Arsenic oral bioavailability in soils, housedust, and food: implications for human health

L.Q. Ma^{1,2}, H.B. Li³, D. Zhao³ & A.L. Juhasz⁴

¹Research Center for Soil Contamination and Environment Remediation, Southwest Forestry University, Kunming, P.R. China

²Soil and Water Sciences Department, University of Florida, Gainesville, FL, USA

³State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing, P.R. China

⁴Centre for Environmental Risk Assessment and Remediation, University of South Australia, Mawson Lakes, SA, Australia

ABSTRACT: Incidental ingestion of As-contaminated soils and housedust is an important non-dietary As exposure contributor for children living nearby contaminated sites, while consumption of rice has been recognized as the most important dietary contributor. However, to accurately assess the health risk associated with soil and dust ingestion and rice consumption, determination of total concentration and oral bioavailability of As are both important. However, compared to soils, assessment of As relative bioavailability (RBA) in housedust and rice is limited. In addition, the suitability of in vitro bioaccessibility assays to predict As bioavailability has not been compared between different exposure scenarios. Recently, by combining in vivo mouse bioassay and in vitro bioaccessibility assays, we measured As-RBA (relative to the absorption of sodium arsenate) in samples of contaminated soils, slightly-contaminated housedust, co-contaminated housedust, and rice. Results showed that As-RBA in these media showed significant variation among individual samples, suggesting the need to incorporate bioavailability to accurately assess the associated health risk. In addition, by establishing in vivo-in vitro correlations, the most suitable in vitro assay to predict As-RBA varied with the target media, suggesting the need of developing specific methodologies to predict As-RBA in different environmental media.

1 INTRODUCTION

Arsenic (As) is a ubiquitous contaminant present in food and the environment. Chronic exposure to As causes various adverse health effects including cancers, skin disorders, vascular disease, and diabetes mellitus (Hinwood *et al.*, 2003). Humans are exposed to As via both dietary and non-dietary pathways, with incidental ingestion of contaminated soils and housedust being important non-dietary contributor, while rice consumption is recognized as an important dietary contributor to inorganic As intake (Juhasz, *et al.*, 2006; Li *et al.*, 2011, 2014, 2017; Ruby *et al.*, 1999; Williams *et al.*, 2009). Reliable assessment of human health risk from both the dietary and non-dietary pathways depends not only on total As concentration in soils, housedust, and rice, but also its bioavailability (Li *et al.*, 2016a; Liao *et al.*, 2005; Ruby & Lowney, 2012; Zhu *et al.*, 2008; Zhu *et al.*, 2013).

While studies have utilized in vivo animal bioassays to determine As relative bioavailability (RBA, relative to the absorption of sodium arsenate) in contaminated soils, limited researches have focused on housedust and rice (Ollson *et al.*, 2017;

Torres-Escribano *et al.*, 2008; Williams *et al.*, 2009). Compared to animal models, bioaccessibility methods offer a simple, inexpensive way to estimate As-RBA. However, it is important to establish the relationship between As bioaccessibility and As relative bioavailability (RBA) so the assay is valid to predict As-RBA in soils, housedust, and food (Li *et al.*, 2016b).

2 METHODS/EXPERIMENTAL

2.1 Arsenic RBA and bioaccessibility in contaminated soils

Twelve As-contaminated soils (22.2 to 4172 mg As kg⁻¹) were collected from typical mining/smeltering contaminated sites across China. As-RBA was assessed using in vivo mouse blood AUC (area under the blood As time curve over 48-h period) bioassay following a single dust gavage dose, while As bioaccessibility was measured using five in vitro assays (UBM, SBRC, IVG, DIN, and PBET). Linear correlation between As-RBA and As bioaccessibility was established to investigate the As-RBA prediction ability of in vitro assays.

2.2 Arsenic RBA and bioaccessibility in housedust

As-RBA in 12 housedust samples across China slightly contaminated with As contamination ($7\text{--}38\text{ mg kg}^{-1}$) was measured using an *in vivo* mouse blood AUC model and compared to As bioaccessibility determined using 4 *in vitro* bioaccessibility assays (SBRC, IVG, DIN, and PBET).

In addition, 15 housedust samples co-contaminated with As ($43\text{--}2380\text{ mg kg}^{-1}$), Cd ($8.46\text{--}329\text{ mg kg}^{-1}$), and Pb ($127\text{--}15486\text{ mg kg}^{-1}$) collected from Pb-Zn ore mining/smeltering sites at Hunan, China were assessed for As-, Cd-, and Pb-RBA using an *in vivo* mouse bioassay with metal(loid) accumulation in liver and kidneys as the biomarker of dust-amended diet consumption over a 10-d period. Arsenic bioaccessibility was assessed using 3 bioaccessibility assays (SBRC, PBET, and UBM).

2.3 Arsenic RBA in rice

A mouse model based on steady state As urinary excretion (SSUE) was developed to determine As-RBA in rice to refine inorganic As exposure in humans (Li *et al.*, 2011). Fifty-five rice samples from 15 provinces in China were analyzed for total As, with 11 cooked for As speciation and bioavailability assessment using A mouse bioassay.

3 RESULTS AND DISCUSSION

3.1 Correlation between As-RBA and bioaccessibility for contaminated soils

Arsenic RBA in the 12 soils ranged from $6.38 \pm 2.80\%$ to $73.1 \pm 17.7\%$ with soils containing higher free Fe contents showing lower values (Li *et al.*, 2016). Arsenic bioaccessibility varied within and between *in vitro* assays. All *in vitro* assays show strong linear correlation with As-RBA data ($R^2 = 0.50\text{--}0.83$), with the IVG assay providing the best estimate of As-RBA ($R^2 = 0.81\text{--}0.83$) although the IVIVC slope did not meet the criteria of $0.8\text{--}1.2$ (Fig. 1). This suggests that the IVG assay has the potential to predict As-RBA in contaminated soils from China.

3.2 Correlation between As-RBA and bioaccessibility for housedust

For the 12 slightly contaminated housedust samples, As-RBA ranged from 21.8 ± 1.6 to $85.6 \pm 7.2\%$ with samples containing low Fe and high total organic carbon content having higher As-RBA (Li *et al.*, 2014). Strong *in vivo-in vitro* correlations (IVIVC) were observed between As-RBA and As bioaccessibility for SBRC and DIN assays ($R^2 = 0.63\text{--}0.85$), but weaker ones for IVG and PBET assays ($R^2 = 0.29\text{--}0.55$).

For the 15 As, Cd, and Pb co-contaminated housedust samples, As-, Cd-, and Pb-RBA was $7.64\text{--}37.0$, $20.3\text{--}94.3$, $7.21\text{--}52.1\%$, averaging 21, 52, and 30%, respectively. Analyses of relationship between

Figure 1. *In vivo-in vitro* correlations between As relative bioavailability (RBA) in 12 As-contaminated soils from China using a mouse model and As bioaccessibility determined using gastric (GP) and intestinal phases (IP) of five *in vitro* assays (UBM, SBRC, IVG, DIN, and PBET).

metal(loid) RBA and concentrations showed that Pb-RBA decreased with increasing As concentration, while As-RBA decreased with increasing Pb and Cd concentration ($R^2 = 0.62\text{--}0.72$), suggesting that co-presence of As and Pb decreased each other's RBA, while Cd reduced As-RBA.

By correlating metal(loid) RBA data with bioaccessibility data using the SBRC, PBET, and UBM assays, the strongest As *in vivo-in vitro* correlations were observed for the PBET assay ($R^2 = 0.69$).

3.3 As-RBA in rice

Following oral doses of individual As species to mice at low levels of As exposure ($2.5\text{--}15\text{ }\mu\text{g As}$ per mouse) over a 7-d period, strong linear correlations ($R^2 = 0.99$) were observed between As urinary excretion and cumulative As intake, suggesting the suitability and sensitivity of the mouse bioassay to measure

As-RBA in rice. RBA in cooked rice ranged from $26.2 \pm 7.0\%$ to $49.5 \pm 4.7\%$ (averaging $39.9 \pm 8.3\%$) for inorganic As. Calculation of inorganic As intake based on inorganic As concentration in rice led to an overestimate of As exposure by 2.02–3.67-fold compared to that calculated based on bioavailable inorganic As.

4 CONCLUSIONS

The results suggested that in vitro assays suitable to predict As-RBA varied with the target media. For accurate assessment of the health risk associated with incidental ingestion of soil and housedust and consumption of rice, it is important to consider As bioavailability.

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