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A Novel Method to Improve Health Risk Assessment Using Bio-accessible Arsenic in Rice Grain Grown in Contaminated Soils

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ABSTRACT

The experiment was conducted during *kharif* (June to September) of 2020 at the net house facility in Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi, India which evaluated the efficacy of organic amendments, specifically sugarcane bagasse, and vermicompost, in mitigating soil As contamination and reducing its uptake by rice crop. Furthermore, the human health risk assessment protocol was refined and improved to prevent its over-estimation using bio-accessible grain As content. Sugarcane bagasse enhanced SOC and reduced Olsen-As compared to vermicompost. The rice grain As content, although below the Codex safe limit of 0.2 mg kg^{-1}, varied proportionally with soil Olsen-As. The bioaccessibility of As in rice grains, determined using in-vitro gastrointestinal method, ranged from 67% to 69% of the total grain As. Health risk assessments using bio-accessible As highlighted non-cancer risks (HQ>1) for both adults and children, suggesting a potential health concern upon continued rice consumption grown in these soils. Despite this, the severity-adjusted margin of exposure (SAMOE) values categorized cancer risk as low. Among both the amendments, sugarcane bagasse demonstrated superior efficacy in reducing soil and plant As levels. The findings underscore the potential of organic amendments, particularly sugarcane bagasse, in improving soil quality and reducing As bioavailability. Using bioaccessible As content instead of total rice grain As content can essentially improve the accuracy and reliability of health risk assessments.

KEYWORDS: Bio-accessibility, health risk, *in-vitro* gastrointestinal

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1. INTRODUCTION

Soil arsenic (As) pollution poses a significant threat to agriculture and food security (Kumar et al., 2021; Raza et al., 2023; Mishra et al., 2024). The need for remediation is urgent to ensure safe food production (Golui et al., 2023). Cost-effective organic amendments offer sustainable solutions by reducing arsenic bioavailability in soils and improving soil health (Khanam et al., 2024). Eco-friendly approaches can help mitigate the impact of As pollution while supporting sustainable farming practices.

Understanding the chemistry of As interactions with various soil properties is essential for developing effective strategies to minimize its uptake by crops (Sinha and Bhattacharyya, 2017; Raza et al., 2025). Researchers are exploring the potential of organic waste materials and their derived products as cost-effective amendments to address arsenic contamination in soils. In India, several organic materials, such as rice husk, rice straw (Mandal et al., 2019a), sugarcane bagasse (SB) (Mandal et al., 2019a), vermicompost (Pan et al., 2022), compost (Arco-Lázaro et al., 2016), farmyard manure (FYM) (Majumder et al., 2021), and mustard cake (Sinha et al., 2011), have demonstrated promise in reducing arsenic mobility and its transfer to plants. Sugarcane bagasse has shown superior performance in decreasing As accumulation in crops like wheat and maize compared to rice husk, rice straw, and vermicompost (Mandal et al., 2019a, b). Recent studies have highlighted the efficacy of amendments like FYM, cow dung, biogas slurry, and SB in enhancing rice yield while significantly reducing grain arsenic concentrations (Hussain et al., 2021). These findings emphasize the importance of utilizing locally available resources to mitigate arsenic risks sustainably while improving crop productivity.

Bio-accessibility refers to the fraction of a substance, such as a nutrient or contaminant that is released in the gastrointestinal (GI) tract for absorption during digestion, assimilation, and pre-systemic metabolism. It accounts for both absorbed and unabsorbed portions of a substance, with in-vitro digestion models replicating gastric and intestinal conditions (Courraud et al., 2013). Bioavailability, on the other hand, measures the amount of a substance that enters the bloodstream post-GI digestion and is available for biological activity. However, due to ethical and practical challenges, assessing bioavailability directly in humans is complex. Importantly, bioavailability always represents a fraction equal to or less than bio-accessibility (Ruby et al., 1996). Moreover, *in-vitro* methods cannot fully replicate the physiological or metabolic endpoints associated with bioavailability. There remains a significant knowledge gap in understanding the health effects of dietary As intake and the fraction of As in food that is bio-accessible. Presently, total inorganic As (i-As) content is considered by CODEX for fixing the permissible limit for rice grains. For polished rice, the recommended limit is 0.2 mg kg^{-1}, and for husked rice, it is 0.35 mg kg^{-1} (Mandal et al., 2021). However, these thresholds may overestimate the health risks associated with As in rice, as they do not account for bio-accessibility. He and Zheng (2010) using *in-vivo* mass balance methods showed that approximately two-thirds of ingested As from rice is excreted through urine within 24 hours, indicating that a significant portion of dietary As does not contribute to systemic toxicity. This underscores the importance of bio-accessibility studies, which can refine our understanding of how much As is assimilated in the human GI tract. By integrating bio-accessibility data into health risk assessments, we can develop more accurate and reliable health risk assessment protocols.

Under this background, the present investigation has been carried out with the following objectives: 1) study the effect of the application of different organic amendments on arsenic uptake by rice plant grown in As contaminated soils; 2) improve the health risk assessment by using a bio-accessible fraction of cooked white rice assessed through *in vitro*-gastrointestinal method.

2. MATERIALS AND METHODS

A pot experiment was conducted during the *kharif* season (June to September) of 2020 at Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi, India with rice (IR-36 variety) as a test crop to assess the effect of organic amendments on bioaccessible arsenic in grain and its uptake by rice grown in arsenic-contaminated soils. For this purpose, two bulk surface soil samples (0–15 cm) were collected from farmer's fields located at Ranaghata (soil-1) and Arbetai (soil-2), West Bengal, India. Soil samples were processed and analysed for various properties (Table 1). Soil texture was determined according to the texture triangle proposed by USDA (Brady and Weil, 2002). The pH and electrical conductivity (EC) were determined in the 1:2 soil water suspension (Datta et al., 1997) and its supernatant (Jackson, 1974), respectively. Soil organic carbon content was determined by the wet oxidation method (Walkley and Black, 1934). The Olsen extractable (0.5 *M* $NaHCO_3$ (pH 8.5)) As was analysed using ICP-MS (Olsen, 1954). Total soil As after soil digestion with aqua regia (Quevauviller, 1998) was determined using ICP-MS (Model: Nexlon 300, Make: Perkin Elmer, USA).

Two organic amendments, viz. vermicompost and sugarcane bagasse were employed in the study. Vermicompost was purchased from the Biomass Production Unit, IARI, New Delhi. Sugarcane bagasse was collected from a local sugar mill located at Ghaziabad sugarcane farms. Bagasse was

Table 1: Initial characteristics of soils collected from arsenic-contaminated areas of West Bengal for pot culture study

Soil	Soil-1	Soil-2
Location	Ranaghata	Arbetai
Soil order	Inceptisol	Entisol
pH	7.02	6.45
Electrical Conductivity (dS m^{-1})	0.71	0.78
Texture	Clay loam	Clay loam
Sand %	43.3	40.3
Silt %	25.0	27.2
Clay %	31.7	32.5
Walkley-Black organic carbon (g kg^{-1})	10.0	11.1
Cation exchange capacity (cmol (+) kg^{-1})	16.8	18.6
Olsen extractable As (mg kg^{-1})	0.31	0.30
Total As (mg kg^{-1})	9.16	6.80

air dried and later oven dried at 60±5°C until attaining constant weight. It was ground and kept in an air-tight polypropylene box. The total elemental composition of both the amendments used in the study is presented in Table 2.

Table 2: Initial characteristics of various organic amendments

Soil	Vermicompost	Sugarcane bagasse
C (g kg^{-1})	212	392
N (g kg^{-1})	15.0	31.0
P (g kg^{-1})	8.00	18.0
K (g kg^{-1})	10.0	5.00

2.1. Pot culture study

Pots were filled with 4 kg soil and treated with organic amendments, viz. vermicompost @ 5 g kg^{-1} and sugarcane bagasse @ 5 g kg^{-1}. Nitrogen (N), phosphorus (P_2O_5) as well as potash (K_2O) were applied equivalent to 150% of the recommended dose of NPK for rice using Urea, di-ammonium phosphate (DAP) and muriate of potash (MOP). All the fertilizers were applied in solution form and mixed thoroughly except nitrogen which was added in three splits i.e. 1/3rd each at sowing, 25 and 50 DAS. Pre-germinated seeds were sown in the pots and a uniform plant stand of 5 plants pot^{-1} was maintained. Plants were irrigated with distilled water to maintain anaerobic conditions. Rice was harvested at maturity. Dried plants were ground and used for subsequent chemical analysis. The grains were kept in a moisture-proof polypropylene box for further analysis and bio-accessibility study.

After harvesting, soil samples were used for the determination of various physical and chemical soil properties to assess the effect of different amendments on soil. The soils were analysed for pH, EC, SOC and Olsen-As content following standard protocols. A 0.5 g powdered rice plant sample (straw, grain, root) was weighed and put in digestion tubes. To this, 7 ml of suprapure conc. HNO_3 (Merck KGaA, 64271 Darmstadt, Germany) was added and kept overnight for pre-digestion. The tubes were put in a microwave digester and the plant sample digestion was carried out. The digested solution was transferred to 50 ml volumetric flask and the volume was made up using Milli-Q water. The extract was stored at cool temperatures until further analysis for As using ICP-MS.

2.2. Bio-accessibility of arsenic from rice grain

The bio-accessibility of As from rice grain was assessed in cooked rice. The cooking protocol for harvested grain samples was standardized in laboratory conditions. One gram of white rice was taken in a 50 ml beaker. To this, 20 mL of Milli-Q water was added and kept over a hot plate cum magnetic stirrer whose temperature was kept at 200°C. The rice grains were cooked for 45 minutes until no water was left in the beaker. The cooked rice was cooled and crushed using a glass rod.

2.2.1. Preparation of artificial gastrointestinal solutions in the laboratory

The gastrointestinal (GI) solutions were a combination of three-phase artificial solution mixture of saliva, gastric juice, and intestinal juice (Horner and Beauchemin, 2013). Artificial saliva was prepared with 6.8 g of KH_2PO_4 and 77 mL of 0.2 *M* NaOH, adjusting pH to 6.5 using 0.2 *M* NaOH and diluting to 1 l using Milli-Q water. Gastric juice was prepared by mixing 2.0 g of NaCl, 3.2 g of pepsin, and 7.0 ml of sub-boiled HCl and diluting to 1 L using Milli-Q water. Intestinal fluid was prepared by mixing 6.8 g of KH_2PO_4, 10 g of pancreatin, and 77 ml of 0.2 *M* NaOH and diluted to 1 l using Milli-Q water with final pH adjusted to 6.8.

2.2.2. Bio-accessibility study

The detailed protocol of batch method of *in vitro*-gastrointestinal method (Horner and Beauchemin, 2013) of assessing bio-accessibility of As from rice grain is presented in Figure 1. The rice grain residue was oven-dried and digested in a microwave digester by adding 7 ml of concentrated HNO_3. The solution was then diluted to 25 ml before analysis by ICP-MS. Total digestions of 1 g rice were also carried out to analyse the actual total As in grains using the same procedure.

2.2.3. Mass balance

Bioaccessible fraction+As remaining in the residue=total concentration of As in the rice grain sample.

Bioaccessible As (%)=(Bioaccessible As/Total grain As (actual))×100

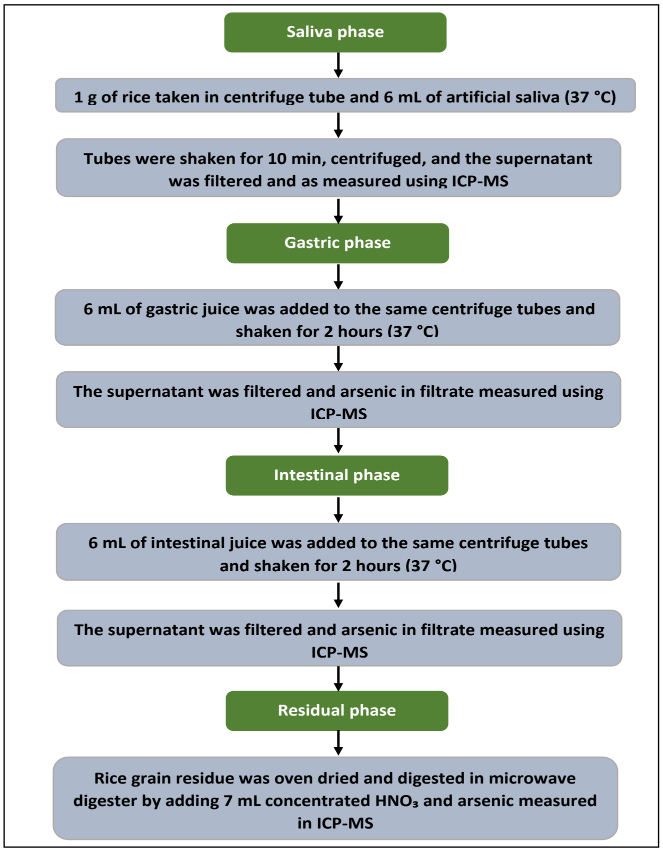

Figure 1: Detailed protocol of sequential batch *in vitro*-gastrointestinal method

2.3. *Modification of health risk assessment protocol*

2.3.1. *Non-cancer risk assessment*

The hazard quotient (HQ) is the deterministic means for assessing the chronic non-carcinogenic hazard associated with As (Eq. 1):

HQ=ADD/RfD ....(1)

This is a relationship between the average daily dose (ADD; mg kg^{-1} d^{-1}) of arsenic by a population and the toxicological endpoint (reference dose (RfD) mg kg^{-1} d^{-1}) which is an estimate of the limit of daily exposure to the population (including sensitive subpopulations) where there are no deleterious lifetime health effects. For arsenic, the RfD value is 0.0003 mg arsenic (kg body weight)$^{-1}$ day^{-1} (Anonymous, 1996). In this study, HQ has been modified (*Mod.* HQ) by integrating bio-accessible As concentration for computing ADD via oral intake (Eq. 2).

$ADD=\sum_{i=1}^{N}(C_i \times CR_i)/(BW)$ ....(2)

Where, N is the number of exposure routes to arsenic, C_i is the concentration of bio-accessible As (mg kg^{-1}) in i^{th} route, CR_i is the consumption rate (kg day^{-1}) of the subscripted ingested material.

2.3.2. *SAMOE (Severity adjusted margin of exposure)*

The human dietary exposure of As through rice consumption is calculated using the following equation (Sengupta et al., 2021).

$SAMOE=TDI/(AF_{BMR} \times AF \times SF \times E)$ ....(3)

where, TDI=3.0 μg kg^{-1} bodyweight^{-1} day^{-1} value for As, AF_{BMR}=Non-linear relation in dose range (1/10; BMR–Benchmark response), AF (Assessment factors)=a factor of 10 (conservative assessment), SF (Severity factor)=100 (For cancer, the most severe category) and E=Different exposure factor (here, bio-accessible As concentration).

Based on the SAMOE value, the classes of risk in the risk thermometer are prescribed, as, class 1 (no risk, >10); class 2 (no to low risk, 1–10); class 3 (low risk, 0.1–1); class 4 (moderate to high risk, 0.01–0.1) and class 5 (high risk, <0.01) (Sand et al., 2015).

3. RESULTS AND DISCUSSION

3.1. *Effect of various amendments on physico-chemical properties of post-harvest soils*

Application of organic amendments viz. sugarcane bagasse and vermicompost had variable impacts on the pH of different soils. The application of organic amendments increased soil pH in the acidic soil (soil-2; pH of untreated soil is 6.79), while decreasing the pH of near-neutral pH soils (soil-1; pH of untreated soil is 7.07) (Table 3). The increase in pH of acid soil may be ascribed to the buffering capacity of organic matter. The addition of organic manure to acid soils can induce higher soil pH values in soil due to H^+ ion adsorption (Hue and Licudine, 1999). Contrarily, the decrease in pH of circum-neutral soil due to organic matter application can be attributed to the release of organic acids (Choudhary et al., 2023). The mineralization of the organic form of N and S could also produce H^+ ions decreasing the soil pH (Eid et al., 2020). Electrical conductivity (EC) is an important property of soil that has a significant influence on plant growth. In our study, the EC of soils was not significantly influenced as a result of organic amendments application. The Walkley-Black soil organic carbon (SOC) was positively influenced by the external application of organic amendments, which was quite natural. At the same rate of application of both the organic amendments, the increase in SOC across both soils due to sugarcane bagasse application varied between ~15–17% compared to the control, while the percent increase of SOC varied between ~9–14.7% (compared to control) with vermicompost application. The proportion of increase of SOC was visibly high in both soils due to the application of organic amendments (Table 3), which could be attributed to the high clay content in these soils (Choudhary et al., 2023).

Table 3: Effect of amendments on physico-chemical properties of post-harvest soil of rice grown in arsenic-contaminated soils

Treatments	pH	EC** (dS m^{-1})	SOC* (g kg^{-1})	Olsen extractable As (mg kg^{-1})
Soil-1				
Control	7.07± 0.04[a]	0.68± 0.02[a]	9.60± 0.08[b]	0.31± 0.02[a]
Vermi-compost	6.92± 0.03[b]	0.73± 0.02[a]	10.5± 0.19[ab]	0.20± 0.01[b]
Sugarcane bagasse	6.98± 0.03[b]	0.71± 0.08[a]	11.1± 0.78[a]	0.18± 0.02[b]
Soil-2				
Control	6.79± 0.11[a]	0.61± 0.06[a]	10.2± 0.37[b]	0.28± 0.03[a]
Vermi-compost	7.04± 0.07[b]	0.60± 0.05[a]	11.7± 0.08[a]	0.30± 0.01[a]
Sugarcane bagasse	7.02± 0.03[b]	0.63± 0.01[a]	12.0± 0.15[a]	0.25± 0.02[a]

*Soil organic carbon; **Electrical conductivity; Different letters in superscript indicate significant differences in mean values, while same letters indicate at par values at $p<0.05$

The effect of each amendment varied with different soil types as far as extractable As content is concerned. Overall, the amendments had a notable effect in reducing the Olsen-As content in soil-1 compared to unamended soils. However, no notable effect of amendments was recorded in soil-2. Organic matter has a variable impact on As mobility in soil. Arsenic may form soluble or insoluble organo-arsenic complexes affecting its bioavailability. In environments with elevated pH levels, where the general notion suggests that As repulsion should logically lead to an increase in As availability within the system, there have also been instances of As retention defying this trend. These findings have been linked to the phenomenon of metal cation bridging, resulting in the formation of positively charged pockets within the system, which in turn, promote the retention of As despite the expected repulsion effects (Wang and Mulligan, 2006). The increased availability of As in soil-2 due to organic matter application through vermicompost can be attributed to the rise in pH due to the buffering action of organic matter leading to competition of hydroxyl ion with As oxyanion for the binding sites.

3.2. Effect of various amendments on arsenic content in rice grain, straw and husk

The application of various soil amendments significantly influenced the As content in rice plant parts (grain, straw, husk). In comparison to the control treatment, sugarcane bagassse successfully decreased the As content in rice plants in soil-1. However, in the case of soil-2 the application of vermicompost led to an increase in As content in both rice grain and husk as compared to the control. This trend in the variation of As content in rice plants corresponded with the observed changes in Olsen extractable As content in the soil. This was quite natural considering the positive relationship existing between extractable As content in soil and As content in rice plants (Giri et al., 2011; Das et al., 2013; Golui et al., 2017). The As accumulation by rice plants generally followed the pattern: straw>husk>grain (Table 4). The results were in close agreement with the reports of Bhattacharya et al. (2010) and Roy et al. (2020). Such low As accumulation in rice grain compared to that in straw and husk could be attributed to the symplastic discontinuity of As movement hindering its transfer from husk to rice endosperm (Meharg and Zhao, 2012; Roy et al., 2023). Additionally, the As entrapment in glutathione present in the leaf could be another possible reason for low grain As content (Heuschele et al., 2017).

A general overview of the results revealed the better performance of sugarcane bagasse in reducing the plant As content compared to vermicompost application and unamended control. The grain As content in soil-1 as affected by various amendments varied between 0.10 and 0.13 mg kg^{-1}; while that in soil-2 was in the range of 0.10 to 0.14 mg kg^{-1}, respectively (Table 4). It must be noted that the total grain As content in both soils were well below

Table 4: Effect of amendments on arsenic content in grain, straw, and husk of rice grown in arsenic-contaminated soils

Treatments	Grain As (mg kg^{-1})	Straw as (mg kg^{-1})	Husk As (mg kg^{-1})
Soil-1			
Control	0.14± 0.011[a]	2.02± 0.11[a]	0.55± 0.03[a]
Vermicompost	0.13± 0.007[a]	1.76± 0.14[b]	0.52± 0.04[a]
Sugarcane bagasse	0.10± 0.007[b]	1.68± 0.11[b]	0.37± 0.01[b]
Soil-2			
Control	0.12± 0.003[a]	1.49± 0.18[a]	0.45± 0.03[a]
Vermicompost	0.14± 0.008[b]	1.35± 0.12[b]	0.58± 0.03[b]
Sugarcane bagasse	0.10± 0.009[c]	0.82± 0.09[c]	0.32± 0.05[c]

Different letters in superscript indicate significant differences in mean values, while same letters indicate at par values at $p<0.05$

the permissible safe limit for human consumption (0.2 mg kg^{-1}) defined by the Codex Committee on Contaminants in Food. Sugarcane bagasse has been reported to have a higher content of lignin, cellulose, hemicellulose, and a large number of functional groups facilitating active binding sites for As adsorption. Mandal et al. (2019b) have advocated the higher effectiveness of sugarcane bagasse in comparison to vermicompost in immobilizing soil As due to the higher stability of organo-As complex formed by the former. This substantiates the better performance of sugarcane bagasse over vermicompost-treated soils in our study.

3.3. Bio-accessibility of arsenic from rice grain as affected by amendments

Bio-accessibility pertains to the amount of an element that undergoes dissolution within the gastrointestinal tract when in contact with various digestive juices following the ingestion of food. Rice constitutes a significant portion of the dietary intake among the population in Asian regions. Therefore, it is crucial to quantify the amount of As going through the ingestion of rice grain grown in contaminated areas into the human body. Previous reports show that the proportion of As that can become truly bioavailable and enter the bloodstream through the consumption of rice grains can vary from 16 to 100% of the total grain As content (He et al., 2012; Althobiti et al., 2018). The percentage of bio-accessibility varies primarily with the total arsenic content in the grain and all the factors that control the grain As loading. In this study, an attempt was made to reduce the plant-available fraction of soil As by application of various organic amendments and bring reduction of the bio-accessible As content in grain. Given that only a single rice variety was cultivated in the pot culture experiment, the percentage of bio-accessible As in all treatments across both the soil types, remained consistently within a narrow range of ~67–69% (Table 5, Figure 2).

This indicates that upon ingestion of this rice, approximately 31 to 33% of total grain As may not get assimilated into the human body and is likely to be eliminated through human excreta. It was quite natural to find that the bio-accessible As in rice grain varied in a similar pattern as that of total grain As content due to the application of various amendments. The share of grain As solubilized by different types of gastro-intestinal juices is shown in Figure 2. Saliva is noted to extract the largest proportion of grain As, making a substantial contribution to the bio-accessible As fraction, accounting for approximately 53% to 56% (with respect to total actual grain As content). In contrast, the intestinal (~4.8 to 7.3%) and gastric juices (~6.5 to 7.2%) contributed roughly similar amounts of As to the bio-accessible fraction.

The total grain As computed after summing all the fractions of grain As extracted by the IVG method exceeded the actual

Table 5: Bio-accessible As fraction of rice grain (cooked white rice) extracted by artificial saliva and gastro-intestinal juices

Treatment	Bio-accessible (mg kg^{-1})	Total grain As (mg kg^{-1})	Total grain as (mg kg^{-1}) (expected)
Soil-1			
Control	0.10± 0.007[a]	0.16± 0.010[a]	0.14± 0.011[a]
Vermicompost	0.09± 0.004[a]	0.15± 0.010[a]	0.13± 0.007[a]
Sugarcane bagasse	0.07± 0.004[b]	0.13± 0.002[b]	0.10± 0.007[b]
Soil-2			
Control	0.08± 0.002[a]	0.14± 0.001[a]	0.12± 0.003[a]
Vermicompost	0.09± 0.006[a]	0.17± 0.006[b]	0.14± 0.008[b]
Sugarcane bagasse	0.07± 0.008[a]	0.13± 0.012[a]	0.10± 0.009[c]

Different letters in superscript indicate significant differences in mean values, while same letters indicate at par values at $p<0.05$

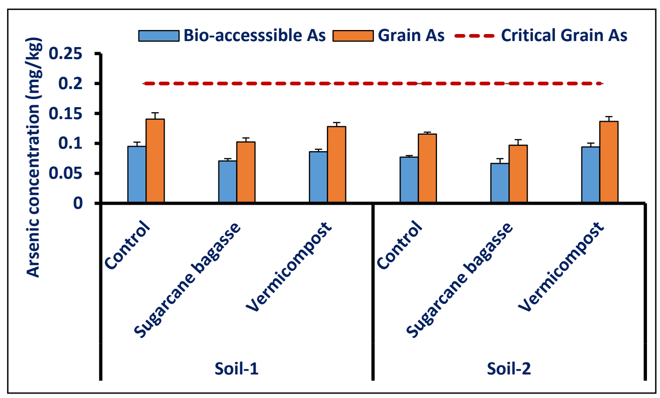

Figure 2: Effect of different organic amendments on bio-accessible fraction of arsenic in cooked white rice grown on arsenic contaminated soils of West Bengal

total grain As content to the tune of 15–32%. This difference could be attributed largely to the possibility of residual saliva (or gastric juice) remaining in the container or temporarily being absorbed by the rice after the process of centrifugation and decanting the supernatant. These residual amounts of gastrointestinal juices may contain notable concentrations of As, potentially causing "contamination" of the subsequent gastrointestinal fluid and leading to a significant increase in the final total grain As concentration. Similar observations were also recorded in a study by Horner and Beauchemin (2013). In fact, this is one of the major disadvantages of the batch method of IVG bio-accessibility assessment. Further, it is inferred from this study that the bio-accessibility of As was found to be relatively low when compared with the total grain As content. This implies that the bio-accessible As grain As content could potentially be employed instead of total grain As content for refining the health risk assessment further.

3.4. Human health risk assessment

The associated health risk was computed for both the sub-populations like adults and children by considering the bioaccessible As content instead of total inorganic As content in grain to make health risk assessment more accurate and realistic (Table 6). The results showed that the values of both HQ_{adult} and $HQ_{children}$ through consumption of rice grains grown on amended soils were greater than 1 in all the amendments across all the soils, indicating that the rice grains may induce non-cancerous health hazards in both the sub-populations upon continued long term consumption of rice grown in contaminated soils (Figure 3). Even after considering the bio-accessible As concentration in rice grains (for computation of HQ) for modifying health risk assessment protocols, the values of $HQ_{modified}$ for both adults and children were above the critical limit. Golui et al. (2017) proposed the permissible value of HQ as 0.5 for rice grain, considering that the health hazard will also be shared by drinking water and consumption of food items other than rice. Therefore, at HQ=0.5, it was quite obvious to note that the both sub-populations were not safe as far as any non-cancer health risk was concerned. In both soils, reduction in HQ values as affected by the application of various amendments can be arranged as follows: sugarcane bagasse> vermicompost. The severity-adjusted margin of exposure (SAMOE) was also computed to assess the cancer risk involved with the consumption of rice grain grown in amended As contaminated soils (Table 6). Based on the SAMOE values, all the treatments across all the soils could be classified under low-risk category (0.1-1). The effectiveness of amendments followed the same order as that observed in HQ.

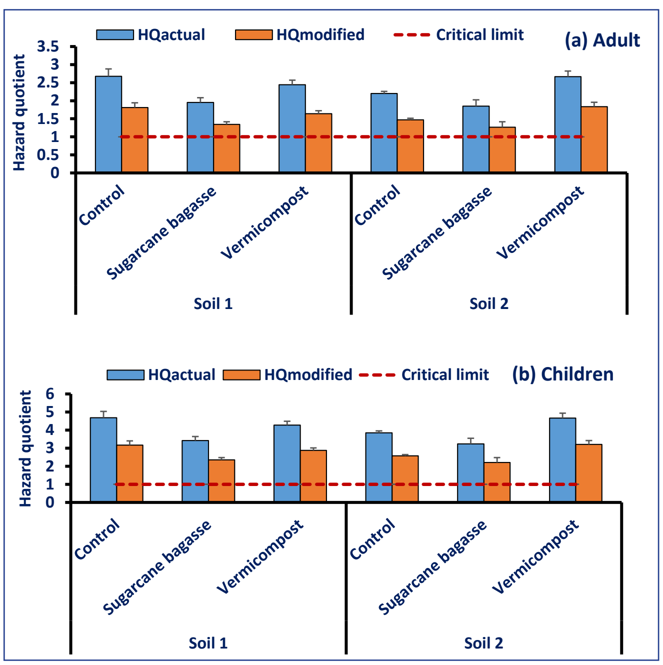

Figure 3: Comparison of actual and modified hazard quotient (HQ) in (a) adult and (b) children as affected by application of different amendments to arsenic-contaminated soils

Table 6: Health risk indices levels in adult and children population due to ingestion of rice grain grown in As contaminated soils

Treatment	HQ_{adult}	HQ_{child}	SAMOE
Soil-1			
Control	1.81	3.17	0.32
Vermicompost	1.64	2.87	0.35
Sugarcane bagasse	1.34	2.35	0.42
Soil-2			
Control	1.47	2.57	0.39
Vermicompost	1.83	3.21	0.32
Sugarcane bagasse	1.26	2.21	0.45

HQ_{adult}: Modified hazard quotient in adult; HQchild: Modified hazard quotient in children; SAMOE: Modified severity-adjusted margin of exposure

4. CONCLUSION

Sugarcane bagasse-amended soils reduced Olsen extractable As, thus lowering rice grain, straw, and husk As content. Bio-accessible As content in rice grain varied proportionately with total grain As content, comprising 67–69% of total grain As content in As-contaminated soils. Non-cancer health risk (HQ) for adults and children exceeded 1, indicating the soils are unsafe for rice consumption. However, SAMOE values suggested a low risk associated with consumption of rice grains grown in these soils.

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