IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

IJARSCT
Impact Factor: 5.731

Volume 12, Issue 4, December 2021

Role of Edaphic Factors in Accumulation and Chemical Speciation of Arsenic in Agricultural Food Produce

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Abstract: *Arsenic (As) is recognized as a toxic element and has been classified as a human carcinogen (group I) causing skin, lungs and bladder cancers. Arsenic contamination is a worldwide problem including several parts of India. While As contamination in drinking water has attracted much attention, plant based foods are also an important source of As. From irrigation water As gets loaded in agricultural soil and eventually accumulates in food grains and vegetables. Arsenic exists in several chemical forms and its accumulation and toxic effect to plant strongly depends on its availability and chemical speciation in soil. The chemical speciation and availability of As in soil is a complex phenomenon impacted by several edaphic and environmental factors. Both organic and inorganic forms of As are present in soil. Arsenate[As(V)]and arsenite [As(III)] are the major soluble inorganic forms of As and are also the most abundant As species. In aerated/aerobic soil As(V) while in anaerobic soil As(III) is the predominant form. Further, the availability of As(III) is generally higher in soil solution than As(V) because the former is relatively more weakly retained in the soil matrix. Organic As i.e. methylated forms of As are also present in small amount. However, depending on soil organic matter, moister and mineral composition they can be in significantly high concentration in some soils. Thus, availability of As in soil is driven by multiple factors, such as rain fall, temperature, pH, CEC, texture, Fe oxides & hydroxides, organic matter, sulfur & phosphorus concentration, soil redox conditions etc. Understanding these factors is important for mitigation of As problem in food through proper soil amendment or by selection appropriate crop.*

Keywords: Arsenic in Crops, Edaphic Factors, Inorganic and Organic Arsenic

I. Introduction

Arsenic (As) is ubiquitously present, considered a nonessential metalloid for plants and animals, and poses serious health hazards to humans. Arsenic hazard has become a global concern due to its severe contamination in many regions of the world, particularly South-East Asia. Bangladesh and West Bengal in India are the two worst As-affected areas in world with reference to level of Arsenic and its severity to local population. The WHO permissible limit of As in drinking water is 10 µg L^{-1} [1], while concentrations exceeding even 3000 µg L^{-1} have been reported from regions of West Bengal (India) and Bangladesh [2,3]. In these regions millions of people are at risk of As poisoning through drinking water and food [4,5]. In India the ground water of 17 states and 3 union territories are As contaminated [3]. From irrigation water As gets loaded in agricultural soil and eventually taken up by the cereal crops and vegetables grown in that soil [6]. While As exposure through drinking water has attracted much attention, plant based foods are also an important source of inorganic As, which is the more deleterious and carcinogenic form of As[7]. Arsenic accumulated in the edible parts of crop plants, such as rice, wheat and vegetables pose serious health hazards to humans. Rice is specifically a problem regarding the entry As into the food chain because it accumulates 10 times more As than other cereal grains. Further, rice is the major staple food for half of the world and it is a major source of inorganic As for population based on rice diet, who are not exposed to highly As contaminated drinking water. However, other staple crops such as wheat also accumulates significant amount of As. Wheat is another most important staple in India, particularly in northern and north western India. Cereal grains, such as rice and wheat contribute to 57-

67% of the energy intake in India, particularly in rural areas [8].Arsenic also affect the productivity and nutritional quality such and minerals and amino acid content, of the cereal grains [9,10,11]. Thus, As contamination pose a threat to the sustainability of food production and food quality.

The accumulation and toxic effect of As to plant strongly depends on As availability and its chemical form[12]. It has been reported that the As build up in soil depends on environmental factors, such as rainfall and temperature. Whereas, the availability of As to plants may strongly depends on edaphic factors such as, soil type, soil pH, total organic matter etc. Further, it was observed that the level of soil organic matter greatly effects As accumulation and it chemical speciation in rice [13]. Norton et al. [14] reported high accumulation of As and with higher percentage of organic As species in soil having high concentrations of organic matter. Therefore, in the following section the common chemical species of As in soil, factors affecting As speciation in soil and accumulation of As and its species in crops and vegetables are discussed.

II. Common Species of Arsenic in Soil

The common As species found in water and soil are inorganic arsenate [$HAsO_4^{2-}$ or As(V)], arsenite [H_2AsO3^- or As(III)] and organic As *viz*., methylarsonic acid [MA(V)] and dimethylarsinic acid [DMA(V)] (Fig. 1). The level of As in ground water used for irrigation in contaminated areas commonly exceed 100 μgL^{-1} leading to As load over 50 $mgKg^{-1}$ in soil [9]. Ground water generally contain inorganic As with 50% of each As(V) and As(III)[15]. In soil also inorganic As(V) and As(III)predominate. Under aerobic conditions As(V) is the major species in soil while under anaerobic conditions As(III) dominates. The methylted As species, MA(V) and DMA(V)are also present in soil, however, in smaller quantity [16,17,18]. However amount of these As species vary greatly in different soils as well as during the crop growing period. For example, during paddy growth the level of As(III) changes from lower than 20% during transplant to more than 80% near the harvesting time [10]. On the other hand the soil fertilized with organic manure contain higher amount of organic As[13] also the soil having past uses of arsenical pesticides and herbicides contain more organic As [19].

III. Factors affecting As Availability and Speciation in Soil

It has been found that up to 96% of the Aspoured out in the soil through irrigation water retain in the top soil[10]. However, total retention of arsenic in soil, its availability to plants and its chemical speciation depends greatly on environmental and edaphic factors.

3.1 Edaphic Factors

Soil properties its chemical and mineral composition, anion adsorption capacity and organic matter play important role in As adsorption, mobility and chemical speciation. Soil properties includes pH, cation exchange capacity, its texture and clay content and redox conditions etc. Arsenate and As(III) are interconvertible depending on pH and redox state of soil. Some elements such as, Fe, S, P and Si are particularly important with respect to As chemistry in soil as well as in plants. Presence of Fe oxides & hydroxides and phosphorous influence the availability of As because AsV gets adsorb on these minerals. Si also play role in release As through exchange of As(III) with $Si(OH)_3$in Si containing mineral. Further high organic matter facilitate methylated As species by enhancing microbial action [14].

3.2 Environmental Factors

Among environmental factors rainfall and temperature have greatest impact on As content and speciation in soil. A significant amount of As loaded through irrigation water may be washed off from the top soil during mansoon flood depending on soil organic matter and other soil properties. Further, it also reduces the need of irrigation, thus As loading into the soil. Temperature also plays role in As built up through evaporation, but also though transformation to volatile As compound by affecting microbial activities. Further, soil warming increases the As availability in the rhizosphere, particularly in rice [20].

IV. Accumulation and Speciation of As in Crops and Vegetables

Crops and vegetable commonly accumulate inorganic As [As(V) and As(III)], however, organic forms particularly DMA(V) has also been detected in significant amounts. Plants take up As(V) through phosphate transporters [21] and As(III)through silicon and other neutral molecules transporting aquaporins [22]. Organic As has also been reported to be transported through aquaporins[23].Among the cereal crops, rice has been found to be most efficient accumulator of As in the grains due to its physiological and agronomic conditions [12,19]. Though wheat also accumulate significant amount of As and make a significant exposure route as major staple in many region [24].The average level of As in rice grain vary from 0.03 to 2.05 mg Kg^{-1} from Bangladesh, 0.11 to 0.46 mg $Kg^{-1}$from The United State and 0.04 to 1.6 mg $Kg^{-1}$from India. The level of As in wheat ranged from 0.49 to 1.15 mg Kg^{-1} from Bangladesh, 0.01-0.234 mg Kg^{-1} from India, 0.02 to 0.365 mg $Kg^{-1}$from China and 0.01- 0.50 mg $Kg^{-1}$from England. The level of As in different vegetables were also found to range from 0.279 to 0.654 $mgKg^{-1}$ from India and 0.1 to 9.8 $mgKg^{-1}$ from Bangladesh. In addition to total As concentration the contribution of different chemical species also vary greatly in these food grains and vegetables as summarized in the Table 1.

V. Conclusion

There is considerable variation in soil As depending on the level of As in irrigation water and to a significant extent to the soil properties and environmental factors. The availability and chemical speciation of As is also governed by these factor to a great extent which ultimately lead to variable plant uptake and accumulation in edible plant parts as well as toxicity to the plants. Thus analysis of edaphic and environmental factors will help the identification of the best soil type suitable for cultivation of suitable crop in As contaminated areas. This will ultimately help to reduce the arsenic exposure to humans.

Acknowledgement

SM is grateful to University Grant Commission, New Delhi for the research grant UGC-Start up grant (F.30-505/2020(BSR)) and SM and SD is grateful to Department of Science and Technology (SEED Division), New Delhi for the project grant SEED/TIASN/2018/74.

References

[1]. World Health Organization (WHO) WHO Guidelines for Drinking-Water Quality. Geneva, Switzerland: WHO; 1993.

[2]. D. Chakraborti, M.M. Rahman, K. Paul, U.K. Chowdhury, M.K. Sengupta, D. Lodh, C.R. Chanda, K.C. Saha, S.C. Mukherjee, "Arsenic calamity in the Indian subcontinent: what lessons have been learned?" Talanta, 58(1), 3-22, 2002.

[3]. S. Mishra, S. Dwivedi, A. Kumar, R. Chauhan, S. Awasthi, J. Mattusch, R.D. Tripathi, "Current status of ground water arsenic contamination in India and recent advancements in removal techniques from drinking water" Int. J. Plant Environ. 2(1 & 2), 01-15, 2016.

[4]. U.K. Chowdhury, B.K. Biswas, T.R. Chowdhury, G. Samanta, B.K. Mandal, G.C. Basu, C.R. Chanda, D. Lodh, K.C. Saha, S.K. Mukherjee, S. Roy, "Groundwater arsenic contamination in Bangladesh and West Bengal, India" Environ. Health Perspect. 108, 393-397, 2000.

[5]. P. L. Smedley & D. G. Kinniburgh, "A review of the source behaviour and distribution of arsenic in natural waters" Appl. Geochem. 17, 517–568, 2002.

[6]. R.D. Tripathi, S. Srivastava, S. Mishra, N. Singh, R. Tuli, D. K. Gupta, F.J. Maathuis, "Arsenic hazards strategies for tolerance and remediation by plants" Trend. biotechnology. 25(4), 158-165, 2007.

[7]. International Agency for Cancer Research (IARC) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*. Some drinking-water disinfectants and contaminants, including arsenic. Vol. 84. Lyon, France, 2004.

[8]. National Sample Survey (NSS), Government of India (2014) NSS Report No.560: Nutritional Intake in India, 2011-12; http://www.indiaenvironmentportal.org.in/files/file/nutritional%20intake%20in%20India%20 2011-12.pdf. 2014.

[9]. H. Brammer & P. Ravenscroft, "Arsenic in groundwater a threat to sustainable agriculture in South and South-east Asia" Environ. Int. 35, 647–654, 2009.

[10]. G.M. Panaullah, T. Alam, M.B. Hossain, R.H. Loeppert, J.G. Lauren, C.A. Meisner, Z.U. Ahmed, J.M. Duxbury, "Arsenic toxicity to rice (Oryza sativa L.) in Bangladesh" Plant soil. 317(1), 31-39, 2009.

[11]. S. Dwivedi, R.D. Tripathi, P. Tripathi, A. Kumar, R. Dave, S. Mishra, R. Singh, D. Sharma, U.N. Rai, D. Chakrabarty, P.K. Trivedi, "Arsenate exposure affects amino acids, mineral nutrient status and antioxidants in rice (Oryza sativa L.) genotypes" Environ.Sci.Technol. 44(24), 9542-9549, 2010.

[12]. S.Mishra, J. Mattusch, R. Wennrich, "Accumulation and transformation of inorganic and organic arsenic in rice and role of thiol-complexation to restrict their translocation to shoot" Sci.Rep. 7(1), 1-13, 2017. (DOI: 10.1038/srep40522)

[13]. Y. Jia, G. X. Sun, H. Huang, Y. G. Zhu, "Biogas slurry application elevated arsenic accumulation in rice plant through increased arsenic release and methylation in paddy soil" Plant Soil. 365, 387–396, 2013.

[14]. G.J. Norton, E.E. Adomako, C.M. Deacon, A.M. Carey, A.H. Price, A.A. Meharg, "Effect of organic matter amendment arsenic amendment and water management regime on rice grain arsenic species" Environ.Poll. 177, 38-47, 2013.

[15]. G. Samanta, T. R. Chowdhury, B. K. Mandal, B. K. Biswas, U. K. Chowdhury, G. K. Basu, , C. R. Chanda D. Lodh, D. Chakraborti, J. Microchem, "Flow injection hydride generation atomic absorption spectrometry for determination of arsenic in water and biological samples from arsenic-affected districts of West Bengal, India, and Bangladesh." Microchem. J. 62(1), 174-191, 1999.

[16]. M.J. Abedin, J. Feldmann, A.A. Meharg, "Uptake kinetics of arsenic species in rice plants" Plant Physiol. 128, 1120-1128, 2002.

[17]. R. Bentley & T. G. Chasteen, "Microbial methylation of metalloids: Arsenic, antimony, and bismuth" Microbiol. Mol. Biol. Rev. 66, 250–271, 2002.

[18]. Y. Jia, H. Huang, G.X. Sun, F. J. Zhao, Y.G. Zhu, "Pathways and relative contributions to arsenic volatilization from rice plants and paddy soil" Environ. Sci. Technol. 46, 8090-8096, 2012.

[19]. F. J. Zhao, S. P. McGrath, A.A. Meharg, "Arsenic as a food-chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies" Ann. Rev. Plant Biol. 61, 535–559, 2010.

[20]. R.B. Neumann, A.L. Seyfferth, J. Teshera□Levye, J. Ellingson, "Soil warming increases arsenic availability in the rice rhizosphere" Agric. Environ. Lett. 2(1), 170006, 2017.

[21]. C. J. Asher & P. F. Reay, "Arsenic uptake by barley seedlings. Aust" J. Plant Physiol. 6, 459-466, 1979

[22]. J.F.Ma, N. Yamaji, N. Mitani, X.Y. Xu, Y.H. Su, S.P. McGrath, F.J. Zhao, "Transporters of arsenite in rice and their role in arsenic accumulation in rice grain" Proc. Nat. Acad. Sci. 105(29), 9931-9935,2008.

[23]. R.Y.Li, Y. Ago, W.J Liu,N. Mitani, J. Feldmann, S.P. McGrath, J.F. Ma, F.J Zhao, "The rice aquaporin Lsi1 mediates uptake of methylated arsenic species" Plant Physiol. 150(4), 2071-2080, 2009.

[24]. S. Suman, P.K. Sharma, A.B. Siddique, M.A. Rahman, R. Kumar, M.M.Rahman, N. Bose, S.K. Singh, A.K. Ghosh, H. Matthews, D. Mondal, "Wheat is an emerging exposure route for arsenic in Bihar, India" Sci. Tot. Environ. 703, 134-774, 2020.

[25]. P.N. Williams, A.H. Price, A. Raab, S.A. Hossain, J. Feldmann, A.A. Meharg, "Variation in arsenic speciation and concentration in paddy rice related to dietary exposure" Environ.Sci. Technol. 39(15), 5531-5540, 2005.

[26]. A. Shrivastava, A. Barla, S. Singh, S. Mandraha, S. Bose, "Arsenic contamination in agricultural soils of Bengal deltaic region of West Bengal and its higher assimilation in monsoon rice" J.Hazard.Mater. 324, 526 -534, 2017.

[27]. H. Hironaka, A. Ahmad, "Arsenic concentration of rice in Bangladesh". In Proceedings of the International Symposium on Fate of Arsenic in the Environment, Dhaka Bangladesh February 2003; FerozeAhmed,M., Ed.; Bangladesh University Engineering Technol, United Nations University: Dhaka, Bangladesh, 123-130, 2003.

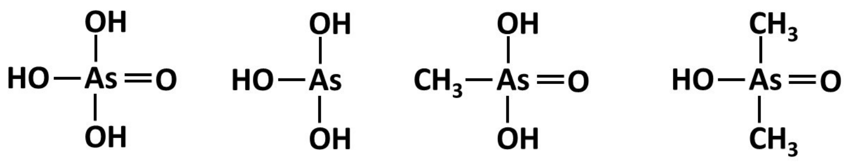
IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Impact Factor: 5.731
Volume 12, Issue 4, December 2021

[28]. Z. M. Xie, C. Y. Huang, “Control of arsenic toxicity in rice plants grown on an arsenic-polluted paddy soil” Commun. Soil Sci. Plant Anal. 29, 2471-2477, 1998.

[29]. P. Bhattacharya, A.C. Samal, J. Majumdar, S.C. Santra, “Arsenic contamination in rice, wheat, pulses, and vegetables: a study in an arsenic affected area of West Bengal, India. Water, Air, Soil Pollut. 213(1), 3-13, 2010.

[30]. J. Laizu, “Speciation of arsenic in vegetables and their correlation with inorganic phosphate level. Bangladesh J.Pharmacol. 2(2), 88-94, 2007.

[31]. B.M. Dahal, M. Fuerhacker, A. Mentler, R.R. Shrestha, W.E. Blum, “Screening of arsenic in irrigation water used for vegetable production in Nepal” Arch.Agron. Soil Sci. 54(1), 41-51, 2008.



Arsenate [As(V)] **Arsenite [As(III)]** **Monomethylarsonic Acid [MMA]** **Dimethylarsinic Acid [DMA]**

Fig.1: Common arsenic species found in ground water and soil. In ground water inorganic As(V) and As(III) are present in almost equal amount while in soil small amount of MMA and DMA are also present along with inorganic As.

Table 1: Level of total arsenic and various species in crops and vegetable.

Crop/vegetable	Country	Total As (mg/Kg)	Inorganic as (mg/Kg)	Organic as (mg/Kg)		Reference
			As(V) +As(III)	MMA	DMA	
Rice	India	0.01 – 1.6	36-67	4-25		25,26
Rice	Bangladesh	0.03 – 2.05	0.19		0.05	27
Rice	China	0.31 – 0.70				28
Rice	Taiwan	0.6 – 0.22	0.12	0.06	0.05	25
Rice	Vietnam	0.03 – 0.47	-	-	-	25
Rice	United States	0.11 – 0.46	0.10	-	0.24	25
Wheat	India	0.09-0.234	-	-	-	24
Wheat	China	0.07 – 0.37	-	-	-	24
Wheat	Pakistan	0.09±0.06-0.317±0.1	-	-	-	24
Wheat	Bangladesh	0.49-1.15	-	-	-	24
Wheat	Europe	0.01-0.5	-	-	-	24
Potato,Arum, Radish, Lady’s finger, Cauliflower, Brinjal	India	0.279-0.654	-	-	-	29
Fruiting vegetables	Bangladesh	0.05 – 9.81	-	0.02 - 4.56	0.00 – 4.41	30
Root and tuber vegetables	Bangladesh	1.01 – 8.41	-	0.10 – 3.62	0.00 – 3.88	30
Leafy vegetables	Bangladesh	0.19 – 3.82	-	0.00 – 2.70	0.00 – 2.31	30
Potato, Onion, Cauliflower, Brinjal	Nepal	0.25 ± 0.01-0.58 ± 0.01	-	-	-	31