Rahman, Mohammad Mahmudur; Alauddin, Mohammad; Alauddin, Sarah T.; Siddique, Abu Bakkar; Islam, Md. Rashidul; Agosta, Gabriella; Mondal, Debapriya; Naidu, Ravi. "Bioaccessibility and speciation of arsenic in children's diets and health risk assessment of an endemic area in Bangladesh". Journal of Hazardous Materials Vol. 403, Issue 5 February, no. 124064, (2021).

Available from: http://dx.doi.org/10.1016/j.jhazmat.2020.124064

Bioaccessibility and speciation of arsenic in children's diets and health risk assessment of an endemic area in Bangladesh

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Abstract

This study determines the bioaccessibility of toxic and carcinogenic arsenic (As) in composite food samples and evaluates potential exposure from food intake in Bangladesh children. Total As (tAs), inorganic As (iAs) and bioaccessible As (BAs) in food composite samples consumed by children were compared between an exposed and a control group (based on As in drinking water). Total As concentrations in composite food samples of children exposed to mean As level of 331 µg/l in drinking and cooking water ranged from 586 to 1975 µg/kg, dry weight over 76 to 90 µg/kg in the unexposed group. Average iAs in food composites was 73.9% (range: 49.3 to 90.8%). The fraction of BAs using gastric and gastrointestinal phases was 91±13 % and 98±11%, respectively. Daily intake of iAs in exposed group ranged from 0.41 to 6.38 µg per kg body weight (BW), which was much higher than the unexposed group (0.08-0.15 µg per kg

BW). High iAs content and BAs in composite food samples indicated elevated risk to exposed children. Further research should include both adult and children using larger sample size to determine overall As exposure from food intake in Bangladesh, attention must be given to lowering of As in food.

Keywords: Arsenic; Children; Food composites; Arsenic speciation; Arsenic bioaccessibility; Health risk.

1. Introduction

Human health risk assessment of trace elements, specifically arsenic (As) in food has received considerable attention in recent years because of food safety concerns (Antoniadis et al., 2017; Antoniadis et al., 2019). Health risk assessment of trace elements including As and its effects on plants and humans is crucial for effective regulatory guidelines. A recent study explored the transfer of the trace elements from soil to humans, emphasising that the human health risk assessment is a global one. This is due to their possible transfer through the food chain to people and is considered to be the main exposure route (Antoniadis et al., 2019). Arsenic is a carcinogen that has been detected in the groundwaters of Bangladesh, used both for drinking and cooking. Chakraborti et al. (2010) reported 27.2% and 42.1% of the 52,202 water samples analysed in Bangladesh had concentrations above 50 and 10 μg/l, respectively. In addition to drinking water, people from the As-endemic areas in Bangladesh are significantly exposed to As through their daily diet (Rahman et al., 2011; Rahman et al., 2013; Rahman et al., 2009). The risk posed by rice based diet has been well reported (Carbonell-Barrachina et al., 2012; Islam et al., 2017c; Signes-Pastor et al., 2016) since rice is consumed in large quantities in Bangladesh. Its people usually consume more than 170 kg per capita per annum compared to the world average of 57 kg per capita per annum (Shew et al., 2019).

Average As content in the uncooked and cooked rice samples collected from households of Nawabganj district in Bangladesh was found to be 340 µg/kg and 460 µg/kg, respectively (Ohno et al., 2007) indicating a rising As concentration in cooking whereas average As concentration in cooked rice (139 µg/kg) was lower than uncooked rice (153 µg/kg) in paired samples collected from households in the Noakhali district of Bangladesh (Rahman et al., 2011). Concentration of As may vary between uncooked and cooked rice, depending on the rice variety, As in raw rice, As in cooking water and process of cooking (Bae et al., 2002; Laparra et al., 2005; Mwale et al., 2018). A recent study reported that transfer of As from water to rice grains was influenced by the increasing concentration of As in water and rice type; concentrations of 84-105 µg/L in cooking water significantly increased As concentration (24-337%, and 114 % from sunned and parboiled rice, respectively) in cooked rice (Chowdhury et al., 2020). (Sengupta et al., 2006) found that the traditional cooking procedure commonly used in Bangladesh (whereby rice is washed with water until clear and excess water is discarded after cooking) can remove up to 57% of rice As. In a study conducted in the Monohordi and Munshiganj districts of Bangladesh, the average As content reported in cooked rice and cooked vegetables were 358 µg/kg and 333 µg/kg, respectively (Smith et al., 2006). Hence, having cooked rice as a mainstay of the diet can be an important route of As exposure.

Infant and young children are most susceptible to As toxicity, although arsenical symptoms in children are rare except when they are exposed to very high concentrations of As or suffer from malnutrition (Rahman et al., 2001). Chronic exposure to As pose high health risks including neurobehavioural problems and decreased intellectual function in children (von Ehrenstein et al., 2007; Wasserman et al., 2004). In a study from Mexico the total As (tAs) and inorganic As (iAs) concentrations in children's diets ranged from 50 to 1150 µg/kg, and 23 to 88 µg/kg, dry weight (DW), respectively and daily intake of tAs and iAs ranged from 0.15 to 10.49 µg per kg BW and from 0.06 to 1.11 µg per kg BW, respectively (García-Rico et al.,

2012). In one study from Bangladesh, 2–5 yrs and 6–10 yrs age groups were more exposed to As due to rice consumption (Islam et al., 2017b). These results are alarming considering the higher risk of children being exposed to As through the food they eat.

In characterisation of As exposure and risk from food intake both in adults and children, one aspect that has received increased attention is the bioaccessibility of As (BAs) in consumed food (Laparra et al., 2005). Various studies have estimated the BAs in uncooked food (Signes-Pastor et al., 2012; Trenary et al., 2012) including shrimp, radish, mushroom, etc. (Chi et al., 2018; Hu et al., 2019; Koch et al., 2013) while other studies concentrated on raw and cooked rice (Laparra et al., 2005; Zhuang et al., 2016). A few studies investigated the BAs through simulated gastric phase (GP) and gastrointestinal phase (GIP) digestions (Llorente-Mirandes et al., 2016; Zhuang et al., 2016). The BAs of GP and GIP in raw rice and cooked rice varied from 36-102% and 72-96% respectively (He et al., 2012; Signes-Pastor et al., 2012; Zhuang et al., 2016). While health risk assessments based on the evaluation of BAs using different *in-vitro* assay for individual food items, whether raw or cooked have been reported (Laparra et al., 2005; Llorente-Mirandes et al., 2016; Zhuang et al., 2016), As speciation and bioaccessibility in food composites using both GP and GIP are limited. Furthermore, estimates of children's exposure to As in based on bioavailability of As in a composite diet are rare. To the best of our knowledge, no study has determined the concentrations of tAs, iAs and BAs in cooked food composites consumed by children in endemic areas which can provide an accurate estimate of As intake, exposure, and risks in children.

In this communication, for the first time we report As exposure in children from diet (lunch and dinner) comprising cooked rice, vegetables and pulses (which are the most commonly consumed foods by Bangladeshi people) from two As-contaminated villages in Bangladesh. The aim of this study is to determine tAs, iAs and BAs in the children's diet in As-endemic areas of Bangladesh to estimate the health risks for children.

2. Materials and methods

2.1. Sample collection and preparation

All the reagents used in this study were of analytical grade. The details of chemicals and reagents are given in the Supplementray Information (SI). For this study, a total of 14 diet samples from lunch and dinner menus were collected in 2018 from 14 households in two As-contaminated villages (*Shahpur* and *Sursoi*), which are located in Chandpur district of Bangladesh. It is worth noting that Chandpur was reported to be a severely As-contaminated area with 95.7% and 92.6% groundwater samples (n=1165) having As above 10 µg/L, the WHO provisional guideline value and 50 µg/L, the Bangladesh standard value of As in drinking water, respectively (Chakraborti et al., 2010). Usually in these areas, lunch and dinner comprise of cooked rice, fish curry with different vegetables and lentil soup (locally known as dal). Households with at least two children were selected at random. Details of ethical approval are presented in SI. Altogether 31 children were selected from these two contaminated villages (9 boys and 8 girls from Shahpur and 7 boys and 7 girls from Sursoi) for this study (denoted as exposed group) and their food portion sizes were weighted for lunch and dinner to determine their daily dietary intake rates. For these 31 exposed children (16 boys and 15 girls) age, body weight as well as daily amount of food consumption (rice, curry and dal) was determined. The average age and weight of these children were 8.3 yrs (range 2 - 15 yrs) and 26 kg (range 10 - 56 kg), respectively. The average daily food consumption (fresh wt.) was 304 g (range: 85 – 563 g). For the sake of comparison, diet samples of 4 children were also collected from Bhelanagar (denoted as unexposed group) which is situated in the Narsingdi Municipality where As-safe drinking water supply was available through a pipeline.

Food samples were collected from a plate (duplicate portion) when it was being served to children. The separately cooked rice, curry and dal were mixed and homogenised properly to create a composite sample. The mixed food samples were stored in zip-lock bags and stored

125 in an ice box with ice and transported to the laboratory and then kept refrigerated until
126 processing. These samples were dried in an oven at 65°C for 72h. The dried samples were again
127 homogenised by grinding them. The samples were stored in zip-log bags. We also collected
128 cooking and drinking water samples from both exposed and unexposed groups. Water samples
129 from both these groups were collected in plastic bottle (pre-washed with 1:1 nitric acid) and
130 preserved with 0.1% (v/v) nitric acid. The samples were subsequently transported to the
131 University of Newcastle by courier under strict biosecurity protocol.

132 For tAs determination, the samples were digested using microwave acid digestion
133 system that was employed by Islam et al. (2017c). The digests were diluted to 10 mL using
134 0.1% HNO_3 and passed through a 0.45 µm syringe filter for the determination of tAs in the diet
135 samples and water samples using inductively coupled plasma mass spectroscopy (ICP-MS,
136 PerkinElmer, NexION 350, USA).

137 Arsenic speciation analysis for inorganic As – sum of arsenite (AsIII), and arsenate
138 (AsV), monomethylarsonic acid (MMA) and dimethyl arsinic acid (DMA) was carried out
139 following the method of Signes-Pastor et al. (2016). Details of the procedure have been
140 discussed in our previous publication (Islam et al., 2017c). High performance liquid
141 chromatography (HPLC, Agilent 1200) coupled with ICP-MS (Agilent 7900) was used for As
142 speciation analysis.

143 *2.2. In-vitro BAs assay*

144 Physiologically-based extraction test (PBET) is one of the most practical and feasible
145 *in-vitro* methods to determine metal bioaccessibility. The method was adopted from the
146 previously described studies (Kafaoglu et al., 2016; Llorente-Mirandes et al., 2016; Zhuang et
147 al., 2016). Details procedure are given in SI. The prepared samples were anayzed using ICP-
148 MS for bioaccessible As.

149 The BAs (%) was calculated according to the following equation.

150 $$\text{BAs (\%)} = \frac{Bioaccessible\ As\ concentration\ in\ food\ composite}{Total\ As\ concentration\ in\ food\ composite} \times 100$$

151 *2.3. Quality control*

152 Standard reference material (SRM 1568b rice flour) obtained from the National Institute
153 of Standard and Technology (NIST), USA was used to validate the analysis. Concentration of
154 total As in SRM rice flour (1568b) was 266±11 (n=6) µg/kg, indicating 93% recovery (certified
155 value of 285±14 µg/kg). Blanks, duplicates and calibration check verification (CCV) samples
156 were included. The mean variation between duplicate samples (n=12) was 2.8% (0.5-7.1%) and
157 the recoveries for CCVs (n=5) amounted to 103% (99 -105%). In addition, we determined the
158 accuracy of the As speciation method using SRM rice flour. The certified values for DMA,
159 MMA and iAs in SRM rice flour were 180 ± 12 µg/kg, 11.6 ± 3.5 µg/kg and 92 ± 10 µg/kg,
160 respectively. The analytical results (n=5) for As speciation indicated that the values for DMA,
161 MMA and iAs were 162 ±14 µg/kg, 8.2 ± 3.1 µg/kg and 83 ± 8 µg/kg, respectively. Thus,
162 recoveries for DMA, MMA and iAs were 90%, 70.7% and 90.2%, respectively.

163 *2.4. Statistical analysis*

164 Data were analysed and represented graphically using statistical software JMP version
165 14, IBM SPSS version 25, Microsoft Excel 2013, and Graph Pad Prism 8. Confidence level
166 from 95% was considered for all statistical analyses.

167 *2.5. Risk assessment*

168 To evaluate the potential exposure of children to As , we evaluated the established daily
169 dietary intake (EDDI) of As, hazard quotient (HQ) and cancer risk (CR) from cooked food
170 using the following equations:

171 $$\text{EDDI} = \frac{\text{FC x iAs x \%BAs x ED x EF}}{\text{BW x AT}}$$

172 $$\text{HQ} = \frac{\text{EDDI}}{\text{RfD}} \text{ and}$$

173 $$\text{CR} = \text{EDDI} \times \text{CSF}$$

174 Where, FC is cooked food consumption (g/day, fresh weight, FW); iAs is the concentration of
175 the inorganic As in food component (µg/kg using FW); BAs is bioaccessibility of As through
176 GIP tract (%); BW stands for body weight, (kg) of respective children; ED represents exposure
177 duration (years) of the children taking into consideration their respective ages; EF is exposure
178 frequency (365 days per year); AT represents average lifetime (365 days per year × number of
179 exposure years); CSF is cancer slope factor (1.5 mg/kg per day); and RfD is oral reference dose
180 (3×10^{-4} mg/kg per day for As), as suggested by USEPA (IRIS 2013). In the case of HQ <1,
181 non-carcinogenic risks are not considered but for HQ >1, there may be adverse health effects
182 arising from exposure (Abtahi et al., 2017; Shibata et al., 2016; Zhuang et al., 2016). In terms
183 of carcinogenic risk assessment, if CR $<10^{-6}$, the increased cancer risk is deemed to be
184 negligible, and $>10^{-6}$ a departure from negligible risk, CR > 10^{-4} is considered to be an
185 unacceptable increased cancer risk (Fakhri et al., 2018; Shibata et al., 2016).

186 **3. Results and discussion**

187 *3.1. Total As in diets*

188 Mean As in cooking and drinking water (n=5) for the exposed group was 331 µg/l
189 (range: 88 - 720 µg/l) whereas As concentration in cooking and drinking water (supply tap
190 water, n=2) of the control group was <1 µg/l. The concentration of tAs, iAs and BAs (%) in
191 the composite food samples are summarized in Table 1. The mean and range of As in food (dry
192 wt.) were 1072 µg/kg and 586 – 1975 µg/kg for the exposed group, respectively. Considering
193 that on average the moisture content was 80% in cooked composite food in this study, the mean
194 and range of As in food (fresh wt.) were 214 µg/kg and 117 – 395 µg/kg, respectively. The tAs
195 concentrations (mean and range) in composite food samples (dry wt.) for the control group were
196 85 µg/kg and 76-90 µg/kg, respectively (Table 1), which were equivalent to 17.1 µg/kg and
197 15.3 – 18.1 µg/kg, fresh wt., respectively. The results (Fig. 1) revealed that there was a
198 significant difference between the mean As concentrations in food samples between the

199 exposed and control groups ($p<0.001$), while the mean As concentration in food samples
200 collected from exposed group was 12.5 times higher than in the unexposed group. The highest
201 concentrations of tAs were 1975 µg/kg (DW) and 395 µg/kg (FW) from sample RC1. The tAs
202 concentration in the diets of children in Sonora, Mexico ranged from 50 to 1150 µg/kg, dry wt
203 (García-Rico et al., 2012), which was much lower than reported in this study.

204 It is important ot note here that although children from the control group live in
205 municipal areas and use tap water (As<1 µg/L) for drinking and cooking, we do not know
206 whether they use food items that are low in As. Generally in the municipal and city areas of
207 Bangladesh, food crops including rice, vegetables and pulses are sourced from As-contaminated
208 villages which are available in local markets. In this study, we were not sure about the sources
209 of food crops for both the exposed and control groups, whether they originated from
210 contaminated or uncontaminated areas or mixed agro-ecological zones. However, since As
211 concentrations in composite food samples for the exposed group were much higher than those
212 in the control group, we expect that As concentration in cooking water contributed to the
213 increase in As in the cooked food composites. It is also expected that the cooking procedure
214 would have affected the concentration of As in food samples (Bae et al., 2002; Laparra et al.,
215 2005).

216 *3.2. Inorganic As content and speciation*

217 In this study, inorganic As was the major species present in the food samples (Table 2)
218 with an average of 74% (range 49-91%). This is similar to the study conducted by Laparra et
219 al. (2005) who reported 77 % (range: 32-103%) of iAs in cooked rice. Smith et al. (2006)
220 reported iAs content of 87% and 96% in cooked rice and vegetables, respectively, in samples
221 from Bangladesh. Ohno et al. (2007) found up to 100% of iAs in cooked rice from Bangladesh.
222 Based on their duplicate diet survey conducted in Pabna, Bangladesh, Kile et al. (2007) reported

223 that on average 82% of As present in food samples was iAs (n=35). We could not detect any
224 MMA (V) in the food samples but DMA (V) was present in all samples except RC 8.

225 The iAs concentration in the diets of children in Sonora, Mexico was 23 to 88 µg/kg,
226 dry wt (García-Rico et al., 2012), which is much lower than the present study. The higher iAs
227 (289 to 1624 µg/kg, dry wt) detected in this study could be attributed to both cooking process
228 and As-contaminated water used for cooking (Bae et al., 2002; Laparra et al., 2005; Zhuang et
229 al., 2016). Laparra et al. (2005) reported a 5-17 fold increase in iAs content in the rice, after
230 cooking with simulated As-contaminated water. This to a great extent reflects the reality of the
231 situation concerning As-endemic areas throughout Asia. A recent study reported that cooking
232 water (84-105 µg/l) significantly increased As concentration in sunned (24-337%) and
233 parboiled rice (114%) (Chowdhury et al., 2020).

234 Maximum tolerance level of iAs in the rice (uncooked) for infants and young children
235 is 100 µg/kg as recommended by the European Union (EU) (Ashmore et al., 2019). Out of 14
236 samples in the exposed group, all exceeded the EU safe level for infants and young children.
237 Simulating the cooking practices followed in Asian As-endemic areas, Laparra et al. (2005)
238 reported that both tAs and iAs increased when cooking with As-contaminated water and BAs
239 depends on toxic iAs content. However, iAs in cooked rice could be more harmful due to the
240 high bioaccessibility of As (>90%) compared to raw rice (Laparra et al., 2005).

241 *3.3. BAs in cooked food composite*

242 The bioaccessible fractions of As (mean ± SD) determined in both *in-vitro* GP and GIP
243 digestion were 91 ± 13 % (range 68 -106%) and 98 ± 11% (range 72 -117%), respectively
244 (Table 1). No significant difference were observed between the two phases (GP and GIP)
245 although slightly more BAs is found in the GIP, which could be due to the effect of time. There
246 was no noticeable difference of BAs between the samples collected from the control and
247 exposed group. In Sonora, Mexico, BAs ranged from 4 to 97% (mean 44%) (García-Rico et al.,

248 2012), hence, the average value of BAs was much higher in this study compared to Sonora. In
249 our previous study, we determined *in-vivo* BAs in various rice genotypes ranging from 25-94%
250 and we reported that the BAs varied based on rice varieties (Islam et al., 2017a). Cooking
251 process affects the BAs both in GP and GIP extraction as Zhuang et al. (2016) reported that
252 BAs in raw rice using GP and GIP extraction were 62-93% and 75-96%, respectively, whereas
253 38-67% and 72-80% were evident in cooked rice. Several studies have investigated the BAs,
254 which ranged from 20% to 99% considering rice, seaweed, mushroom, radish and shrimp using
255 different *in-vitro* methods (Table 2). Based on the limited data of BAs regarding cooked and
256 composite food samples further analysis is recommended and particularly for children's diets
257 from other As-contaminated areas.

258 The concentrations of tAs, iAs and BAs in both GP and GIP in food composite samples
259 of the exposed group were significantly higher ($p < 0.001$) than the control group (Figs. 1A and
260 B). There was, however, no noticeable difference in BAs fraction (shown as percentage)
261 between the control and exposed groups. No correlation was observed between tAs, iAs and
262 BAs with cooking water. This could be attributed to the food composites, including types of
263 rice, vegetables, fish and pulses used in this study.

264 Bioaccessibility is generally influenced by the level of contamination in food samples
265 (Zhuang et al., 2016). The linear regression illustrated in Fig. 2 displays statistically significant
266 relationships ($R^2 = 0.964 - 0.983$, $p < 0.001$) between tAs with iAs and BAs (both GP and GIP)
267 in composite food samples, which confirmed that BAs does rely on As concentration (Zhuang
268 et al., 2016). A similar strong relationship ($R^2 = 0.928$, $p < 0.01$) has been found between
269 contamination level and bioaccessibility of As in raw rice, and this dose's proportional
270 relationship was considered for the purposes of risk assessment (Zhuang et al., 2016).

271 *3.4. Potential health risk assessment*

272 Different risk assessment indices such as EDDI, HQ, CR have been calculated using the
273 generated data of different cooked food composites for 31 children, which is presented in Table
274 3. Daily intake of tAs and iAs ranged from 0.84-7.75 (mean: 2.7 ± 1.8 and median: 2.1) µg per
275 kg/ BW and 0.41-6.38 (mean: 2.0 ± 1.5 and median: 1.7) µg per kg/ BW, respectively. In this
276 study, the exposed group had unusually higher values of As intake than the control group. Daily
277 intake of tAs was 2.7 (0.15-10.49) µg per kg/BW in García-Rico et al. (2012) study, similar to
278 our findings, yet daily intake of iAs 0.52 (0.06-1.11) µg per kg/BW was much lower than this
279 study. A few studies reported higher iAs intake than our findings (Díaz et al., 2004; Martí-Cid
280 et al., 2007). The recommended upper limit for iAs exposure by the Joint FAO/WHO Expert
281 Committee on Food Additives (JECFA) using the benchmark dose lower confidence limit for
282 a 0.5% (BMDL0.5) increased incidence of lung cancer is 3 µg/kg BW per day (Cubadda et al.,
283 2017). The mean iAs exposure in this study was below the upper recommended limit of 3 µg/kg
284 BW per day although the maximum exposure is more than double the limit. Overall, 32% of
285 the children in our study exceeded the above tolerance level, which is also consistent with the
286 32% reported by (Kile et al., 2007) based on a duplicate dietary survey at Pabna district in
287 Bangladesh. The USEPA has stated that there is no "safe" level of exposure to iAs because it is
288 very toxic. Inorganic As is directly related to BAs, so there is a need to elucidate the risk
289 assessment. A recent study showed that regulation limits in most countries do not take into
290 account of the environmental interfaces such as mobility of trace elements in plants. It
291 concluded that there were reduced limits of trace elements and consequently health risk
292 associated with As were underestimated (Antoniadis et al., 2019).

293 Considering BAs as the input parameter for As, EDDI value was 0.35-6.2 µg/kg BW
294 per day which was substantially higher than that of the control group in this study (Table 3) and
295 higher than the US-based study of Shibata et al. (2016) who reported 0.82 -1.1 µg/kg BW per
296 day and the value of 0.53-0.74 µg/kg BW per day as reported by Zhuang et al. (2016). In this

297 study, the HQ ranged from 1.2-20.5 (mean: 6.8 and median: 5.6) and the highest value was for
298 Sh-B1 in the RC 1 group (Table 3, Fig. 3). All participants in the study area exceeded the
299 tolerance level of HQ (>1) that could induce adverse health effects, and HQ was less than 1 in
300 the control group. Zhuang et al. (2016) found HQ value of 2.3-5.8 for cooked rice while (Shibata
301 et al., 2016) stated values of 0.02-0.37 and 0.19-5.17 for acute and chronic doses of As from
302 rice cereal and other dietary sources for infants and toddlers in the USA, respectively, which
303 were all much lower than this study. Based on the CR assessment, all children in this study had
304 a risk level greater than 10^{-4} and Sh-G1 in the group showed the highest risk of $9.2x10^{-3}$. The
305 CR value in this study was notably higher than what Fakhri et al. (2018) found (0.2-5.5) $\times 10^{-5}$
306 for shrimp but much lower than the value of (4.5-5.5) $\times 10^{-2}$ reported for rice in Iran.

307 To the best of our knowledge this is the first study on bioaccessibility of As in children's
308 composite diet over single food item comparing exposed and non-exposed participants in
309 Bangladesh. It is important to note that all soluble fractions of metals are not
310 bioavailable/absorbable in the human body (Laparra et al., 2005). Furthermore the *in-vitro*
311 metal bioavailability technique has many problems and limitations, for example, human
312 physiology of food digestion is quite complex, involves many biochemical reactions and varies
313 from person to person. Also, the amount of soluble/digested metals is not fully accessible or
314 absorbable to animal organs (Van Campen and Glahn, 1999). Therefore, further research is
315 recommended and both *in-vitro* and *in-vivo* bioaccessibility models using a wide range of
316 samples must be considered.

317 **4. Conclusion**

318 This study evaluated the tAs, iAs and BAs in food composites consumed by children in
319 Bangladesh, comparing samples from As exposed and unexposed (based on As in drinking
320 water) groups. Results indicated that exposure to iAs from food composite is one of the major
321 risks to health due to very high bioaccessibility and consequently should be considered a high

322 priority public health issue in Bangladesh where major mitigation measures are focused on
323 drinking water. This study revealed that the mean As concentration in food composite samples
324 from the exposed group was much higher than those of the unexposed group. It also appears
325 that BAs was higher in GIP digestion than GP digestion in food composites. Based on the BAs
326 results, the mean EDDI of As from food composite was just below the JECFA's recommended
327 upper limit of 3 μg/kg BW per day. The higher values of HQ and CR observed for the exposed
328 group indicated high risk to children in As-endemic areas. As a part of routine As monitoring
329 in Bangladesh, further research is required with larger sample sizes along with other food
330 components to estimate the actual risk of As from food intake. Furthermore, considerable
331 attention must be given to lowering of As in food to curtail exposure and health risk in As-
332 endemic populations, especially children. Certain practices such as use of As-safe cooking
333 water for food preparation and appropriate cooking methods to reduce As content should be
334 advocated in As-endemic areas to ensure consumption of food, especially rice in a protective
335 way. This study highlights the importance of BAs estimation in food and provides a framework
336 for better exposure and risk assessment.

337 **Acknowledgements**

338 We are grateful to the authority of the GCER, The University of Newcastle for
339 laboratory support. Financial support from CRC CARE is highly appreciated. This study was
340 also partially supported by a Fox Fellowship grant from Wagner College, New York, USA.
341 Authors are grateful to Mr Sanjit Kumer Shaha, Diabetic Association of Bangladesh for his
342 help in sampling the food samples.

343 **Declaration of interests**

344 Authors declare there are no conflicts of interest.

345 **Authors contributions**

346 MMR, concept, design of the study, analysed the data and wrote the first draft of the manuscript,
347 final approval of the manuscript; ABS and MRI, data analysis and interpretation and drafted
348 the manuscript; MA, STA and GA, participated in data collection, analysis and edited the
349 manuscript; DM and RN revised and edited the manuscript critically, provided technical
350 oversight to the manuscript. All authors read and commented on drafts of the manuscript.

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