Metalloids in rice: bioavailability, potential risk and management

By

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(2018-11-135)

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Seminar report submitted in partial fulfilment of requirement of the course

Agron. 591: Masters Seminar (0+1)

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2019

DECLARATION

I, Mounisha J. (2018-11-135), hereby declare that the seminar report entitled "**Metalloids in rice: bioavailability, potential risk and management**" has been completed by me independently after going through the reference cited here in and I have not copied from any of the fellow students or previous seminar reports.

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20-01-2020 2018-11-135

CERTIFICATE

This is to certify that the seminar report "**Metalloids in rice: bioavailability, potential risk and management**" has been solely prepared by Mounisha J. (2018-11-135) under my guidance and has not been copied from seminar reports of seniors, juniors or fellow students.

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1. Introduction:

Metalloids contamination is reported in several places of the world as well as in various states of India. As it is already widespread in nature, slowly and gradually it enters our food chain through our staple food rice and causes severe health hazards. In a study conducted by LaMotte in 2019, 168 foodstuffs were tested for metalloids contaminants in USA and out of which, 34% found contaminated with lead, 27% each were contaminated with arsenic and cadmium, and 12% with mercury. It is also reported that the rice cereals, rice dishes, rice-based snacks which topped the list, contained all the metalloids. This indicates the vulnerability of the rice crop for metalloid contamination, which poses a major risk for people like us, as we are all 'rice eaters'.

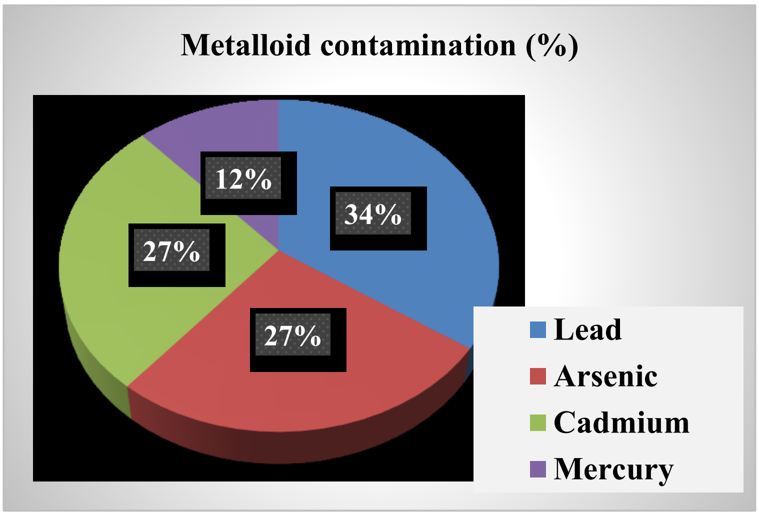

Figure 1. Metalloid contamination in foodstuffs

(LaMotte, 2019)

2. What are metalloids ?

A metalloid is an element that exhibits intermediate properties between metals and non-metals. They are also called as semi-metals. In the periodic table, it is represented in a downward diagonal series starting from group 13 to group 17. Also, some of the post-transitional or weak metals and some non-metals can act as metalloids under varying environmental conditions. The heavy metals are metallic elements whose density is heavier than that of water and is often confused along with metalloids. All the metalloids may be heavy metals (if the density is greater than water), but all the heavy metals need not behave as metalloids.

3. Metalloids in rice:

Arsenic (As), lead (Pb), mercury (Hg), cadmium (Cd), selenium (Se) are the metalloids present in rice cultivation sites. Metalloids like As, Cd, Pb, Hg are having no known benefits and are toxic to humans and animals at low concentration at which they are not phytotoxic to plants, whereas, Se is not considered to be essential to humans but at low doses it has some beneficial effects on plants.

4. Sources of metalloids:

4.1. Natural sources:

The natural sources includes the parent material from which the element is disintegrated and made available for the plant uptake. The mineral ore of arsenic is arsenopyrite (FeAsS), lead is galena (PbS), mercury is cinnabar (HgS), cadmium is greenockite (CdS) and selenium is clausthalite (Pb_2Se). Also, other natural sources includes volcanic eruptions and forest fires. The natural sources accounts for about less than 10% of the total metalloids contamination in the world.

4.2. Anthropogenic sources:

The anthropogenic sources or man-made sources includes activities like mining and coal combustion, inappropriate use of agrochemicals and pesticides in crop lands, and the use of untreated sewage sludge in agricultural soils increases the metalloids contaminant levels in the soil profile.

5. Mechanism of plant uptake:

Metalloids present in the soil are absorbed by rice roots. In the roots, xylem loading of these metalloids occur and travels through xylem till the upper most nodes of the rice plant. Then, at these nodes, xylem to phloem transfer of these metalloids occurs. In the grains, it is accumulated by the remobilization of these metalloids via the phloem.

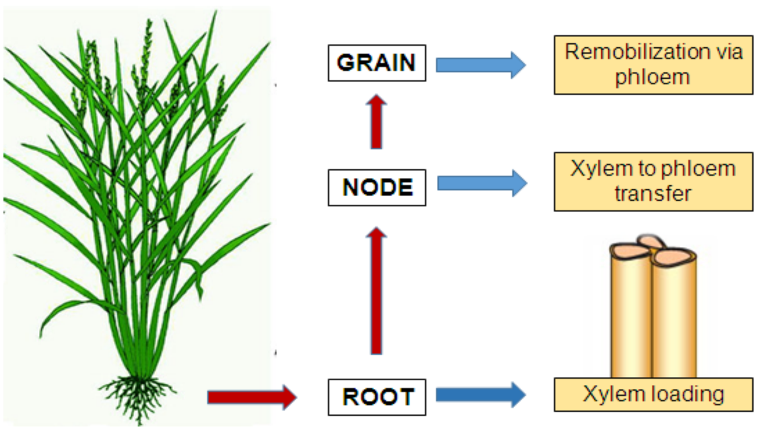

Figure 2. Mechanism of plant uptake of metalloids

5.1. Metalloid forms and their uptake channels:

Different forms of each and all the metalloids are absorbed through various ionic channels and few important of them are listed below:

Element	Forms absorbed	Uptake channels	References
Arsenic	Arsenite (As^{3+})	silicon transporters	(Awasthi *et al.,* 2017)
	Arsenate (As^{5+})	phosphate transporters	
Lead	Pb^{2+}	calcium transporters and ionic channels	(Kim *et al.,* 2002)
Mercury	Methyl mercury $(CH_3)_2Hg$	along with water absorption	(Rothenberg *et al.,* 2012)
Cadmium	Cd^{2+}	iron transporters	(Clemens *et al.,* 2013)
Selenium	Selenite (Se^{4+})	phosphate transporters	(Zhang *et al.,* 2014)
	Selenate (Se^{6+})	sulphate transporters	

Table 1. Metalloid forms and their uptake channels

6. Distribution of metalloids in rice plant:

The distribution or accumulation of the metalloids in the rice plant is based on their mobility inside the plant and in the soil. Khanam *et al.* (2019) reported the distribution of these metalloids inside the rice plant. The arsenic, lead and cadmium are highest in the roots, whereas the mercury is highest in the rice grains and, selenium in the straw.

Element	Distribution in rice plant
Arsenic	root > straw > husk > grain
Lead	root > shoot > grain
Mercury	grain > leaves > root
Cadmium	root > straw > grain
Selenium	straw > grain > polished rice > husk

Table 2. Distribution in rice plant

(Khanam *et al.*, 2019)

7. Bioavailability of metalloids:

The fraction of an element that is available for plant uptake is called bioavailability. The factors like chemical forms in which these metalloids exist, uptake mechanisms by which it is transported into the plant, and its distribution inside the plants are inter-related with each other, as changing any factor influences the bioavailability of a particular element.

7.1. Factors governing bioavailability:

7.1.1. Physico-chemical factors:

The physical properties of the soil like texture, structure, color, porosity, density, temperature and air, and the chemical properties of the soil like organic and inorganic matter, colloidal properties, soil reaction, and buffering action influences bioavailability of the metalloids present in the soil. For example, the dissolved organic carbon present in the soil, on a rainy day dissolves with rain water and leaches to underground soil, and thus increases the decomposition rate of arsenic containing parent materials if present.

7.1.2. Biological factors:

The presence of soil micro organisms and macro organisms can alter the bioavailability of the metalloids. For example, in paddy soils, iron and sulphate-reducing bacteria like Geothrix, *Desulfovibrio vulgaris*, etc. converts inorganic form of mercury (Hg^{2+}) to its organic form (methyl mercury) through a process called methylation (addition of a methyl group).

$$\underset{\text{inorganic}}{Hg^{2+}} \xrightarrow{\text{methylation}} \underset{\text{methyl mercury}}{(CH_3)_2Hg}$$

7.1.3. Environmental factors:

The environmental factors like soil type, water availability, climate, natural vegetation and land forms influences bioavailability of all the metalloids, in common.

7.1.4. Plant genetic factors:

Plants genetic and its environmental interaction plays a major role in determining the bioavailability of the metalloids. For example, some plants like rice and tobacco has inherent affinity for the absorption of these metalloids and thus, poses a major risk to rice cultivation activities and consumption.

8. Potential risks of metalloids:

8.1. Metalloid toxicity to plants:

8.1.1. Primary effects:

The primary effects in plants includes the generation of reactive oxygen species, damage to lipids and DNA, spindle activity disturbances which leads to chromosomal aberrations and ultimately cell injury/death.

8.1.2. Secondary effects:

All these primary effects causes the secondary effects such as overall decrease in nutrient uptake, plant biomass, root growth, protein synthesis, photosynthesis, pigments, and respiration.

8.2. Metalloid toxicity to humans:

The maximum permissible limits of these metalloids in rice grains (mg/kg) and in drinking water (mg/L) is given as per the standards of World Health Organization, 2011.

Element	**Maximum Permissible Limits**	
	In rice grains (mg/kg)	**In drinking water (mg/L)**
Arsenic	1.00	0.010
Lead	0.20	0.010
Mercury	0.02	0.006
Cadmium	0.40	0.030

Table 3. Metalloid toxicity to humans (WHO, 2001)

8.2.1. Metalloids concentration (mg/kg) in rice grain:

This table shows the combined data of all these metalloids reported in various countries. In this, USA has the highest for arsenic, Bangladesh for lead and China for mercury, cadmium and selenium. In India, concentration of lead is greater than the maximum permissible limits of WHO, 2011.

Country/ Element	**India**	**Bangladesh**	**China**	**Japan**	**USA**
Arsenic	0.640	**1.400**	**1.180**	**1.760**	**1.710**
Lead	**0.218**	**3.190**	0.060	0.002	0.098
Mercury	0.001	-	**0.174**	0.011	**0.023**
Cadmium	0.078	0.099	**0.312**	0.050	0.018
Selenium	0.008	0.160	**2.110**	0.109	0.094

Table 4. Metalloids concentration (mg/kg) in rice grain (Khanam *et al*., 2019)

8.2.2. Arsenic contaminated states in India:

Arsenic is the major contaminant in irrigation and drinking water in Ganges-Brahmaputra-meghna plains which is considered as the most acute arsenic contaminated site in the world. According to Chakraborti *et al, (*2016), 70 million people are potentially at risk from Indian states of Uttar Pradesh, Bihar, West Bengal, Jharkand, Chattisgarh, Assam and Manipur. Also further states like Rajasthan, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu has increase in reports for arsenic contamination. Hence, timely management practices should be taken immediately to avoid worsening of the metalloid contamination.

8.2.3. Arsenic:

The arsenic is the 1^{st} most hazardous heavy metal in the world reported by the Agency for Toxic Substances and Disease Registry. The poisoning of arsenic is called as arsenicosis. Some serious health effects due to As poisoning includes anemia, melanosis (hyperpigmentation or dark spots and hypopigmentation or white spots), hyperkeratosis (skin hardening), restrictive lung disease, peripheral vascular disease (Blackfoot disease), gangrene, diabetes mellitus, hypertension, ischemic heart disease and cancer.

8.2.3. Lead:

The lead is the 2^{nd} most hazardous heavy metal in the world reported by the Agency for Toxic Substances and Disease Registry. Children are more susceptible to lead toxicity. The high levels of exposure of Pb increase the production of reactive oxygen species (ROS) in cell, which oxidizes biological proteins and may even cause cell death. Its chronic exposure can result in birth defects, mental retardation, brain damage, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, kidney damage and may even cause death.

8.2.4. Mercury:

The mercury is the 3^{rd} most hazardous heavy metal in the world reported by the Agency for Toxic Substances and Disease Registry.New born babies and pregnant women are prone to mercury toxicity. The nervous system is very sensitive to Hg and its poisoning is referred to as acrodynia or pink disease. EPA has declared $(CH_3)_2Hg$ to be highly carcinogenic and its exposure can disturb brain functions and lead to shyness, memory problems, tremors, irritability and changes in vision or hearing. Excess Hg intake leads to Minamata disease as reported in Japan is characterised by symptom of fatigue, loss of memory, cortical blindness and Nigata in Iran.

8.2.5. Cadmium:

The International Agency for Research on Cancer has declared Cd as Group 1 carcinogens for humans. The cadmium is the 7^{th} most hazardous heavy metal in the world reported by the Agency for Toxic Substances and Disease Registry. Its bioavailability is very high, it has higher tendency of bioaccumulation. In animals, 50% of cadmium gets absorbed in the lungs, gastrointestinal tract and it can cause both acute and chronic intoxications. Its chronic exposure leads to deposition in kidney and finally leads to kidney failure, lung diseases and fragile bones. A classic example of excessive Cd intake through contaminated foodstuffs is Itai-Itai disease in Japan.

8.2.6. Selenium:

The recommended dietary allowance (RDA) of Se for an adult human is 55 µg/day. Higher Se intake causes adverse health problems like loss of hair and nails, skin lesions, nervous system disorders and paralysis, whereas, in human body Se deficiency causes Keshan disease and in sheep and goats it causes White muscle disease.

9. Management of metalloids:

9.1. Agronomic practices for metalloid management:

9.1.1. Soil amendments

9.1.2. Nutrient management

9.1.3. Water management

9.1.4. Tillage practices

9.2. Bioremediation for metalloid management:

9.2.1. Phytoremediation

9.2.2. Microbial remediation

9.3. Transgenic approaches for metalloid management:

9.3.1. Gene editing

9.1. Agronomic practices for metalloid management:

Effect of biochar on cadmium immobilization in paddy soil:

Kosolsaksakul *et al*. (2018) conducted a study in Thailand. The soil is collected from 18 different cadmium contaminated paddy fields. Here, two types of biochar namely rice and miscanthus char were used in two different experiments. In both experiments, five sets of treatments such as control and biochar @ 5, 10, 15, 20 % w/w basis were applied. In both cases, it is observed that the addition of biochar causes decrease in cadmium concentration in paddy soils. This is due to the high surface area and negative charge of the biochar makes cadmium ions to adsorb on it.

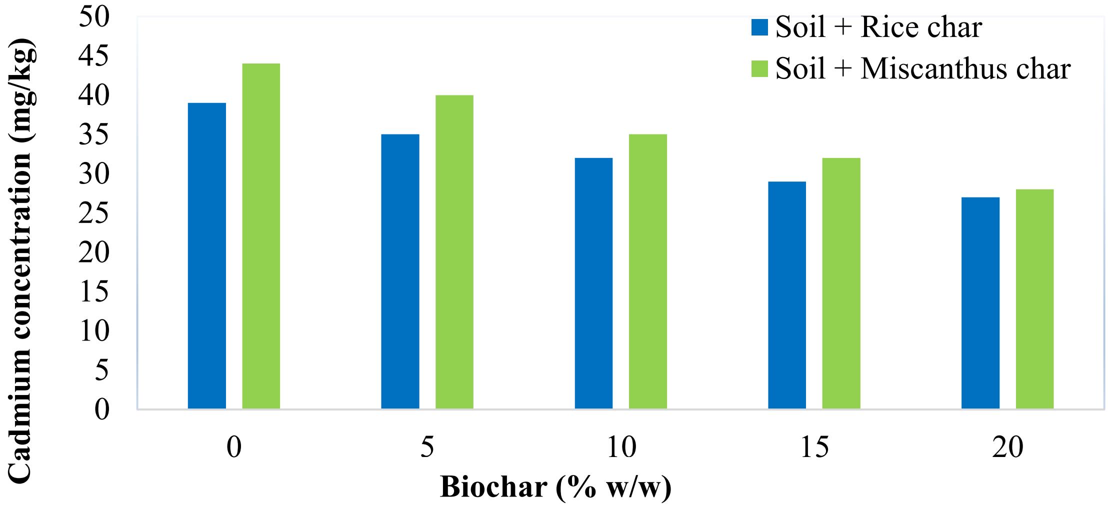

Figure 3. Effect of biochar on cadmium immobilization in paddy soil

Effect of iron materials on arsenic concentration in rice grain:

Matsumoto *et al.* (2016) conducted a concrete frame experiment of size 0.8 * 0.9 * 0.6 m with 400 kg contaminated soil in Japan, showing the effects of various iron materials on arsenic concentration in rice grains. The experiment has 4 treatments which includes control and 3 iron materials and 10 replications. The iron materials used were Fe oxide, Furnace slag and metal Fe powder @ the rate of 1 kg/m^2. From the figure, it is evident that the addition of iron materials reduced the arsenic concentration levels in all the treatments compared to control and in that, the Fe oxide treatment shows the highest reduction of As. This is due to the fact that Parent material of As is arsenopyrite (AsFeS) and thus As has the ability to form complexes with Fe materials

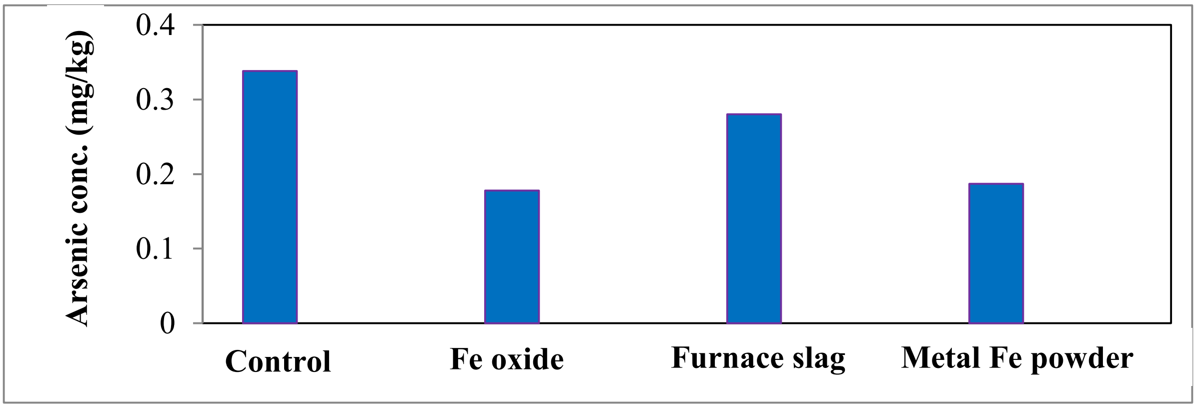

Figure 4. Effect of iron materials on arsenic concentration in rice grain

Effect of fly ash and steel slag on cadmium and lead concentration in rice grain:

Gu *et al.* (2011) conducted a pot experiment in China showing the effects of fly ash and steel slag on cadmium and lead concentration in rice grains. Here, 200g contaminated soil per pot and 3 treatments were applied including control, fly ash and steel slag. Again, fly ash is applied at 5 different doses as 10, 20, 40, 60, 80 g/kg of soil and steel slag is also applied at 5 doses as 1, 3, 5, 6, 8 g/kg of soil. Comparing to control, all the doses of fly ash and steel slag effectively reduced Cd and Pb concentration in rice grain. The reason behind this is fly ash and steel slag when applied in acidic soils, increased the pH and thus makes the phosphorus present in the soil to available form, thus leading to the formation of insoluble Cd PO_4 and Pb PO_4 in soils, reducing the plant uptake of these elements.

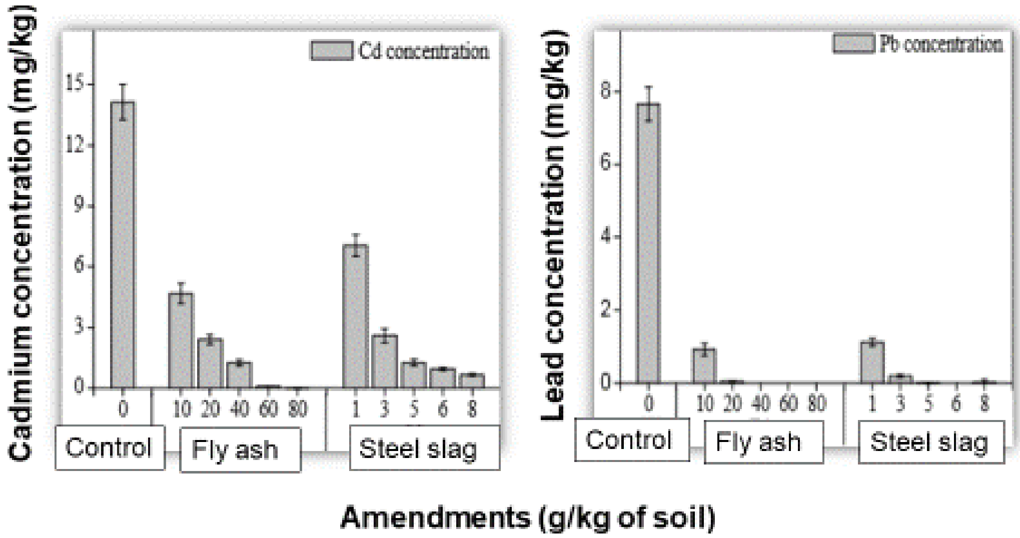

Figure 5. Effect of fly ash and steel slag on cadmium and lead concentration in rice grain

Effect of biochar and selenium on mercury accumulation in rice:

The study by Wang *et al*. (2019) shows the combined effect of biochar and selenium on mercury accumulation in rice. Although selenium is a metalloid, it is used in this study due to its antagonistic effect on mercury. Also widespread of Se toxicity is less compared to mercury contaminations. Here, 5 treatments were applied, in which 2 Se treatments were applied at the rate of 3 and 6 mg / kg of soil and these 2 treatments combined with biochar at 0.5% w/w basis, formed further 2 treatments. Control was taken as biochar at 0.5% w/w basis. From the graph, it is clear that comparing to Se only treatments and control, the combined treatments of Se and biochar were found effective in reducing methyl mercury present in rice grains and straw

Figure 6. Effect of biochar and selenium on mercury accumulation in rice

Effect of irrigation on arsenic accumulation in rice:

Carrijo *et al.* (2018) in USA reported the effect of irrigation on arsenic accumulation in rice. Here, continuous flooding is taken as control. 3 degrees of water stress is given based on the water potential values obtained from tensiometers such as at 0 kPa low, -71 medium and -154 kPa high stress. These stresses were imposed at stages panicle initiation and heading. During the other growth period of the crop, alternate wetting and drying method is followed. It is observed that under low water potential i.e. high water stress conditions, the arsenic concentration in rice is decreased compared to all the other treatments. Although stress has been imposed at the critical growth stages of rice, only mild yield reduction was reported which was due to the alternate wet and dry method of irrigation followed in other growth stages.

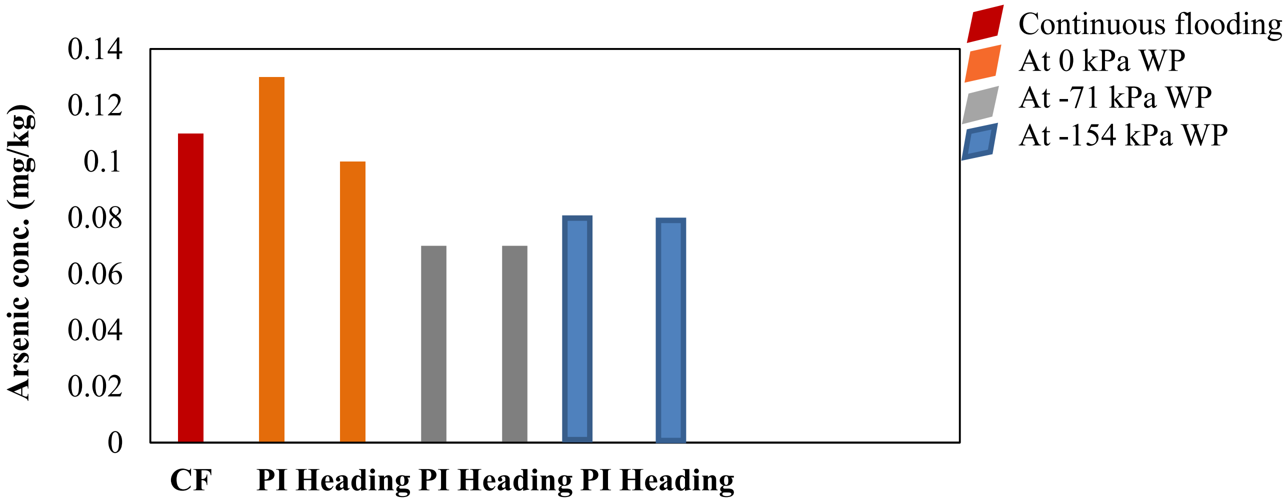

Figure 7. Effect of irrigation on arsenic accumulation in rice

Effect of tillage practices for reducing cadmium uptake by rice plant:

High soil organic matter under reduced tillage conditions enhances adsorption and complexation of cadmium. Stubbles/crop residues left on soils decompose and produces high organic matter. Due to its negative charge, complexation of Cd occurs on it and reduces availability for plant uptake.

9.2. Bioremediation for metalloid management:

Phytoextraction of metalloid by crops:

Shaheen and Rinklebe in 2015 conducted a study in Germany. Metalloids like As, Pb, Cd, Se were phytoextracted by the crops namely rapeseed, sunflower and Indian mustard when grown in metalloid contaminated sites. After one complete growing season, the crops were harvested and analysed for metalloids concentration. From the figure, we can conclude as sunflower is a good phytoextractor for Cd and Pb whereas, Indian mustard phytoextracts

As and Se. Thus, these crops can be successfully included in crop rotations for cleaning up the metalloids present in the soils.

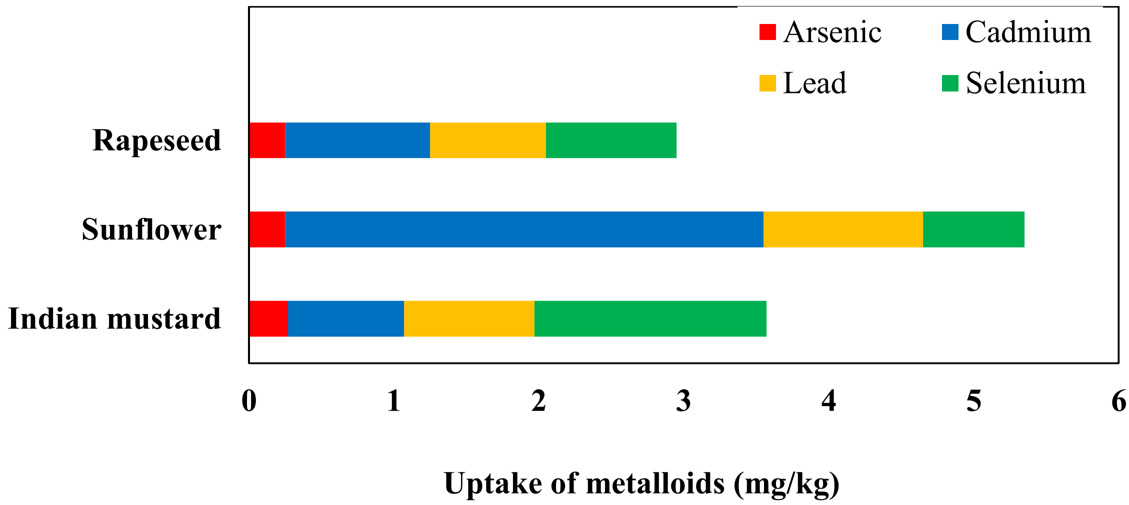

Figure 8. Phytoextraction of metalloid by crops

Phytoremediation of metalloid by *Eichhornia crassipes:*

Sasidharan *et al.* (2018) conducted a study in Regional Agricultural Research Station, Kerala Agricultural University in Kumarakom. Vembanad lake is to be reported with metalloids contamination and thus water hyacinth samples obtained from the lake is analysed for metalloid contamination. It is found that stem + petiole portions of the water hyacinth samples are accumulated with higher levels of metalloids compared to root and leaf lamina samples. As the water hyacinths and seaweeds accumulate metalloids in higher levels they indicate the prsesnce of metalloids contamination and thus, can be used as biomonitors.

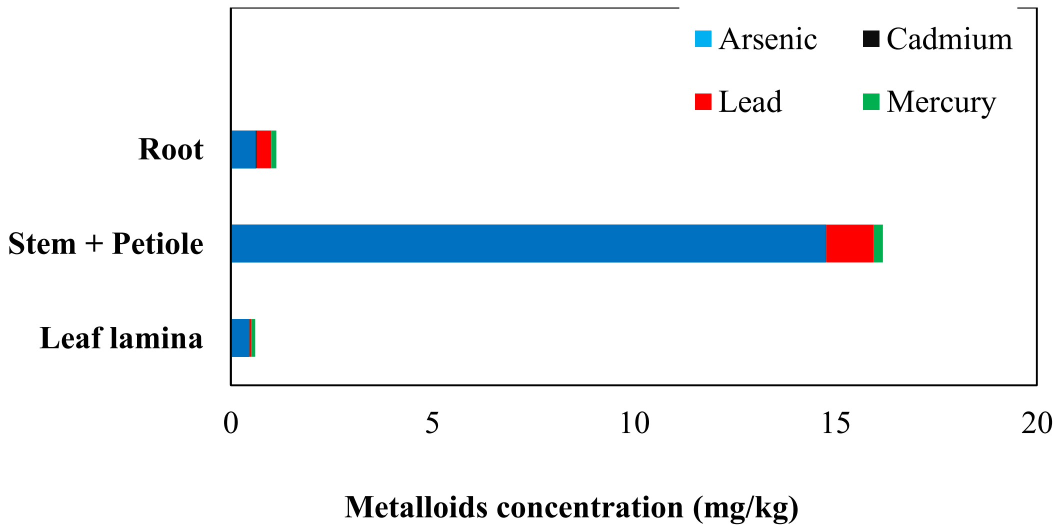

Figure 9. Phytoremediation of metalloid by *Eichhornia crassipes*

Arsenic bioremediation by *Azolla* spp.:

Zhang *et al.* (2008) conducted a study with 40 different spp. of azolla in China for arsenic bioremediation. It was reported that *Azolla caroliniana* accumulated As in higher levels compared to all the other spp. and also it showed high degree of tolerance to arsenic contamination. Although *Azolla filiculoides* accumulated lower levels of As, it showed high resistance characteristics to As concentration.

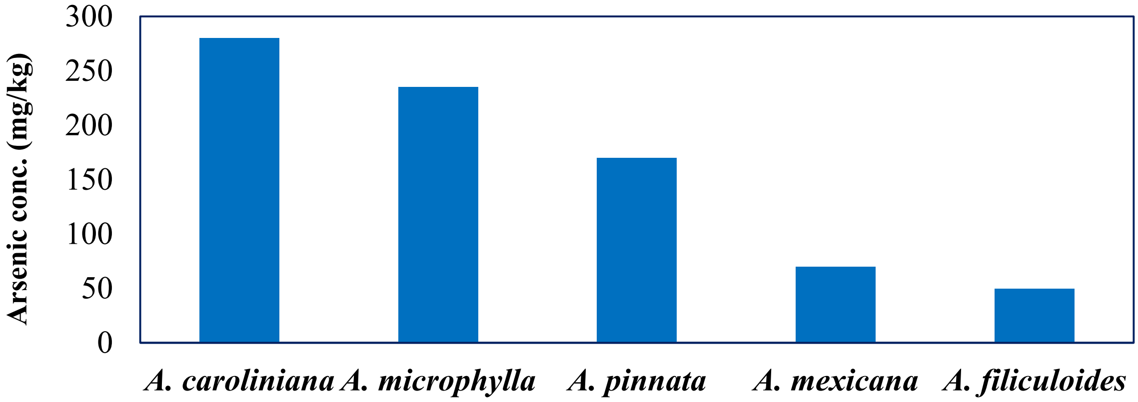

Figure 10. Arsenic bioremediation by *Azolla* spp.

Microbial remediation on reducing cadmium uptake in rice:

Treesubsuntorn *et al.* (2017) conducted a study showing the microbial remediation on reducing cadmium uptake in rice in Thailand. This experiment has 4 treatments namely control, with EM (Effective Microorganisms), with *Bacillus subtilis*, and with *Bacillus cereus* and 6 replications. The EM is applied at the rate of 10*8 CFU/ml and other treatments @ 2 % v/w basis. From the figure, it is seen that cadmium is accumulated highly in roots in all the treatments and the treatment with *Bacillus subtilis* reduced the cadmium concentration in all the three samples of roots, shoots and grains to a much lower level. Also the author suggested, as *Bacillus subtilis* is a benign organism i.e. it does not cause any diseases in humans and animals, it can be successfully inoculated in areas where cadmium contamination is a major problem.

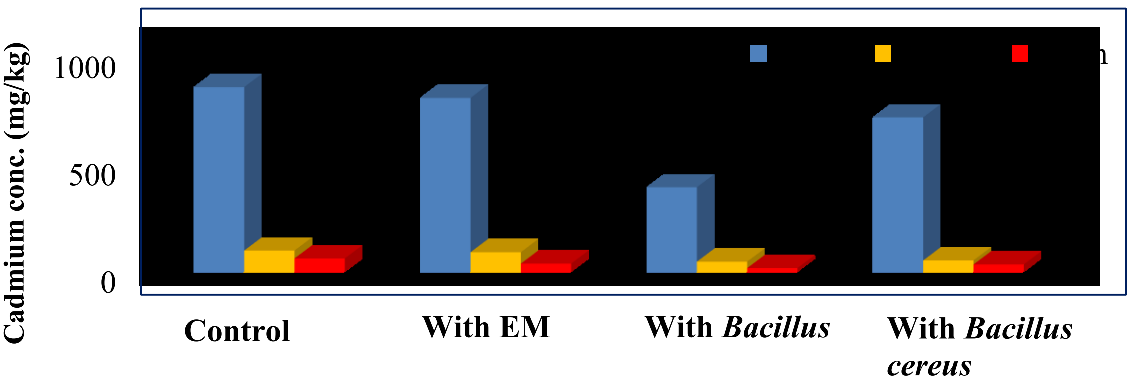

Figure 11. Microbial remediation on reducing cadmium uptake in rice

Arsenic accumulation by Mycorrhizal fungi:

De Andrade *et al.,* (2015) conducted a arsenic bioremediation study with mycorrhizal fungi. The treatments included control, sprays of As^{3+} @ 50 µmol/L arsenate and As^{5+} @ 50 µmol/L arsenite at the time of transplanting with both with mycorrhizal and without mycorrhizal fungi. Application of mycorrhizal fungi is common in upland rice. Here, the mycorrhizal fungi used is *Rhizophagus irregularis* @ the rate of 400 spores at the time of transplanting. The rice is harvested at 8 weeks stage and roots and shoots were analysed for arsenic accumulation. In both roots and shoots, the concentration of As^{5+} is lesser in plants with mycorrhizal fungi, whereas, As^{3+} is higher in plants with mycorrhizal fungi and also, the fungi promotes the growth in rice plants.

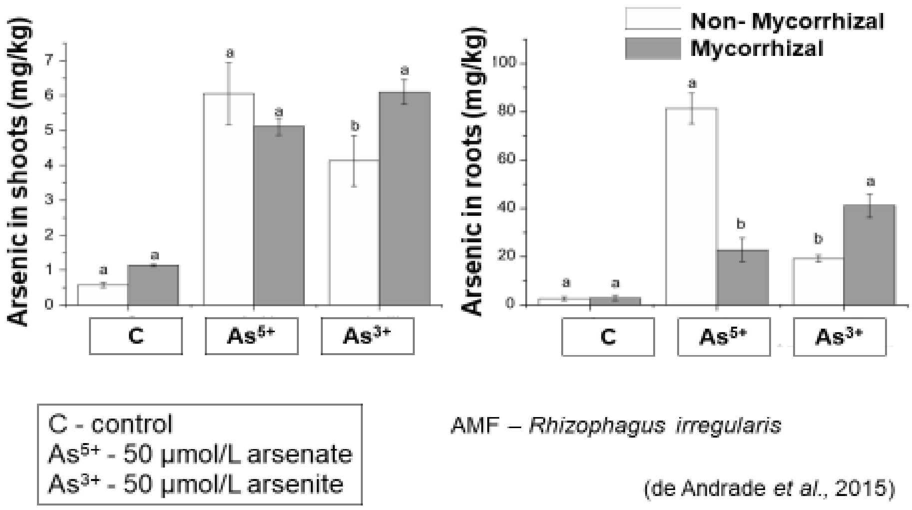

Figure 12. Arsenic accumulation by Mycorrhizal fungi

9.3. Transgenic approaches for metalloid management:

Several genes have been identified for sequestering these metalloids out of the uptake mechanism channels. Some of the examples are

Genes	Functions in rice plant	References
Arsenic		
OsABCC1	In the upper nodes of rice plant, this gene selectively sequesters As into the vacuoles of the phloem companion cells	(Song *et al.,* 2014)
Cadmium		
OsNRAMP5	Marker-assisted selection of the mutant *OsNRAMP5*, reduces the Cd concentration in rice	*(*Yang *et al.,* 2019)
OsHMA3	This gene selectively sequesters Cd into the root vacuoles, thus making it unavailable for the plant	(Ueno *et al.,* 2010)

Table 5. Transgenic approaches for metalloid management

10. Management practices in reducing arsenic contaminants in rice:

<table>
<tr><td>Agronomic methods</td><td rowspan="2">• Avoid continuous flooding irrigation method
• Use arsenic-tolerant rice varieties like Muktoshri
• Add iron and phosphorus to form insoluble complexes
• Use alternate irrigation sources like water from deep aquifer / river / lake /reservoir /pond (tank)</td></tr>
<tr><td>Water management</td></tr>
<tr><td>Phytoremediation</td><td>• Include hyperaccumulator crops in crop rotation</td></tr>
<tr><td>Postharvest processing</td><td>• Remove husk in grains as arsenic is highly accumulated in husk region
• Cook in excess water and drain it, as arsenic is water soluble</td></tr>
</table>

Table 6. Management practices in reducing arsenic contaminants in rice

(Brammer, 2009)

11. Campaigns for metalloids free future:

There are several International organizations emerging, to create awareness among the world people about this major arising issue and in which one of them is IPEN (International Pollutants Elimination Network). Their motto is ‘Campaigns for a toxics free future’. They paved ways for solving the metalloid contamination problems by promoting Mercury-Free Campaigns, which lead to the Global Mercury Treaty in 2013 and they also encouraged the Global Lead Paint Elimination Campaigns.

12. Conclusion:

Anthropogenic actions play a significant role in further accentuating the metalloid related health problems in soil-plant-animal-human system. Rice scientists need to widen focus to recommend management practices that take metalloid contaminants into consideration

13. Future thrust areas:

- Understanding the exact uptake mechanisms, translocation and distribution of the metalloids in different rice varieties
- New genotypes with metalloid resistance and metalloid avoidance characteristics
- Research on efficient low cost mitigation approaches

“Not only through rice, but also we have several products, causing day to day exposure to these metalloids. Metalloids are present in the air we breathe, in the water we drink and in the food we eat. As the world is developing, it is also destroying.”

14. Discussion:

1) What is the rate of metalloid contaminant added to the soil in India ?

In USA, researchers claim that in every 2.5 minutes, a metalloid contaminant is added to the soil. As USA is a developed nation, the number of industries is high compared to India. Approximately, it has 6 times more number of industries than India. So, obviously the metalloid contaminant emission will be higher than that of India. Also in India, there are no such studies relating metalloid contaminants to time.

2) Is there any reports of metalloid toxicity in Kerala ?

In Kerala, still now there is no reports of metalloid toxicity in humans and animals. But certain species of fishes in Vembanad lake, due to industrial pollutant emission are reported to be dead.

3) In Kerala, where is the lab for testing metalloids ?

In the Radio tracer lab under Kerala Agricultural University in Vellanikkara, testing of metalloid levels can be done. Also, these metalloids are analysed using the instrument Atomic Absorption Spectroscopy.

4) What is gene editing and name some tools employed in it ?

Gene editing is a type of genetic engineering method in which DNA or genes are inserted, deleted, modified or replaced in the genome of a living organism. Some of the known gene editing tools are Zinc Finger Nucleases (ZFN), transcripton activator-like effector nucleases (TALENs), cluster regularly interspaced short palindromic repeat (CRISPR)-associated nuclease Cas9.

5) Name some methods to overcome arsenic contamination in cooked rice.

- By cooking in excess of 5 to 10 parts of water and draining it. As arsenic is water soluble, it dissolves with water and drains away.
- By removing the husk in rice, arsenic concentration is reduced to maximum. Because arsenic is more concentrated in husk regions of rice.

6) Is there any arsenic resistant rice varieties in India ?

In West Bengal, the rice variety named 'Muktoshri' is released in 2016 by West Bengal Government's rice research centre to adapt to arsenic prone areas. Also, jute variety named 'Goranga' is released to withstand arsenic contaminated soils.

14. References:

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Venue : Seminar hall
Date : 20-12-2019
Time : 10.45 am

Metalloids in rice: bioavailability, potential risk and management

Abstract

A metalloid is a chemical element that has intermediate properties between metals and non-metals. They are not biodegradable and hence are persistent environmental contaminants. Several natural and anthropogenic sources make rice cultivation sites one of the biggest reservoirs of potentially toxic metalloids like arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg) and selenium (Se). As per the report of the U.S. Department of Health and Human Services (2012), exposure to these elements through the consumption of contaminated rice causes carcinogenic and non-carcinogenic health hazards. Evidence of increasing contents of metalloids like arsenic in rice in India and other parts of the world are becoming frequent of late.

Metalloids are absorbed by the rice roots along with various ionic transporters and distributed to different plant parts. Their bioavailability (the fraction of an element that is accessible for plant uptake) depends on factors like physical, chemical and biological properties of soil, environmental conditions, and plant's inherent affinity for these elements.

The problem of metalloid accumulation by rice can be managed by different measures which can be classified as: (i) Agronomic practices (soil amendments, nutrient and water management, and tillage practices), (ii) Bioremediation (phytoremediation and microbial remediation) and (iii) Transgenic approaches (gene editing and marker-assisted selection). These measures prevent metalloid intake by humans by immobilizing or reducing their uptake into rice.

Arsenic accumulation in rice can be reduced by application of iron and silicate materials (Matsumoto *et al.,* 2015). The arsenic content in the soil solution, seedlings and mature rice was higher under flooded conditions compared to aerobic rice (Wan *et al.,* 2018).

Shaheen and Rinklebe (2015) reported phytoremediation of metalloids like As, Pb, Hg and Cd by rapeseed, sunflower and Indian mustard and hence these crops can be included in crop rotations. Several species of Azolla like *A. caroliniana* and *A. microphylla* accumulate As and so can be dual-cultured with paddy (Zhang *et al*., 2008).

The gene *OsABCC1* reduced the amount of As in the rice grain by sequestering it into the vacuoles of the phloem companion cells (Song *et al.,* 2014) and *OsHMA3* limited the translocation of Cd from the roots to the above-ground tissues by sequestering Cd into the root vacuoles (Ueno *et al.,* 2010). Genetic engineering can therefore develop crops with reduced metalloid absorption.

Although there are several management practices, the population under potential risk due to metalloid contamination is increasing day by day. In USA, researchers claim that in every 2.5 minutes, a metalloid contaminant is added to the soil. Hence rice scientists should widen their focus while recommending management practices, so that metalloid contamination/bioaccumulation is minimized by reducing their bioavailability.

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