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Response of Taro to Arsenic Contamination in the Ganga Basin of Eastern India

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Abstract

Taro (*Colocasia esculenta* [L.] Schott.) is an important tropical tuber crop grown in Eastern and Northern States of India, where both cormels and leaves are eaten as a vegetable. During the past decade, arsenic (As) contamination in food chain has been reported from the Ganga basin of West Bengal and Bangladesh. The epidemiological studies show that chronic As poisoning can cause serious health problems to human beings through contamination of ground water and drinking water. Presence of As in vegetable and tuber crops was found to vary with crops and even among the cultivars of the same crop. Keeping this in view, field experiments were conducted at Nonaghata village of Nadia district during 2007-2008 and 2008-2009 to evaluate the varietal tolerance and accumulation of As in different taro cultivars. The experiment was laid out in Randomized Block Design with eight selected cultivars replicated thrice. The As accumulation was estimated using standard procedures. Results revealed that accumulation of As in different plant parts was in the order of leaf > petiole > cormel, irrespective of cultivars. Regarding varietal tolerance, cultivars, Telia, Muktakeshi and Nadia local accumulated lesser amounts of As in edible parts and produced greater cormel yield.

Key words: Arsenic, taro, cormels, tolerance, cultivar, yield, Ganga basin

Introduction

Taro (*Colocasia esculenta* [L.] Schott.) is one of the important tropical tuber crops grown in several countries. In India the major area under taro cultivation lies in Eastern and Northern States. Both tubers and leaves of taro are eaten as fried and cooked vegetable. Cormels are rich in starch and protein and have higher mineral contents and medicinal values compared to other tuber crops (Swarup, 2006). Under intensive cropping, taro is successfully grown as a remunerative vegetable in the Ganga basin, usually cultivated during summer season. But over the past decade, Arscenic (As) contamination in ground water has been reported from these areas. Arsenic causes serious health hazards to human beings through contamination of ground water and drinking water. Among the inorganic species, As^{III} is considered as the major As species present in natural water system and has higher toxicity than As^{V}, because it binds to particular chemical groups - sulfhydryl groups - found on proteins (Baig et al., 2010). The epidemiological studies show that chronic As poisoning can cause serious health hazards including cancer, hyperkeratosis, restrictive lung disease, peripheral vascular disease, gangrene, diabetes mellitus, hypertension and ischemic heart disease (Guha-Mazumder et al., 2000; Morales et al., 2000). Out of 20 countries in different parts of the world, where ground water As contamination and human suffering have been reported so far, the magnitude is considered to be maximum in Bangladesh followed by West Bengal, India (Sanyal, 2005). The wide spread As contamination in West Bengal, in over 111 blocks primarily in 12 districts, adjoining the river Bhagirathi, as well as contiguous districts of Bangladesh deserves special attention.

The ground water As concentration (50-1600 μg l^{-1}), reported from the affected areas of West Bengal are several orders of magnitude greater than the stipulated Indian standard for the permissible limit in drinking water (50 μg l^{-1}), which is also the maximum acceptable concentration for drinking water in India, Bangladesh and several other countries, as well as WHO guideline value (10 μg l^{-1}) (WHO, 1993; CGWB, 1999; Ghosh et al., 2004). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) set a provisional maximum tolerable daily intake (PMIDI) of inorganic As as 2 μg kg^{-1} of body weight for humans in 1983 and confirmed a provisional tolerable weekly intake (PTWI) as 15 μg kg^{-1} of body weight in 1988 (FAO/WHO, 1989). Such guideline value for soil, plant and animal systems are not available (Sanyal and Nasar, 2002; Ghosh et al., 2004). The source of As in water is geogenic and the problem seems to be triggered off by large-scale withdrawal of groundwater for agricultural irrigation during the lean period when the groundwater recharge is at its minimum (Mandal et al., 1996; Sanyal, 2005).

Increased As levels in irrigated soils in West Bengal is well documented by Sanyal and Nasar (2002). Uptake of As by crop plants grown in soils contaminated with high concentrations of As and irrigated with As contaminated water has been reported by Abedin et al. (2002). Arsenic finds its way into the food web other than drinking water, apart from the possible biomagnifications of the food chain. Studies have shown that the contribution of As pollution to human health through food chain is many times greater than that of drinking water (Roychowdhury et al., 2003; Díaz et al., 2004). Hence, immediate attention needs to be given to explore the accumulation of As in plants. Presence of As in vegetables and tubers crops and its translocation to the edible parts were observed to vary with crops (Alam et al., 2003) and even among the cultivars of the same crop (Kundu and Pal, 2010). In this context, a thorough understanding of As-plant-soil interaction is necessary in order to examine As uptake by plants grown in soils contaminated with high concentration of As and irrigated with As contaminated water as well as the entry of As in food chain. In West Bengal, rice-based cropping system is the predominant cropping system. Arsenic contamination in rainy season rice is not much of a problem due to its rainfed cultivation. But winter and summer crops are mainly cultivated through irrigation using ground water by shallow tube-well which in turn creates lot of problems with regard to As uptake. With this background information, the present study was undertaken to evaluate the varietal tolerance of taro to As and relative pattern of As accumulation by selected cultivars of taro in farmers' field.

Materials and Methods

Study site

The experiment was conducted in farmers' fields in alluvial soil at Nonaghata village (latitude 22°57'N, longitude 88°33'E and altitude 7.8 m above mean sea level), Haringhata block, Nadia district, West Bengal, India during summer seasons of 2007-2008 and 2008-2009. The experimental site has subtropical humid climate with an average rainfall ranging between 1200 to 2500 mm and mean minimum and maximum temperatures of 12 and 40°C, respectively. Many wells contaminated with As have been used as irrigation source in this zone.

Experimental design

The experimental soil is silty clay loam in texture with the following chemical properties: pH:7.52, EC:0.21 ds m^{-1}, organic C: 0.47%, available N:187 kg ha^{-1}, available P: 39 kg ha^{-1} and available K: 141 kg ha^{-1}, respectively (Jackson, 1967). Arsenic content in the irrigation water and soil of the experimental site was 0.110 and 0.129 mg l^{-1}; 9.08 and 9.24 mg kg^{-1} during the first and second years, respectively. The experiment was laid out in Randomized Block Design with eight selected taro cultivars *viz.* Satamukhi, Gadamoni, Kadma, Muktakeshi, Jhankhri, Telia, Nadia local and Bankura local, replicated thrice. The experiment was conducted for two consecutive years (2007-2008 and 2008-2009) in the same land without changing the experimental layout.

Taro was planted in mid April at a spacing of 60 x 45 cm with the recommended dose of fertilizers NPK @ 80: 60: 60 kg ha^{-1}. Half N, half K and full dose of P were applied at the time of final land preparation and the rest half N and K was top dressed at the time of earthing up after two months of planting. The sources of NPK were urea, single super phosphate and muriate of potash.

Irrigation was given immediately after planting taro and subsequent irrigations were given at ten days interval and the source of irrigation was As contaminated shallow tube-well (STW) water.

Plant sample collection

The plant samples were taken from the experimental field at different crop growth periods viz. 2 months (early period), 4 months (mid-growth period) and at harvest 6-7 months (maturity). The plant samples were first washed with pure water to remove the soil particles attached to the plant body and then with ultrapure de-ionized water. The cormels, pseudostem (petioles) and leaves were collected separately and cut into small pieces, oven dried and then ground and kept in sample containers for further analysis.

Arsenic concentration determination

The ground plant samples were weighed to one gram and digested with tri acid mixture (HNO_3: H_2SO_4: $HClO_4$: 10:1:4, v/v) until a clear solution was obtained. The digest was filtered by using Whatman No. 42 filter paper. From the filtrate, 10 ml was taken in a 50 ml volumetric flask and 5 ml concentrated HCl and 1 ml of mixed reagent containing 5% KI (w/v) and 5% ascorbic acid (w/v) were added and kept for 45 min to ensure complete reaction and then the volume was made up to 50 ml. The total As content in the solution was determined by atomic absorption spectrophotometer (AAS), Perkin Elmer (Analyst 200) coupled with flow injection analysis system (FIAS 400) where the carrier solution was 10% v/v HCl, following Olsen method as described by McLaren et al. (1998) using standard solutions of 2.5, 5, 10, and 20 mg l^{-1} As for calibration.

Statistical analysis

Statistical analysis of the data was done using analysis of variance method (Gomez and Gomez, 1976). The significance of different sources of variation was tested by error mean square with the help of Fisher's 'F' test at probability level of 0.05. For comparison of 'F' value and computation of critical difference (CD) at 5% level of significance, Fisher and Yates table was used.

Results and Discussion

Arsenic accumulation pattern

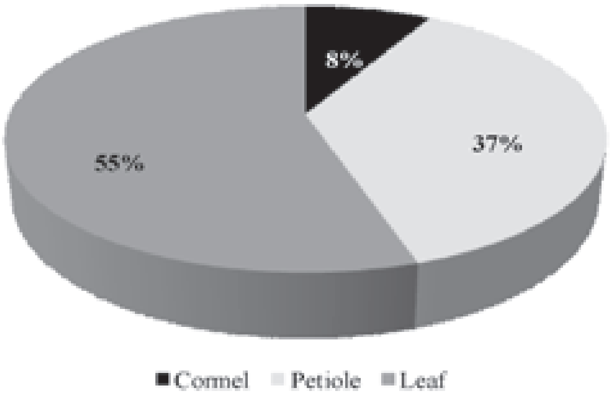

Fig. 1. Arsenic accumulation pattern of taro (average value of cultivars)

Arsenic accumulation pattern of taro plants (Fig. 1) revealed that the maximum accumulation was observed in the leaves (55%) as compared to other plant parts. The petiole contained less As (37%) whereas, cormels accumulated the least concentration (8%).

Arsenic accumulation at early crop growth period

At the early crop growth period of taro (2 months after planting), As accumulation in the different plant parts varied significantly among the cultivars tested (Table 1). It was found that the As accumulation in the different plant parts was in the order of leaf > petiole > cormel, irrespective of the cultivars tested. The maximum As accumulation in cormels was observed in the cultivar, Satamukhi (0.405 mg kg^{-1}), which was on par with the cultivar Gadamoni (0.392 mg kg^{-1}), whereas least As content in the cormels was observed in the cultivar, Telia (0.067 mg kg^{-1}) followed by Muktakeshi (0.085 mg kg^{-1}). The cultivar Gadamoni (1.711 mg kg^{-1}) accumulated maximum As in the petiole. Among the cultivars tested, Nadia local contained the minimum amount (0.529 mg kg^{-1}) of As in the petiole, which was significantly different from Muktakeshi (0.687 mg kg^{-1}) and Bankura local (0.713 mg kg^{-1}). The leaves of the cultivars, Jhankhri, Gadamoni and Satamukhi had As content to the tune of 2.349, 2.114 and 2.058 mg kg^{-1}, respectively which was significantly the highest among all the cultivars. The minimum amount of As accumulation in the leaves was noted in the cultivar, Telia (1.126 mg kg^{-1}) and it was on par with the cultivars, Nadia local and Bankura local (1.385 and 1.429 mg kg^{-1} respectively).

Arsenic accumulation at mid-growth period

At the mid-growth period of taro (4 months after planting), the degree of As accumulation in the different plant parts was also in the order of leaf > petiole > cormel (Table 1). Arsenic accumulation by taro cormels at this period showed similar trends as that in the early growth period. Maximum As concentration in petiole was seen in the cultivar, Gadamoni (2.116 mg kg^{-1}), which was statistically on par with the cultivars, Satamukhi and Jhankhri (2.014 and 1.825 mg kg^{-1}, respectively). Among all the cultivars tested, Muktakeshi (0.985 mg kg^{-1}) had the least amount of As in its petiole followed by the cultivars, Nadia local (1.126 mg kg^{-1}) and Kadma (1.238 mg kg^{-1}). In the case of taro leaves, significantly higher amount of As was noted in Gadamoni, Satamukhi and Jhankhri (2.952, 2.841 and 2.713 mg kg^{-1} respectively). The content of As was least in the cultivar, Telia (1.755 mg kg^{-1}) followed by the cultivars, Kadma, Muktakeshi and Nadia local.

Arsenic accumulation at maturity

At maturity of taro (6-7 months days after planting), the degree of As accumulation in the different plant parts was still in the same order as in the earlier periods and differed significantly among the cultivars (Table 1). The cultivar, Satamukhi accumulated the maximum amount of As in its cormels (0.744 mg kg^{-1}) and it was on par with the cultivar, Gadamoni (0.667 mg kg^{-1}). Cultivar Muktakeshi (0.270 mg kg^{-1}) had the least As in its cormels, followed by the cultivars, Telia and Kadma (0.279 and 0.329 mg kg^{-1} respectively). At maturity of taro also, As loading in aerial parts i.e., petioles and leaves followed the same trend as in the earlier periods.

Comparison of As accumulation in cormels

Comparison of As accumulation in the cormels during the crop growth period among the cultivars is clearly depicted in Fig. 2. It

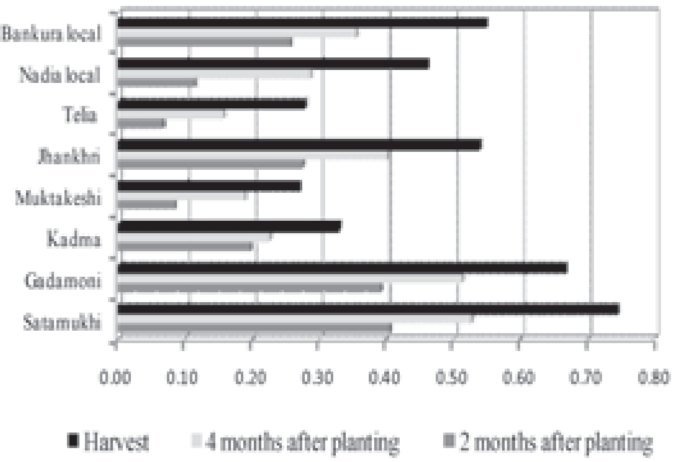

Fig. 2. Arsenic accumulation (mg kg^{-1}) in fresh taro cormels at different growth periods

Table 1. Arsenic accumulation (mg kg^{-1}) in the different plant parts of taro cultivars at different growth periods and cormel yield (kg per plant) at harvest (mean of 2 years data)

Cultivar	Crop growth period									Yield (kg per plant)
	2 months after planting			4 months after planting			6-7 months after planting (at harvest)			
	Cormel	Petiole	Leaf	Cormel	Petiole	Leaf	Cormel	Petiole	Leaf	
Satamukhi	0.405	1.362	2.058	0.527	2.014	2.841	0.744	2.695	3.529	0.726
Gadamoni	0.392	1.711	2.114	0.513	2.116	2.952	0.667	2.845	3.841	0.783
Kadma	0.198	0.927	1.558	0.226	1.238	1.857	0.329	1.764	2.530	0.796
Muktakeshi	0.085	0.687	1.470	0.189	0.985	2.030	0.270	1.334	2.597	0.926
Jhankhri	0.276	1.352	2.349	0.402	1.825	2.713	0.539	2.496	3.457	0.751
Telia	0.067	0.901	1.126	0.158	1.742	1.755	0.279	1.952	2.428	0.931
Nadia local	0.115	0.529	1.385	0.287	1.126	2.159	0.461	1.682	2.634	0.895
Bankura local	0.257	0.713	1.429	0.355	1.359	2.215	0.548	2.026	2.915	0.817
C.D. (0.05)	0.046	0.272	0.337	0.062	0.362	0.440	0.098	0.422	0.519	0.085

Arsenic content in the irrigation water and soil of the experimental site was 0.110 and 0.129 mg l^{-1}; 9.08 and 9.24 mg kg^{-1} in the 1st and 2nd year respectively is seen that the accumulation of As increased continuously during the crop growth period as early growth period < mid growth period < maturity, irrespective of the cultivars tested. Some cultivars like Satamukhi, Gadamoni, Jhankhri and Bankura local accumulated more As at their early growth period and accumulation continuously increased throughout the growing period. On the other hand, the cultivars, Kadma, Muktakeshi and Telia accumulated relatively lower As at the initial growth period and remained almost static during the 4th month, but it increased towards the termination of crop growth. The cultivar Nadia local accumulated very little amount of As during the early growth period, but it increased towards the later growth periods.

Yield

Cormel yield per plant of taro recorded at the time of harvest at 6-7 months after planting differed significantly among the different cultivars (Table 1). Among the cultivars, Telia produced the maximum cormel yield (0.931 kg per plant) on par with the cultivars, Muktakeshi (0.926 kg per plant) and Nadia local (0.895 kg per plant). On the other hand, cormel yield was poor in the cultivars, Satamukhi (0.726 kg per plant), Jhankhri (0.751 kg per plant), Gadamoni (0.783 kg per plant) and Kadma (0.796 kg per plant).

The above field experiment clearly revealed that the different cultivars of taro accumulated different concentrations of As in the various parts and the trend of As accumulation was also different among the cultivars. It may be due to the difference in varietal response to As accumulation. It is seen that As accumulation in taro increased continuously throughout the crop growth period. It may be due to the application of As contaminated irrigation water. The cultivars Muktakeshi and Telia contained the least amount of As in their cormels. These cultivars had maximum yielding capacity among all the tested cultivars, whereas, the cultivar Nadia local had moderate amount of As content in its cormels with a greater cormel yield. On the other hand, the cultivars Satamukhi and Gadamoni had greater recovery of As with lower yielding capacity. The cultivar Kadma accumulated minimum amount of As and also produced relatively lower cormel yield. Hence, it can be inferred that yield of taro was not affected by the level of As concentration in the environment but the cormel and aerial parts accumulated greater As. While selecting cultivars for As affected soils, preference should be given for those cultivars having higher productivity with least accumulation of As in its edible parts.

Conclusion

In Eastern India, particularly in West Bengal, where taro, a common tuberous vegetable, is grown irrigated with groundwater contaminated with As, it is necessary to develop an appropriate agricultural management practice to minimize As content in the edible plant parts. Arsenic accumulation in taro cormel is relatively lower than the other plant parts. But since the leaves are also used as a leafy vegetable, there is need to minimize the As accumulation in taro leaves through appropriate management strategy and this warrants further study in this direction.

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