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Partitioning of arsenic in low and high arsenic accumulating rice (*Oryza sativa*) cultivars

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ABSTRACT

In view of limited information, an attempt has been made to work out the distribution pattern of arsenic (As) between root and shoot of high and low grain-As accumulating rice cultivars (HAC and LAC, respectively). For this purpose, a solution culture experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* 2018-19 with two doses of As (@ 0 and 100 µg/L) and four rice cultivars comprising one HAC (IR-36) and three LACs (Khitish, Satabdi and Badshabhog). Results indicated that the biomass yields were not affected either by As or by cultivars. The highest root As content was recorded with Khitish (4.64 mg/kg), whereas, IR-36 showed the lowest value (2.00 mg/kg) but shoot As content did not vary with cultivars. Cultivars followed almost similar trends for As uptake. The highest translocation coefficient of As from root to shoot ranged from 0.52 (IR-36) to 0.31 (Khitish). It is clear from the study that LACs are more efficient in storing As in root, even though they uptake higher amount of As at the initial phase of growth, whereas, As is mobilized from root to above ground parts more efficiently in case of HACs. Thus, partitioning of As between root and shoot appears to be an important characteristic of rice (*Oryza sativa* L.) cultivars responsible for differential accumulation of As.

Key words: Arsenic, Rice cultivars, Root, Shoot, Solution culture

Rice (*Oryza sativa* L.) is one of the major staple crops safeguarding the food security of mankind since ages. Besides being the largest exporter, India ranks second both in production and consumption of rice. Presence of arsenic (As) in paddy rice adversely affects human health (Golui *et al.* 2017). Arsenic is classified as a class-I carcinogen and rice has been identified as the second most important source of As (after drinking water) in many countries of South-East Asia (Meharg *et al.* 2008). Among the shortlisted regions, Bengal delta plain (BDP) consisting of Bangladesh and West Bengal has been considered as the hot spot for As contamination (Sanyal 2014). Rice shares highly efficient silicic acid uptake pathways which allow easier entrance of arsenite (AsO_3^{3-}) into the plant, which eventually enters human body *via* food chain (Bhattacharyya *et al.* 2012a; Mandal *et al.* 2019a; Mandal *et al.* 2019b).

Arsenic accumulation in rice differs considerably with the cultivars (Norton *et al.* 2010; Pinson *et al.* 2015). Bhattacharyya *et al.* (2012b) identified few cultivars, *viz.* Gobindabhog, Badshabhog, Satika, Khitish, and Satabdi as As-excluder (low accumulator), whereas IR-36, IR-50 and Red Minikit were efficient accumulators of As. Distribution of As in different plant parts determines the grain accumulation of As to a great extent. There is an indication that translocation of As to grain is generally higher in high yielding varieties (HYVs) compared to that of the traditional ones (Bhattacharya 2010). Such differential translocation of As has been reported from soil culture studies. More precise trend can be ascertained if plants are grown in solution culture as it is extremely difficult to collect and wash root samples when plants are grown particularly in fine textured soils. Incomplete washing of soil debris from root samples often causes gross overestimation of As content in roots owing to the fact that plant contains As in ultra-trace range. In view of scarcity of such information, in the present study, an attempt has been made to assess the partitioning of As in root and shoot of low and high As accumulating rice cultivars grown in solution culture experiment.

MATERIALS AND METHODS

A solution culture experiment was conducted at ICAR-Indian Agricultural Research Institute (IARI), New Delhi during *kharif* 2018-19 to address the objective more

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precisely. The experiment was carried out with four rice cultivars, comprised three dwarf non-aromatic HYVs, *viz.* IR-36, Khitish and Satabdi and one tall indigenous aromatic variety, *i.e.* Badshabhog, which were obtained from Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal. In a preliminary screening done by Bhattacharyya *et al.* (2012b), Badshabhog, Khitish and Satabdi were reported to be low accumulator and IR-36 was reported as efficient accumulator of As in grain. Seeds of different rice cultivars were germinated in germination paper. After seven days, well germinated seedlings with healthy root system and uniform growth were transferred to amber coloured conical flasks containing 300 ml of modified Hoagland solution (Hoagland and Arnon 1950) with two doses of As, viz. 0 and 100 µg/l. Each flask contained two plants.The concentration of As in rooting solution, i.e. 100 µg/l was selected to closely match the intensity of As in soil solution (Fitz *et al.* 2002). Volume of the solution was maintained on regular basis. Plants were transferred to fresh solution after 20 days. After 40 days, plants were harvested, washed, dried, separated into root and shoot, weighed and finally ground for subsequent analysis of As content in it. Processed plant samples were digested in concentrated (65%) suprapure nitric acid (Merck KGaA, Germany) using microwave digester (Multiwave ECO, Anton Paar)(Meena *et al.* 2016). Arsenic content in the processed digest was determined with ICP-MS (PerkinElmer NexION 300).The ICP-MS was calibrated with ICP multi-element standard solution (Merck KGaA, Germany) and standard was run after each batch of 20 samples to check instrument stability. Arsenic uptake by root and shoot of the rice cultivars was calculated by multiplying the As content with dry weight.

The relative As translocation efficiency of different rice cultivars was expressed in terms of transfer factor from solution to root (TF_{sr}) and translocation coefficient from root to shoot (TC_{rs}). The formulae are as follows:

$$TF_{sr} = \frac{\text{As content in root}}{\text{As content in Hoagland solution}} \quad (1)$$

$$TF_{rs} = \frac{\text{As content in shoot}}{\text{As content in root}} \quad (2)$$

RESULTS AND DISCUSSION

On an average, root and shoot biomass ranged from 1.41 to 1.57 and 5.50 to 6.13g/flask, respectively. There was no statistically significant effect of any of the factors, *viz.* cultivar or level of added As in Hoagland solution on root biomass (Table 1). The uniformity in biomass yield among the cultivars, as found in the present study, contradicts the report of Mondal *et al.* (2012), which showed significant difference in straw yield among the three HYVs used in this experiment. This may be explained by the much shorter growing period (40 days) in solution culture as compared to their actual growth period of 110 to 150 days. Gang *et al.* (2018) reported that the As content, as normally observed in plant, is less than 1 mg/kg. In the present study, in spite of rice plants having much higher concentration of As (refer to the next paragraph) compared to that reported in literature for plants grown in uncontaminated soil, it did not show any distinct toxicity symptoms of As or yield loss. It implies that the adverse effect of As on biomass yield or phyto-toxicity symptoms should possibly occur at higher As accumulation in plants compared to that in present study. Majumder *et al.* (2019) reported that both the shoot and root yields of rice cultivars like Swarnadhan, Pusa Basmati, Badshabhog and Tulsibhog substantially reduced to applied As in solution culture, where total As content in root and shoot ranged approximately from 90 to 620 and 60 to 450 mg/kg, respectively. It is important to mention here that they used much higher concentration of As in solution culture, i.e. 25 to 75 µM. For the present study, the concentration of As in solution culture was fixed to 100 µg/l to closely match the intensity of As in soil solution (Fitz *et al.* 2002).

On an average, As content in rice root, under 100 µg/l As in solution, was 6.90 mg/kg (Table 1). The highest root As content was recorded in Khitish (4.64 mg/kg) closely followed by Badshabhog (4.03 mg/kg) and Satabdi (3.28

Table 1 Effect of solution arsenic concentration on biomass and arsenic content in the root and shoot of different rice cultivars

Rice cultivar (C)	Biomass (g/flask)						As content (mg/kg)					
	Root			Shoot			Root			Shoot		
	Concentration of arsenic in the solution (µg/l) (As)		Mean	Concentration of arsenic in the solution (µg/l) (As)		Mean	Concentration of arsenic in the solution (µg/l) (As)		Mean	Concentration of arsenic in the solution (µg/l) (As)		Mean
	0	100		0	100		0	100		0	100	
IR-36	1.70	1.44	1.57	6.31	5.94	6.13	0.05	3.96	2.00	0.03	2.03	1.03
Khitish	1.43	1.57	1.50	5.30	5.69	5.50	0.05	9.22	4.64	0.02	2.86	1.44
Satabdi	1.70	1.45	1.58	6.30	5.61	5.95	0.04	6.48	3.28	0.03	2.69	1.36
Badshabhog	1.32	1.50	1.41	5.61	6.10	5.85	0.09	7.97	4.03	0.03	2.76	1.39
Mean	1.54	1.49		5.87	5.83		0.07	6.90		0.03	2.58	
LSD (P=0.05)	C=NS*, As= NS and C×As= NS			C=NS, As= NS and C×As= NS			C=0.49, As = 0.35 and C×As= 0.70			C= NS, As = 0.25 and C×As= NS		

*NS=Non-significant

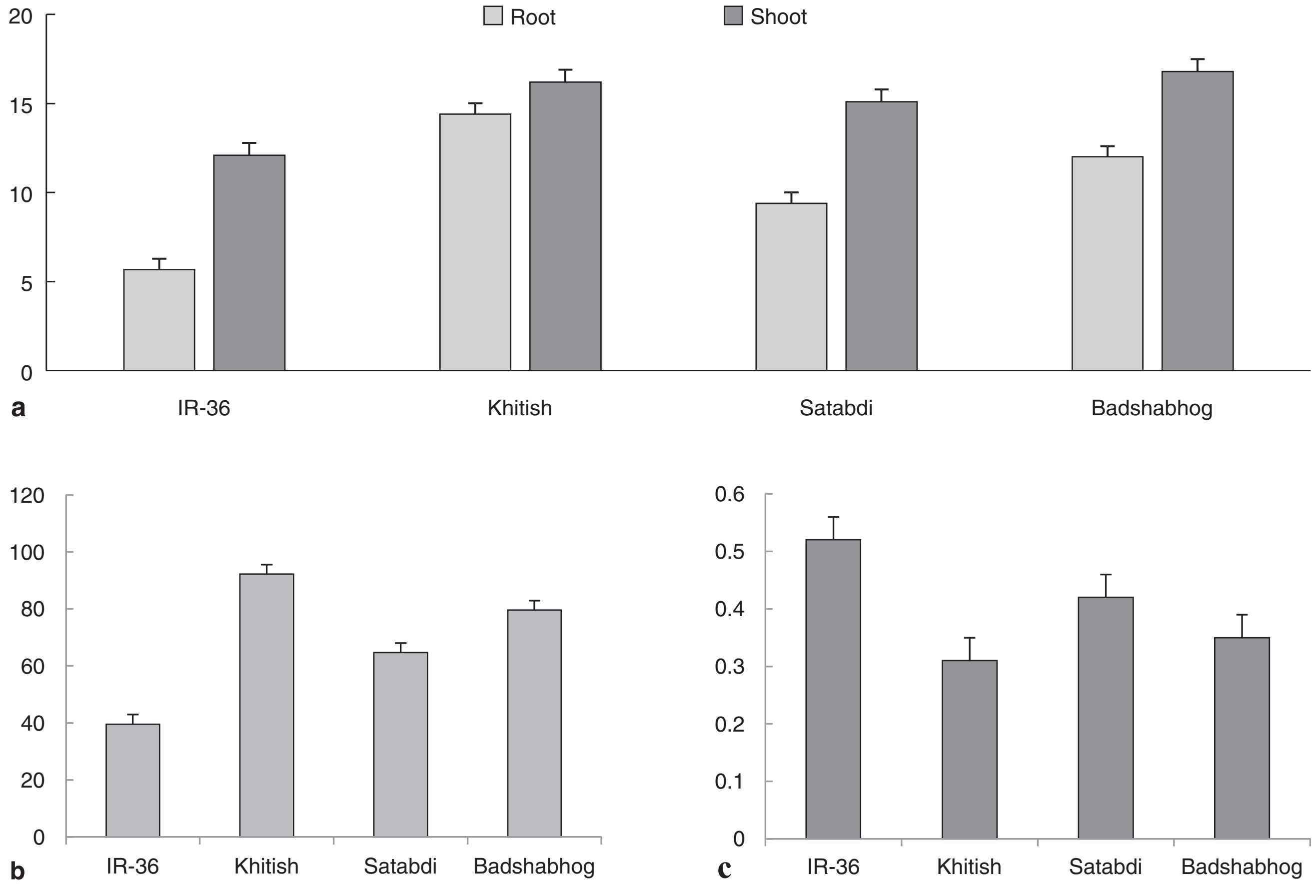

Fig 1 Arsenic uptake (µg/flask) (a) solution to root transfer factor, (b) and root to shoot translocation coefficient and (c) of arsenic in different rice cultivars at 100 µg/L solution As concentration

mg/kg). IR-36 showed the lowest concentration (2.00 mg/kg) of As in its root. On the other hand, mean As contents in shoot were 0.03 and 2.58 mg/kg, where 0 and 100 µg/l As were added, respectively. Shoot As content did not vary significantly among the cultivars.

Previously, Patra *et al.* (2016) also showed that rice cultivars with low grain As accumulation capacity can sequester high concentration of As in their root. Storage of As in root, in fact, is one of the mechanisms by which plants avoid translocation of higher amount of As in grain or other above ground parts (Mitra *et al.* 2017). Generally, shoot As content varies significantly among HYV and local aromatic varieties (Bhattacharyya *et al.* 2012b; Patra *et al.* 2016), but our result did not corroborate to that. This may, again, be ascribed to much shorter growth period of the cultivars in solution culture. As evident from Table 1, traces of As were also detected in root and shoot of different cultivars in solution culture where Hoagland solution is used without As, which may be due to the presence of As in seed material used for this study.

The root As uptake by different cultivars showed almost the same trend as obtained in case of root As content (Fig 1). Khitish (7.26 µg/flask) and Badshabhog (6.03 µg/flask) showed the highest As uptake and both the cultivars were statistically at par, whereas As uptake by Satabdi was lower (4.77 µg/flask) than both of these cultivars. IR-36 showed the lowest uptake of As (2.88 µg/flask) in its root. On the other hand, no significant variation in As uptake by shoot was brought about by the cultivars. Total uptake of As, taking both root and shoot uptake into account, was recorded as 15.4 and 14.5 µg/flask for Khitish and Badshabhog, respectively, which were statistically at par. Satabdi exhibited an As uptake value of 12.4 µg/flask which was lower than both of these varieties. However, the lowest uptake was recorded in case of IR-36 (9 µg/flask).The result of solution to root transfer factor (TF_{sr}) and root to shoot translocation coefficient (TC_{rs}) of As are also presented in Fig 1. The highest TF_{sr} was recorded in Khitish (92.2), followed by Badshabhog (79.6), Satabdi (64.7), whereas IR-36 (39.6) showed the lowest TF_{sr}. TC_{rs} of Badshabhog (0.35) and Khitish (0.31) were statistically similar within themselves and with that of Satabdi (0.42) but significantly lower than that of IR-36 (0.52). Perusal of the values of translocation coefficient indicated that shoot concentration of As was half to one third ofthat of As concentration in root. This clearly shows that substantial share of total As entered into plant accumulated in the root. Several researchers earlier concurred with findings of the present investigation (Abbas *et al.* 2018; Shri *et al.* 2019). Translocation of As from root to shoot and its further distribution among various plant tissues take place through xylem (Kumar *et al.* 2015). Arsenate is reduced to arsenite with the help of arsenate reductase inside the plant after absorption (Abbas *et al.* 2018). Subsequently, As-III forms complexes with thiol rich peptides leading to its detoxification inside plant root (Liu *et al.* 2010).Formation of organo-arsenic complexes and subsequent storage in vacuoles in root cells result in relatively much greater accumulation of As in plant root (Abbas *et al.* 2018). IR-36, being a higher accumulator of As in grain, showed the lowest TF_{sr} and highest TC_{rs}, which indicate that the mechanisms for As sequestration in root are much more weaker in IR-36 than other three low As accumulating cultivars.

From the present study, it can be concluded that As content in root differs substantially in low and high As accumulating rice cultivars. When compared to high As accumulating cultivars, low accumulating ones uptake significantly higher amount of As during the initial phase of growth and sequester it in their roots, whereas high As accumulating cultivars mobilize As from root to above ground parts much easily. Further study is required to understand the reasons for such variation of As partitioning in different rice cultivars.

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REFERENCES

Abbas G, Murtaza B, Bibi I, Shahid M, Niazi N, Khan M, Amjad M and Hussain M. 2018. Arsenic uptake, toxicity, detoxification and speciation in plants: physiological, biochemical and molecular aspects. *International Journal of Environmental Research and Public Health* **15**(1): 1-45.

Bhattacharya P, Samal A C, Majumdar J and Santra S C. 2010. Uptake of arsenic in rice plant varieties cultivated with arsenic rich groundwater. *Environment Asia* **3**(2): 34-7.

Bhattacharyya S, Chatterjee M, Debnath S, Sarkar S and Mukherjee A.2012b. Genetics and physiology of elevated arsenic in grain and straw of rice, pp. 99-110. *Arsenic Contamination in Water and Food Chain: Proceedings of International Workshop on "Arsenic in Food Chain: Cause, Effect and Mitigation"* Guha Mazumder D N and Sarkar S (Eds). DNGM Research Foundation, Kolkata.

Bhattacharyya S, Gupta K, Debnath S, Ghosh U C, Chattopadhyay D and Mukhopadhyay A. 2012a. Arsenic bioaccumulation in rice and edible plants and subsequent transmission through food chain in Bengal basin: a review of the perspectives for environmental health. *Toxicological and Environmental Chemistry* **94**(3): 429-41.

Fitz W J and Wenzel W W. 2002. Arsenic transformations in the soil–rhizosphere plant system: fundamentals and potential application to phytoremediation. *Journal of Biotechnology* **99**(3): 259-78.

Gang L I, Zheng M, Jianfeng T A N G, Hojae S H I M and Chao C A I. 2018. Effect of silicon on arsenic concentration and speciation in different rice tissues. *Pedosphere* **28**(3): 511-20.

Golui D, Mazumder D G, Sanyal S K, Datta S P, Ray P, Patra P K, Sarkar S and Bhattacharya K. 2017. Safe limit of arsenic in soil in relation to dietary exposure of arsenicosis patients from Malda district, West Bengal-A case study. *Ecotoxicology and Environmental Safety* **144**(2017): 227-35.

Hoagland D R and Arnon D I.1950. The water-culture method for growing plants without soil. Circular, California Agricultural Experiment Station, USA.

Kumar S, Dubey R S, Tripathi R D, Chakrabarty D and Trivedi P K. 2015. Omics and biotechnology of arsenic stress and detoxification in plants: current updates and prospective. *Environment International* **74**: 221-30.

Liu W J, Wood B A, Raab A, McGrath S P, Zhao F J and Feldmann J. 2010. Complexation of arsenite with phytochelatins reduces arsenite efflux and translocation from roots to shoots in Arabidopsis. *Plant Physiology* **152**(4): 2211-21.

Majumder B, Das S, Mukhopadhyay S and Biswas A K. 2019. Identification of arsenic-tolerant and arsenic-sensitive rice (*Oryza sativa* L.) cultivars on the basis of arsenic accumulation assisted stress perception, morpho-biochemical responses and alteration in genomic template stability. *Protoplasma* **256**(1): 193-211.

Mandal J, Golui D, Raj A and Ganguly P. 2019a. Risk assessment of arsenic in wheat and maize grown in organic matter amended soils of Indo-Gangetic plain of Bihar, India. *Soil and Sediment Contamination* **28**(8):757-72.

Mandal J, Golui D and Datta S P. 2019b. Assessing equilibria of organo-arsenic complexes and predicting uptake of arsenic by wheat grain from organic matter amended soils. *Chemosphere*. **234**: 419-26.

Meena R, Datta S P, Golui D, Dwivedi B S and Meena M C. 2016. Long-term impact of sewage irrigation on soil properties and assessing risk in relation to transfer of metals to human food chain. *Environmental Science and Pollution Research* **23**(14): 14269-83.

Meharg A A, Lombi E, Williams P N, Scheckel K G, Feldmann J, Raab A and Islam R. 2008. Speciation and localization of arsenic in white and brown rice grains. *Environmental Science and Technology* **42**(4): 1051-7.

Mitra A, Chatterjee S, Moogouei R and Gupta D. 2017. Arsenic accumulation in rice and probable mitigation approaches: a review. *Agronomy* **7**(4): 1-22.

Mondal P, Pal S, Alipatra A, Mandal J and Banerjee H. 2012. Comparative study on growth and yield of promising rice cultivars during wet and dry season. *Plant Archives* **12**(2): 659-62.

Norton G J, Deacon C M, Xiong L, Huang S, Meharg A A and Price A H. 2010. Genetic mapping of the rice ionome in leaves and grain: identification of QTLs for 17 elements including arsenic, cadmium, iron and selenium. *Plant and Soil* **329**(1-2): 139-53.

Patra P K, Sarkar S, Pal S, Roy A and Dhara M C. 2016. 'Screening of low arsenic accumulating rice varieties and hybrids for West Bengal'. Interim progress report, Government of West Bengal.

Pinson S R, Tarpley L, Yan W, Yeater K, Lahner B, Yakubova E and Salt D E. 2015. Worldwide genetic diversity for mineral element concentrations in rice grain. *Crop Science* **55**(1): 294-311.

Sanyal S K. 2014. Arsenic contamination in ground water: an environmental issue. *Journal of Crop and Weed* **10**(2): 1-12.

Shri M, Singh P K, Kidwai M, Gautam N, Dubey S, Verma G and Chakrabarty D. 2019. Recent advances in arsenic metabolism in plants: current status, challenges and highlighted biotechnological intervention to reduce grain arsenic in rice. *Metallomics* **11**(3): 519-32.