals In Plants**

There are different types of process for uptake & translocation of heavy metals in plants. Some of them are: root uptake, root to shoot transport, xylem unloading & sequestration etc. (Wang *et al*., 2020) [33]. Many heavy metals are in soluble form & plant easily uptake them, but many are insoluble form. Plant have several mechanisms for making them one of them is: Plant root secreted some chelating compound that make available them available in the soil (Dalvi & Bhalerao 2013) [32]. The uptake if these heavy metals is by two different ways: one is apoplastic & other is symplastic pathways. Symplastic is an active process in which these heavy metals absorbed through living tissue i.e. cytoplasm, plasma membrane etc. But apoplastic is passive diffusion mean absorbed of metal by non-living tissue (Peer *et al*., 2005) [34].
After classifying in the root cell these heavy metals form complex with different chelators and immobilized at various extra or intracellular spaces within the plant (Ali *et al*., 2013) [35]. The heavy metal ion confiscates inside the cellular space transported into the stele & goes into xylem stream by root symplasm (Thakur *et al*., 2016) [36]. After that it translocated to shoot through xylem vessel.

**Heavy metals-Sources and Effect in the Environment**

Heavy metal relatively has high density and non-biodegradable in nature. Some heavy metals like Zn, Ni, Cu etc. has some known biological function in the plant growth. But many heavy metals like Cd, As, Se & Pb etc. don't have any known biological function in the plant (Gaur & Adholeya 2004) [37] Irrespective of their function in the plant growth if they present in high. They will show toxic effect on the plant & human health. Presence of heavy metals in excessive amount has harsh effect in the soil environment.
Some heavy metals:

**Arsenic (As)**

Arsenic is one of heavy metal which show toxic effect on plant even at low concentration in the soil. Arsenic atomic number is 33 with specific gravity 5.73 (Mohan & Pittman 2007) [38]. It represents symbol is 'As'. Arsenic can combine with the other element to form complex that is called inorganic & organic arsenicals (NGWA 2001) [39]. There are some arsenic pesticide e.g. Copper arsenate, Cacodylic acid & arsenic herbicide e.g. Disodium methyl arsonate (DSMA), Monosodium methyl arsonate (MSMA) (Source: Wikipedia).
There are many forms of arsenic in nature but two are most abundant one in natural water: arsenite ($AsO_3^{-3}$) & inorganic arsenate ($AsO_4^{-2}$), represent as $As^{+3}$& $As^{+5}$ (Mohan & Pittman 2007) [38]. These inorganic species are more toxic than organic form. The pH, microbial activities, oxidation-reduction reaction & mineral compositions present in soil affect the oxidation state & form of arsenic (Tangahu *et al*., 2011) [11].


**Fig 3:** Arsenic treatment effect different dose in rice (Ghosh *et al*., 2013)

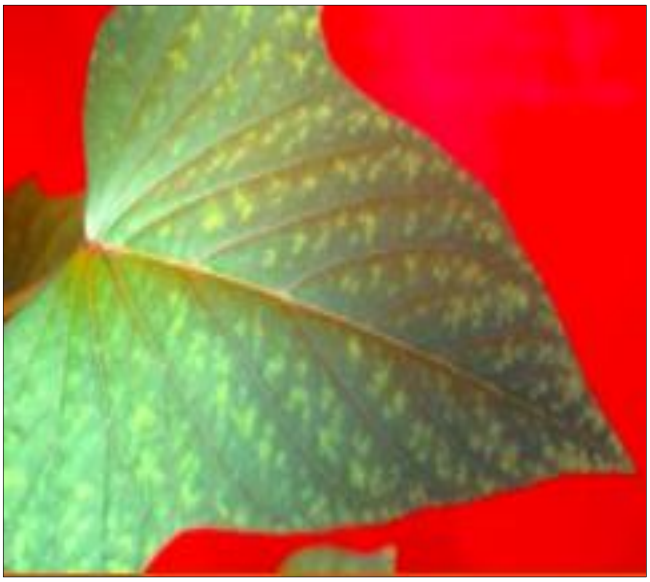
**Lead (Pb)**

Lead is heavy metal represent as Pb with specific gravity of 11.34 & atomic number of 82. It has four different isotopes present in nature (Tangahu *et al*., 2011) [11]. It has poor solubility in water. Pb is now widely disturbed in world. There are different sources by which soil & plant are contaminated such as dust, car exhaust, lead arsenate & many industrial wastes. $Pb^{+2}$ is most toxic to human health cause brain damage. Pb generally confiscated in upper region of the soil & immobilize. If any remedial action doesn't take place it is difficult to get normal of that lead affected soil (Traunfeld & Clement 2001) [42].

**Manganese (Mn)**

Manganese is an important micronutrient which play important in many metabolic activities of the plant such as photosynthesis, respiration etc. it also act as cofactor of many enzyme. Manganese has also important role in photosystem II where splitting of $O_2$ from water (Arya & Roy 2011) [43]. It is available in the form of $Mn^{+2}$. Mn toxicity symptom varies with plant to plant. Some symptom of Manganese is: crinkle leaf of cotton (Reddy 2006) [44], black spot on stems (Vitosh *et al*., 1994) [45] & chlorosis & brown speck on the old leaf (Nikolic *et al*., 2012).

**Fig 4:** Yellowing with necrosis (Mn toxicity)



**Source**: lucidcentral.org

**Fig 5:** Pale green & Sunken Patches

**Mercury (Hg)**

Mercury is heavy metal which represent with symbol Hg & available in different form in the nature. It combines with $Cl^{-2}$, oxygen or sulphur to form inorganic Hg compound. Hg is an important material in different industrial products. There are several sources of mercury that contaminated the soil i.e. industries, mining, petrochemicals, in agriculture fertilizer & fungicide (Yamini *et al*., 2005). There are many medical instrument (thermometer, barometers etc.), batteries, electrical equipment (lamps etc.), pesticide & pharmaceutical products that have mercury.

Mercury affect the photosynthesis & metabolism by interfering electron transport system (ETS) in chloroplast & mitochondria. Mercury reduce the uptake of water uptake (Gray *et al*., 2008). High level mercury reduces the germination & seedling stand.

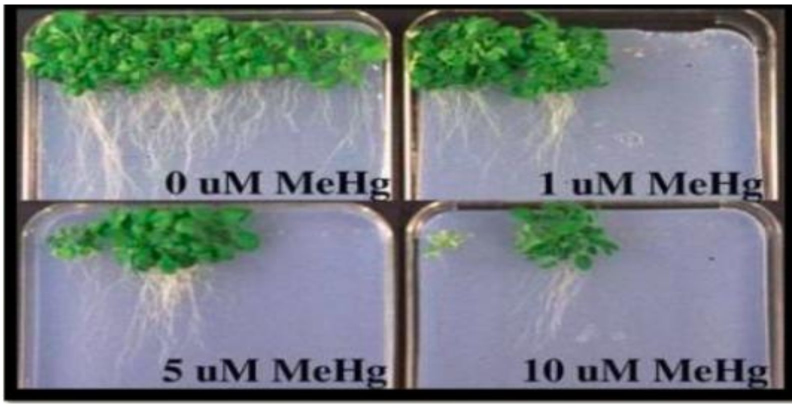
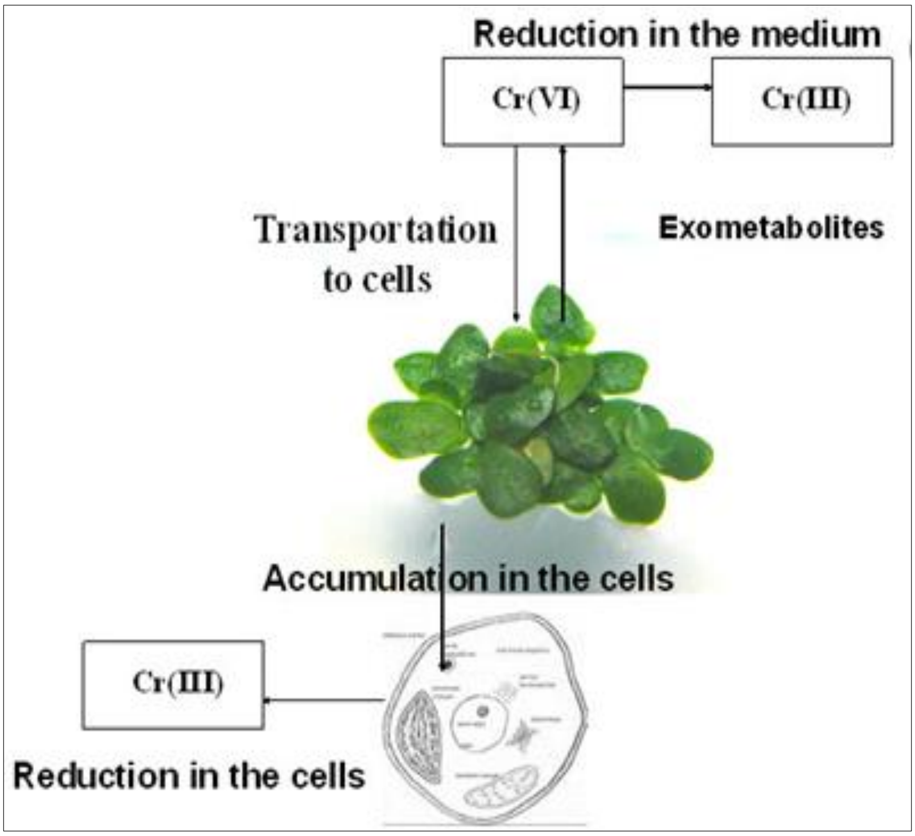



**Fig 6:** toxic effect of mercury on germination

**Chromium (Cr)**

There are several stated that chromium is toxic for the growth of the plant & cause pollution (Panda & Choudhury 2005) [50]. Chromium is found in trivalent ($Cr^{+3}$) & hexavalent ($Cr^{+6}$) form. Chromium is not directly absorbed by the plant, but it is uptake by some carrier ion such as iron or sulfate (Kaur *et al*., 2013). The high concentration of chromium is occurred in root rather than other part of the plant stated by the Kumar & Maiti 2013 [52].

Main reason behind high concentration of chromium in the root is due to immobilization of Cr in vacuoles of root cell reported by Oliveira 2018. Chromium hamper the growth plant in early stage by reducing the dry matter in seedling & reduce the stem & leaves growth (Shanker *et al*., 2005) [54]. Chromium also cause the imbalance of calcium in the plants & also reduce the shoot growth. Das *et al*., 1998 [41] describe that chromium show antagonist effect on different nutrient (Fe, Mn, Ca, P & K) absorption in plant through both root & aerial part.




**Source**: CSIR, Lucknow

**Fig 7:** Chromium transportation & accumulation in cell

## Arsenic in Rice Plant

### Arsenic uptake by Rice

The uptake of Arsenic (As) in the rice plant is totally relied on the quantity/amount or form of as present in the root zone of the plant. Rice is grown under submerged condition so, their anaerobic condition made in the field. In this condition arsenate ($As^{+5}$) change or reduce in into arsenite ($As^{+3}$) form (Yamaguchi *et al*., 2014) [57]. Arsenite is uptake by aquaporins (nodulins 26-like intrinsic protein: NIPs) & after this it goes into stele by silicon uptake pathway (Panda *et al*., 2010) [58]. These NIP genes have various gene present in rice in between 10 to 13 (Forrest & Bhave 2007) [59] and these. The NIP gene is divide into three group based on its selection: NIP I,II,III. From these NIP some are Si transporter & they load up the $As^{+3}$ into xylem from the root (Zhao *et al*., 2010) [60]. Arsenite diameter is similar to silicic acid (441pm) & aquaporin Lsi1 (silicic acid transporter) transports $As^{+3}$ (Ma *et al*., 2008). This gene is expressed outside of the plasma membrane of endodermis & exodermis cells. Lsi2 (silicic acid transporter) promotes $As^{+3}$& transport and expressed inside the plasma membrane of endodermis & exodermis cells. It releases the $As^{+3}$ in the cortex & into the stele (Mitani *et al*., 2008). $As^{+3}$ reacts with the sulfhydryl group of the cytosol proteins & affecting or destroying many biochemical functions.

In aerobic soil $As^{+5}$ form is available in the soil. Unlike silicon is uptake of arsenic in aerobic soil phosphate act as transport of arsenic. It is absorbed by the phosphate uptake system & loaded into xylem by phosphate transporter (PHT) (osPT8, osPT4 etc.) protein (Zhao *et al*., 2010) [60]. Their increase in the expression & concentration of phtyochealtin (osPCS1) in rice root under As exposure. In the end As stress suppress the phosphate transporter & enhance the phyochealtin resulted the As seizing to vacuoles in the root cells &limit the as translocation to shoot.

There are two type organic arsenic: monomethyl arsenic acid (MMA) & dimethyl arsenic acid (DMA). These both forms are taken at slower rate by the root cell due to the low affinity towards organic form of arsenic by the transporters. The order of As uptake in the rice is: $As^{+3}$> $As^{+5}$>dimethyl arsenic acid>monomethyl arsenic acid (Raab *et al*., 2007) [62].

## Translocation of Arsenic

### Translocation of As from root part to shoot part

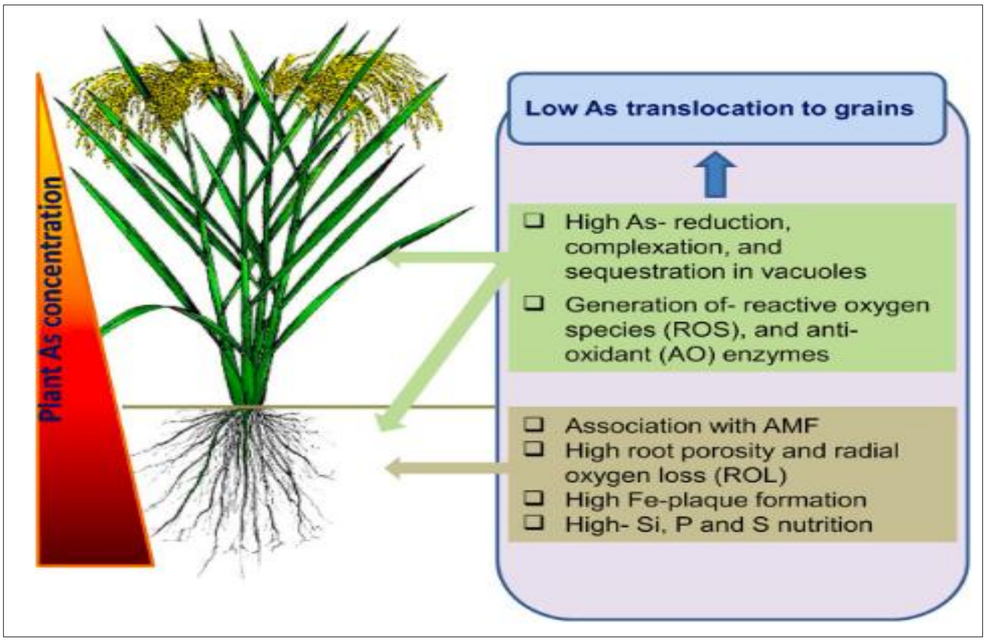
Arsenic is translocated to shoot from root by the xylem. Based on the analysis of xylem sap, seyfferth *et al*., 2011 [63] concluded that oxidised form is dominated in the xylem ($As^{+5}$& DMA) but reduced form of As ($As^{+3}$&As tris-glutathione $AsGlu_3$) dominate in cellular voids. After the translocation of As to shoot, $As^{+5}$ is absorbed to the shoot cell by the phosphate transporter (Zhao *et al*., 2010) [60].

After this process $As^{+5}$ is reduced into $As^{+3}$ or other form (Carey *et al*., 2011) [64]. $As^{+3}$ formed the complex with phytochealtin & after this seize into the vacuoles. Major sequestration $As^{+3}$ it happens in root cell but at smaller extent it happens in the stem & leaves. This can use or adopt by plant to minimize the translocation As into grain. Phytochealtin are derived from glutathione (GSH). After translocation of $As^{+3}$ in shoot cell it taken up into leaf cell by aquaporins.

Organic form of arsenic is taken up in low amount by the root cells. If it is taken organic form will follow same process as $As^{+3}$. In the end it appears that even root & shoot have mechanism of accumulation of As in their vacuole with help of phytochealtin making complex with As still some amount of Arsenic translocated into the grain. Translocated form arsenic depend on the which form is more present in the soil.

**Translocation of As into grain**

Carey *et al*., 2011 [64] studied that 90% of $As^{+3}$ & 55% of DMA from shoot to grain is transported by the phloem. Mainly inorganic form $As^{+3}$ is translocated by phloem but DMA is translocated by both xylem & phloem. From flag leaf dimethyl arsenic acid & monomethyl arsenic acid is translocated into grain but $As^{+3}$ show no translocation. But $As^{+5}$ was translocated because it is reduced into $As^{+3}$. But till now their no transporter is discovered that move arsenic out of phloem & into the grain that cannot be identified (Punshon *et al*., 2017) [65].




Suriyagoda *et al*., 2018 [66]

**Fig 8:** Sequestration of As in vacuole during translocation in rice plant

**Arsenic in grain**

After calculating data from many countries & doing several experiments it is concluded that their no limit to the As concentration defined for safe rice production. But 15mg As/ kg of rice soil (Kitagishi & Yamane, 1981) [67] is expected in Japan & 3.9 mg As/ kg of agricultural soil (Punshon *et al*., 2017) [65] in Thailand. The experiment concluded that as the concentration volume in the soil is at least 120mg. From different exp. it is also concluded that in each type of rice varieties As conc. is below than 1mg total As $kg^{-1}$ grain [permitted limit (Sauvé, 2014) [68] when grown in soil with As concentration below 15mg As/kg. WHO, 2016 announced that rice grains have an allowable limit of 0.2mg of inorganic As/kg inorganic As/kg rice grain is new permissible limit of inorganic As in rice grain. According to WHO acceptable limit for human consumption of rice is when the total concentration in the soil is below than 5.5 mg/kg. Rahman *et al*., 2007 [69] stated that rice grain As content reduced in order of hull> bran polish > brown rice > raw rice > polished rice.

**As in India**

A study conducted by Roychowdhury *et al*., 2002 [70] reported that in India As in soil was 11.35 mg $kg^{-1}$ & in rice plant it was 0.245 mg $kg^{-1}$. But according to Bhattacharya *et al*., 2009 [72] it was 1.34 to 14.09 mg As $kg^{-1}$ in soil & in rice plant: 0.16 to 0.58 mg $kg^{-1}$.

According to present study As in soil is 5.70-9.71 mg $kg^{-1}$& in rice plant- 0.334 to 0.451 mg $kg^{-1}$.

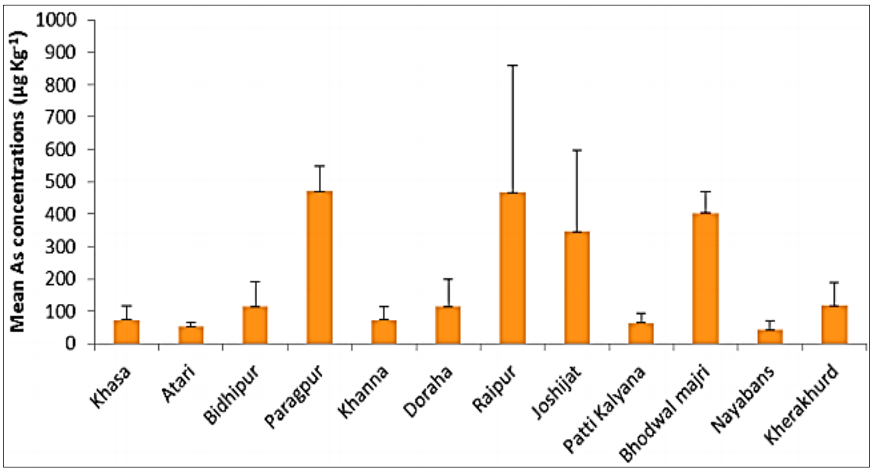
In Nadia district of West Bengal, an experiment conduct by Bhattacharya *et al*., 2010 [71] on As in Boro rice & Aman rice grain. They reported that in Rice grain (Boro) mean arsenic content was 0.451 mg $kg^{-1}$& range of arsenic content was 0.19 to 0.78 $mgkg^{-1}$. For Rice grain (Aman) mean As was 0.334 mg $kg^{-1}$& range 0.06 to 0.60 mg $kg^{-1}$.

**Table 1:** Arsenic levels (µg $kg^{-1}$, dw) in brown rice grain collected from 12 villages of Trans Indo-Gangetic Plain (TIGP) of India

| Village | District | State | n | Mean | Median | SD |
|---|---|---|---|---|---|---|
| Khasa | Amritsar | Amritsar | 4 | 74 | 73 | 43 |
| Atari | Amritsar | Amritsar | 4 | 53 | 52 | 12 |
| Bidhipur | Jalandhar | Amritsar | 4 | 115 | 114 | 78 |
| Paragpur | Jalandhar | Amritsar | 4 | 472 | 465 | 76 |
| Khanna | Ludhiana | Amritsar | 4 | 74 | 73 | 41 |
| Doraha | Ludhiana | Amritsar | 4 | 115 | 115 | 83 |
| Raipur | Sonipat | Haryana | 4 | 468 | 369 | 391 |
| Joshi Jat | Sonipat | Haryana | 4 | 348 | 309 | 248 |
| Patti Kalyana | Panipat | Haryana | 4 | 64 | 55 | 29 |
| Bhodwal Majri | Panipat | Haryana | 4 | 404 | 382 | 67 |
| Naya Bansh | North-West Delhi | Delhi | 4 | 44 | 43 | 26 |
| Khera Khurd | North-West Delhi | Delhi | 4 | 119 | 120 | 68 |

Singh & Goomer, 2018 [9]

**For this data graph is also plotted**




Mean As Content In Brown Rice Grain From 12 Village of Trans Indo- Gangetic Plain (TIGP) of India (Error Bars Are SD)

**Fig 9:** Singh & Goomer, 2018 [9]

Singh & Goomer, 2018 [9] conducted an experiment in 12 villages of Trans Indo-Gangetic Plain (TIGP) of India for determining the total concentration as in the grain of brown rice . In the 12 villages: 6 villages from Punjab, 4 from Haryana & 2 from Delhi area. The total concentration Arsenic in brown rice of TIGPA varies from 14 to 1023µg $kg^{-1}$ (dw). The mean As for all 48 brown rice sample was 196 µg $kg^{-1}$ with a median value of 109 µg $kg^{-1}$ (dw). This average As value is less than the average conc. Of As in brown rice of west Bengal (330 µg $kg^{-1}$) which was reported by Halder *et al*., 2012 [74].

According to this study As is mostly on the surface of brown rice, mainly in the pericarp & aleurone layer of the grain. Meharg *et al*., 2008 [75] reported that As conc. is more brown rice compared to white rice. In this it was concluded that As conc. in brown rice of TIGP contained much lower As conc. in general & also compared to WHO total As permissible limit of 1 mg $kg^{-1}$ for As in rice.

### Detoxify mechanism

Heavy metals(HM) have toxic effect on the growth of plant if they are in excess amount. Even some heavy metals express toxicity at low concentration. Plant shows various mechanisms to deal with toxicity of HM. Some mechanisms are: Avoidance, Tolerance & Phytoremediation. But generally, plant use avoidance & tolerance mechanisms for defending itself from heavy metal toxicity (Hall, 2002) [76].

### Avoidance

It tactic by plant through limiting the uptake of HM & limits its movement in the plant tissue through the root cells (Dalvi & Bhalerao, 2013) [32]. It is first line defend mechanism by exclusion or limiting the uptake of HM from soil to root only.

### Tolerance

After the heavy metal passes from root & reach to shoot tolerance approach or 2nd line defend mechanism come in action. It is by inactivating, chelation & confiscation of heavy metals ions. In rice plant As is seize into the vacuoles of root & shoot so, only some amount of As able to go into the grains.

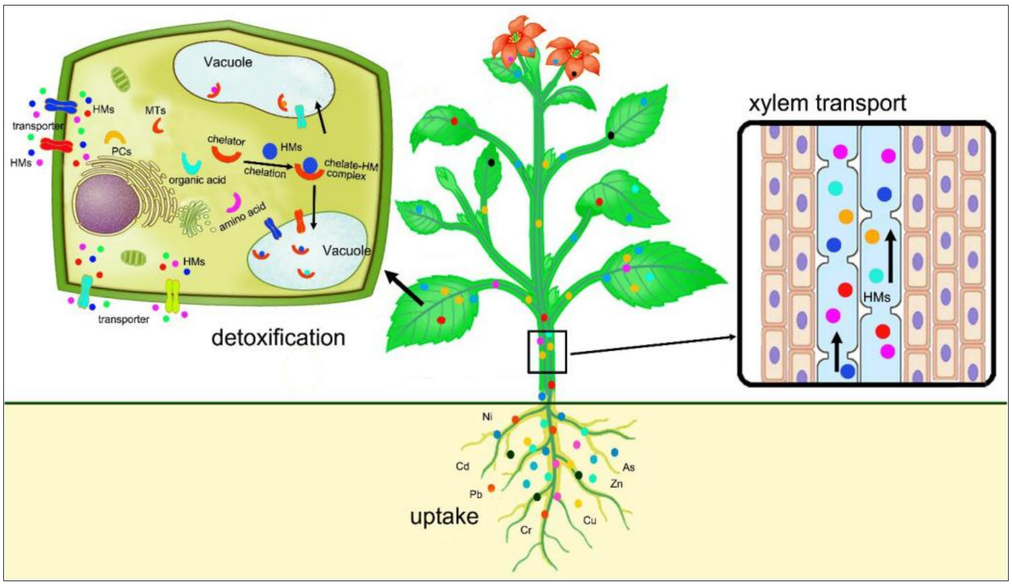



**Fig 10:** Showing uptake, translocation & sequestration of heavy metal in plant

**Phytoremediation**

There are several phytoremediation strategy such as: 1. Phytostablization–by using plants to reduce the heavy metals (HM) bioavailability in soil, 2. Phytoextraction–use plants to extract & remove HM from soil, 3. Phytovolatilization– by plant to absorb the HM form soil & release into atmosphere as volatile compound, 4. Phytofiltration– via hydroponically cultured plant to take up HM ions form groundwater (Salt *et al*., 1995) [77].

**Conclusion**

More amount of heavy metal in soil is show toxic effect on plant, human & animal health shown in various studies. Some heavy metal that come under essential category like Zn, Mn, Mo etc. show their contribution in plant growth & development. But many HM like As, Pb, Hg etc. come under non-essential category & they show toxic effect on plant even under low concentration. There are several studies on As in rice grain. Mainly As uptake by rice plant using different pathway but they get hoarded in vacuole of root & shoot (tolerance mechanism). Some amount of As is able to reach in the rice grain. It indicates that Plant has self-mechanisms to protect itself from heavy metal toxicity at some extent. Major amount of As is present in the hull & less in raw or polish rice. According region in India West Bengal is more to As toxicity. In West Bengal As concentration in rice grain is around 0.3 to 0.4 mg $kg^{-1}$. But like Trans Indo-Gangetic Plain (TIGP): Haryana, Punjab, Delhi has lower amount of As in rice grain (Average–196 µg $kg^{-1}$). Even lower than WHO permissible limit. Some study shows that As in brown rice is less compared white rice.

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