



**QUEEN'S
UNIVERSITY
BELFAST**

Inorganic arsenic removal in rice bran by percolating cooking water

Signes-Pastor, A. J., Carey, M., & Meharg, A. A. (2017). Inorganic arsenic removal in rice bran by percolating cooking water. *Food Chemistry*, 234, 76-80. <https://doi.org/10.1016/j.foodchem.2017.04.140>

Published in:
Food Chemistry

Document Version:
Version created as part of publication process; publisher's layout; not normally made publicly available

Queen's University Belfast - Research Portal:
[Link to publication record in Queen's University Belfast Research Portal](#)

Publisher rights

Copyright 2017 Elsevier.

This manuscript is distributed under a Creative Commons Attribution-NonCommercial-NoDerivs License

(<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits distribution and reproduction for non-commercial purposes, provided the author and source are cited.

General rights

Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

1 **Inorganic arsenic removal in rice bran by percolating cooking water**

2

3 Antonio J. Signes-Pastor^{*,a}, Manus Carey, Andrew A. Meharg

4

5 Institute for Global Food Security, Queen's University Belfast, David Keir Building,
6 Malone Road, Belfast, BT9 5BN, Northern Ireland.

7

8 *Corresponding author

9 Email: antonio.j.signes-pastor@dartmouth.edu

10 ^aCurrent address: Department of Epidemiology, Geisel School of Medicine,

11 Dartmouth College, 1 Medical Center Dr, 7927 Ruben Bldg, Lebanon, NH03766,

12 USA

13

14 **Abstract**

15 Rice bran, a by-product of milling rice, is highly nutritious but contains very high
16 levels of the non-threshold carcinogen inorganic arsenic (i-As), at concentrations
17 around 1 mg/kg. This i-As content needs to be reduced to make rice bran a useful
18 food ingredient. Evaluated here is a novel approach to minimizing rice bran i-As
19 content which is also suitable for its stabilization namely, cooking bran in percolating
20 arsenic-free boiling water. Up to 96% of i-As removal was observed for a range of
21 rice bran products, with i-As removal related to the volume of cooking water used.
22 This process reduced the copper, potassium, and phosphorus content, but had little
23 effect on other trace- and macro- nutrient elements in the rice bran. There was little
24 change in organic composition, as assayed by NIR, except for a decrease in the
25 soluble sugar and an increase, due to biomass loss, in dietary fiber.

26

27 **Keywords:** inorganic arsenic, rice bran, cooking water, nutrient elements, and rice

28 bran composition.

29 **1. Introduction**

30 Rice bran has high concentration in micro- and macro nutrient elements, vitamins and
31 soluble fiber, and is considered a good source of hypoallergenic protein (Zhang,
32 Zhang, Wang, & Guo, 2012). It is becoming a popular ingredient in health-promoting
33 value-added products, it is marketed as a superfood, and has been considered as a
34 health food supplement for malnourished children in international aid programs
35 among other applications (Nagendra Prasad MN, Kr, & Khatokar M, 2011; Qureshi,
36 Sami, & Khan, 2002; Sun et al., 2008; Zhang et al., 2012). However, the realization
37 that rice bran also contains high levels of the carcinogen inorganic arsenic (i-As)
38 (Andrew A. Meharg et al., 2008; Sun et al., 2008), has stalled the development of the
39 utilization of this otherwise very valuable product.

40

41 Rice accumulates much higher levels of i-As than other cereals and foodstuff, in
42 general, due to being cultivated in flooded soils (A. A. Meharg & Zhao, 2012; Sun et
43 al., 2008; Williams et al., 2007). In rice grain most of the i-As is accumulated in the
44 outer bran layers, the pericarp and the aleurone, having i-As concentrations as high as
45 <1 mg/kg (Andrew A. Meharg et al., 2008; Sun et al., 2008). The European Union has
46 formulated regulations on the maximum levels of i-As in rice in order to reduce
47 exposure, and the most restrictive one has been established at 0.1 mg/kg for rice
48 destined for the production of food for infants and young children, the level of which
49 has also been recently proposed as a maximum limit in infant rice cereals by the U.S.
50 Food and Drug Administration (EC, 2015; FDA, 2016). The UN WHO has also set an
51 advisory maximum level of i-As in polished rice grain at 0.2 mg/kg (WHO, 2014),
52 which is also the EU standard. Fortification with rice bran has become popular in
53 health/organic/whole-meal foodstuffs, and such rice bran fortified foods, such as

54 baby/toddler foods, tend to be elevated in i-As, leading them to have i-As
55 concentrations above EU standards, for example (Signes-Pastor et al., 2016).

56

57 Previous studies have shown that i-As in rice is quite soluble in cooking water, and
58 that the larger the volume of cooking water used the greater the i-As removal (Raab,
59 Baskaran, Feldmann, & Meharg, 2009). The method of cooking rice might enable i-
60 As mitigation, especially when low i-As cooking water is available (Carey, JiuJin,
61 Gomes Farias, & Meharg, 2015). Carey *et al.* (2015) developed this observation to
62 pioneer a novel approach to rice cooking to maximize i-As removal. Their findings
63 showed that if rice was percolated with clean, i.e. i-As free, cooking water, up to 85%
64 of i-As could be removed from rice grains while cooking. The percolated cooking
65 water was either recycled (as steam then condensed to form percolating water) or
66 discarded. In the study reported here the efficacy of such percolating cooking
67 technologies in removing i-As from rice bran was trialed. Key to this study was that
68 this cooking of whole rice bran had minimal impact on the beneficial nutritional
69 qualities of bran such as fiber, protein and mineral nutrient content.

70

71 **2. Material and Methods**

72 **2.1. Rice bran cooking**

73 Commercial rice bran samples (16) were purchased, including pure rice bran (n = 14)
74 and rice bran water-soluble (n = 2) products. An off-the-shelf coffee percolator by
75 Andrew James, with no adaptation, was used to cook rice bran, as per Carey *et al.*
76 (2015). This type of coffee-maker provides a continual stream of percolating, near
77 boiling, water through a filter unit. Here, the water reservoir was filled with 1.5 L of
78 deionized water, which took 15 min. to fully discharge through the filter unit. In the

79 metal-mesh filter unit 20 g of bran was placed. The bran samples were then cooked in
80 1- 4 15 min. cycles with the reservoir re-filled at the end of each cycle, water-to-rice
81 bran ratios of which were 75:1, 150:1 and 300:1, respectively.

82

83 **2.2. Sample preparation and chemical analysis**

84 The raw and cooked rice bran samples were freeze-dried using a Christ Alpha 1-4 LD
85 Plus, and then powdered using a Retch PM100. The powder was used for X-ray
86 fluorescence (XRF) and near infrared (NIR) spectroscopy analyses. For arsenic
87 speciation powdered sample, 0.1 g, was accurately weighed into 50 ml polypropylene
88 centrifuge tubes and 10 ml of 1% concentrated nitric acid was added and left
89 overnight. Then samples were microwave digested in a CEM MARS 6 instrument for
90 30 min. at 95°C using a 3 stage slow heating program: to 55°C in 5 min. held for 10
91 min., to 75°C in 5 min., held for 10 min. to 95°C in 5 min., held for 30 min. The
92 digestate was centrifuged with a Sorvall Legend RT at 4,500 g and a 1 ml aliquot was
93 transferred to a 2 ml polypropylene vial and 10 μ l of analytical grade hydrogen
94 peroxide was added to convert any arsenite to arsenate to facilitate subsequent
95 chromatographic species separation by ion chromatography with mass spectrometric
96 detection (IC-ICP-MS). All samples were analyzed in 2 batches including 3 blanks
97 and 3 replicate samples of the certified reference material (CRM) NIST 1568b rice
98 flour per batch. For total element analysis by inductively coupled plasma - mass
99 spectrometric (ICP-MS) 2 ml of concentrated nitric acid and 2 ml of hydrogen
100 peroxide were added into 50 ml polypropylene centrifuge tubes containing 0.1 g of
101 powdered sample and left to stand overnight. The samples were microwave digested.
102 The temperature was raised to 95°C in 5 min. and held for 10 min. and then to 135°C
103 in 5 min. and held for 10 min. Finally the digest was taken up to 180°C in 5 min. and

104 maintained for 30 min. Samples were cooled to room temperature and then an internal
105 standard (30 µl of 10 mg/kg rhodium) was added to the digestate and accurately
106 diluted to 30 ml with deionized distilled water. Several blanks and samples of NIST
107 1568b rice flour CRM were included per batch of total element analysis.

108

109 A Thermo Scientific IC5000 ion chromatography (IC) system, with a Thermo AS7,
110 2x250 mm column and a Thermo AG7, 2x50 mm guard column interfaced with a
111 Thermo ICAP Q ICP-MS in collision cell mode was used to quantify arsenic
112 speciation. A linear gradient mobile phase was carried out over 15 minutes starting at
113 100% mobile phase of 20 mM ammonium carbonate and finishing at 100% mobile
114 phase of 200 mM ammonium carbonate. The resulting chromatogram was compared
115 with that for authentic standards; dimethylarsinic acid (DMA), i-As,
116 monomethylarsonic acid (MMA), tetramethylarsonium and arsenobetaine. DMA
117 concentration series were used to calibrate the arsenic present under each
118 chromatographic peak.

119

120 Total elements were also measured using the Thermo ICAP Q but in direct solution
121 acquisition mode. All elements reported were present both in calibration standards
122 and in CRM NIST 1568b with only elements with good CRM recoveries reported.
123 Additional elements were also analyzed by bench-top XRF (Rigaku CG), including
124 samples of NIST 1568b rice flour CRM in each batch of samples. Only elements
125 present in the CRM and with good analytical recoveries were presented. Rice bran
126 composition was also analyzed with a Thermo near infrared (NIR) spectroscopy. Each
127 rice bran samples was analyzed in triplicate and the mean value was used to calculate
128 the percentage of compositional variation of individual samples.

129

130 **2.3. Statistical analyses**

131 The median and range concentration of the main arsenic species in commercial rice
132 bran samples were determined. Likewise, total elements concentration (Ca, Cu, Fe,
133 Mn, P and S) and the percentage of the rice bran organic composition variation (fat,
134 fiber, protein, starch and sugar) according to the cooking percolating water-to-rice
135 bran ratio was also analyzed. The analysis of variance (ANOVA) and the Tukey's
136 range test were used to determine any significant differences in the main arsenic
137 species and total elements concentration between groups according to the volume of
138 percolating cooking water. All statistical analyses and plots were performed using the
139 R Statistical Software (R Core Team, 2014). The limit of detection (LOD) was
140 calculated as the mean of the blank concentrations plus three times the standard
141 deviation of the blank concentrations multiplied by the dilution factor. The $\frac{1}{2}$ LOD
142 value was assigned for statistical analyses of the data when samples were below the
143 LOD.

144

145 **3. Results**

146 The mean \pm SE concentration and recovery of rice CRM flour NIST-1568b for
147 arsenic species were: 0.099 ± 0.001 mg/kg and $107 \pm 2\%$ for i-As, 0.184 ± 0.007
148 mg/kg and $102 \pm 4\%$ for DMA, and 0.010 ± 0.001 mg/kg and $89 \pm 3\%$ for MMA,
149 based on $N = 6$. The arsenic species in the rice CRM had i-As, DMA and MMA
150 certified at 0.092 ± 0.010 mg/kg, 0.182 ± 0.012 mg/kg, and 0.0116 ± 0.0035 mg/kg,
151 respectively. The limit of detection (LOD) for arsenic speciation, calculated from
152 DMA calibration, was 0.002 mg/kg. All samples presented were above the LOD for
153 DMA and i-As, however, almost half of the rice bran samples analyzed had MMA

154 content below the LOD, and in this case $\frac{1}{2}$ LOD was used in statistical analysis of the
155 data.

156

157 The predominant arsenic species in the commercial rice bran samples analyzed was i-
158 As, followed by DMA and MMA (**Table 1**). The median and range percentage of i-As
159 in the entire commercial raw/uncooked rice bran dataset were 95.4% and 93.4% –
160 97.7 %, respectively. The commercial rice bran water-soluble samples, obtained with
161 the carbohydrases treatment (Qureshi et al., 2002), had 1.6-fold higher median i-As
162 (0.916 mg/kg) than that found in uncooked pure rice bran (0.561 mg/kg). The DMA
163 concentration in uncooked rice bran was about an order of magnitude lower than that
164 of i-As, with a median of 0.025 mg/kg and a range from 0.013 to 0.055 mg/kg for the
165 entire commercial uncooked rice bran dataset. Only ~half of the commercial raw rice
166 bran dataset had traces of MMA higher than the LOD, with a median of 0.003 mg/kg
167 ranging from <LOD to 0.006 mg/kg.

168

169 The i-As concentration in cooked rice bran was significantly lower compared to that
170 in the uncooked rice bran ($p<0.001$) (**Table 2**). This study shows that greater i-As
171 removal from cooked rice bran can be achieved with greater water-to-rice bran ratio,
172 but only up to a certain extent (**Table 2** and **Figure 1**). The i-As concentration in
173 cooked rice bran with 150:1 and 300:1 water-to-rice bran ratios did not differ
174 statistically (**Table 2**). A median percentage of 68% and 76% of i-As could be
175 removed at the highest water-to-rice bran ratios (150:1 and 300:1, respectively), and
176 even higher than 90% in some individual samples (**Figure 1**). The DMA
177 concentration in cooked rice bran was significantly lower compared with that in the
178 uncooked rice bran ($p<0.001$), however, the volume of cooking water did not affect

179 statistically the DMA concentration in the cooked rice bran (**Table 2**). A median
180 percentage of 52%, 62% and 65% of DMA could be removed at 75:1, 150:1 and
181 300:1 water-to-rice bran ratios, respectively (**Figure 1**). The cooking process did not
182 affect the MMA concentration in the rice bran. The MMA traces found in the
183 uncooked samples were still found in the cooked rice bran regardless of the volume of
184 the cooking water tested.

185

186 When a range of trace- and macro- elements were analyzed between uncooked and
187 cooked rice bran with different volumes of cooking water, only copper ($p = 0.002$),
188 potassium ($p < 0.001$), and phosphorus ($p < 0.001$) were significantly different, while
189 calcium, iron, manganese, sulfur and zinc were non-significant (**Table 2**). The loss of
190 copper, potassium and phosphorus during the cooking process was 37%, 54% and
191 16%, respectively, regardless of cooking water volume tested, which did not
192 statistically affect the concentration of these elements in the cooked rice bran (**Table**
193 **2**).

194

195 When the compositional variation in rice bran due to the cooking process with
196 different volumes of water was explored only the fiber and the sugar content seemed
197 to differ from the original content in the uncooked rice bran, while fat, protein and
198 starch appeared to be stable throughout the cooking process regardless of the volume
199 of cooking water (**Figure 2**). The fiber content in cooked rice bran had a median
200 percentage increment of 14%, 35%, and 40% compared to that in uncooked rice bran
201 when 75:1, 150:1 and 300:1 water-to-rice bran ratios were performed, respectively,
202 increment of which is probably due to the overall rice bran biomass decrease caused
203 during the cooking process. On the contrary, the relationship between fiber and sugar

204 had a negative correlation coefficient of -0.63, with a median percentage reduction of
205 sugar content of 35%, 57%, and 82% according to the level of percolating cooking
206 water volume.

207

208 **4. Discussion**

209 Rice bran has become a popular ingredient in “health-products” due to its positive
210 nutritional aspects. However, rice bran contains high concentrations of i-As, up to 1.1
211 mg/kg in this study here, which needs to be reduced to make rice bran suitable for the
212 human consumption. Using a continuous flow of arsenic-free near boiling water
213 percolated through pure rice bran enables an i-As removal from rice bran of up to
214 96%, a higher percentage than that previously reported for whole-grain and polished
215 rice samples where a maximum removal value of 85% was obtained for individual
216 rice samples (Carey et al., 2015). This may be related to the larger cooking water-to-
217 rice bran ratio used in this study (*i.e.* 300:1) compared to that previously tested with
218 rice (*i.e.* 12:1). A moderation of i-As removal efficiency from rice bran was described
219 for the higher volumes of cooking water, reaching a plateau at a cooking water-to-rice
220 bran ratio of 150:1. The i-As removal approach described here provides a novel
221 solution to significantly reduce the i-As concentration in pure rice bran below the UN
222 WHO advisory level and the maximum EU i-As limit for non-parboiled milled rice
223 (0.200 mg/kg). A patented methodology to remove arsenic in rice bran protein has
224 been previously developed in China; however, the patent differs from the approach
225 detailed in this study focused on i-As removal from whole rice bran instead of from
226 the subcomponent rice bran protein. In addition, the patented approach is for an
227 industrial setting, and combines a static cooking chemical extraction with sodium
228 hydroxide at pH 11.5 and a centrifugation step (China Faming Zhuanli Shenqing,

229 2013). Conversely, the approach described here can be applied from a
230 home/homestead to an industrial setting, and only uses pure water in a continuous
231 novel percolation cooking technique.

232

233 The heat involved in cooking may stabilize the rice bran by destruction or inhibition
234 of lipase – the enzyme that causes development of free fatty acids responsible for
235 rancidity, which would save including an extra process to stabilize the rice bran
236 (Nagendra Prasad MN et al., 2011). This remains to be tested along with the effect of
237 the cooking process on the sensorial features of the final rice bran, *i.e.* texture and
238 color; however, moist heat stabilization is one of the methods used in the normal rice
239 bran processing before its use (Kim, Chung, & Lim, 2014; Lakkakula, Lima, &
240 Walker, 2004; Patil, Kar, & Mohapatra, 2016).

241

242 The removal approach reduced the copper, potassium and phosphorus content in the
243 cooked rice bran; however, the concentrations of these elements were still very high
244 compared to that found in rice (Carey et al., 2015), and if necessary, they could be
245 refortified after cooking process. The i-As removal approach described here also
246 reduced the soluble sugar content in favor of an increment of insoluble dietary fiber in
247 treated rice bran, possibly due to the decrease in biomass. This could help in creating
248 healthier food products due to the cooked brans lower sugar and higher fiber content
249 (The Lancet, 2016; Wang, Suo, de Wit, Boom, & Schutyser, 2016). Neither vitamins
250 nor other bioactive compounds removed due to rice bran processing with percolating
251 near boiling water were assessed here, and thus further studies are required to address
252 this, especially for those water-soluble and thermo sensitive, *i.e* B-vitamins group and
253 phenolic compounds, which rice bran contains in notable amounts (Kim & Lim, 2016;

254 Patil et al., 2016; Tuncel, Yilmaz, Kocabiyik, & Uygur, 2014). Again, if key vitamins
255 are remove, these could be refortified if necessary.

256

257 The approach studied here demonstrates that the continual percolating of near boiling
258 cooking water flow principle is an efficient i-As whole rice bran removal method. The
259 high volumes of water used here could be greatly reduced if the cooking water was
260 recycled through distillation by using the previously validated for i-As removal from
261 rice grain (Carey et al., 2015).

262

263 **Acknowledgment**

264 This work was funded by a Marie Curie Intra-European Fellowship within the 7th
265 European Community Framework Programme (PIEF-GA-2013-622096).

266

267 **References**

- 268 Carey, M., Jiujin, X., Gomes Farias, J., & Meharg, A. A. (2015). Rethinking Rice
 269 Preparation for Highly Efficient Removal of Inorganic Arsenic Using
 270 Percolating Cooking Water. *Plos One*, *10*(7), e0131608.
 271 <http://doi.org/10.1371/journal.pone.0131608>
 272 China Faming Zhuanli Shenqing. (2013). One for the removal of arsenic in rice bran
 273 method. Retrieved from
 274 <https://patentimages.storage.googleapis.com/pdfs/5b58c5d309eeb9a5b3ff/CN10>
 275 [3461646B.pdf](https://patentimages.storage.googleapis.com/pdfs/5b58c5d309eeb9a5b3ff/CN10)
 276 EC. (2015). *Commission Regulation 2015/1006 of 25 June 2015 amending Regulation*
 277 *(EC) No 1881/2006 as regards maximum levels of inorganic arsenic in*
 278 *foodstuffs*. Retrieved from [eur-lex.europa.eu/legal-](http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2015_161_R_0006)
 279 [content/EN/TXT/?uri=OJ:JOL_2015_161_R_0006](http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2015_161_R_0006)
 280 FDA. (2016). *FDA proposes limit for inorganic arsenic in infant rice cereal*.
 281 Retrieved from
 282 <http://www.fda.gov/newsevents/newsroom/pressannouncements/ucm493740.htm>
 283 Kim, S., Chung, H., & Lim, S. (2014). Effect of various heat treatments on rancidity
 284 and some bioactive compounds of rice bran. *Journal of Cereal Science*, *60*(1),
 285 243–248. <http://doi.org/10.1016/j.jcs.2014.04.001>
 286 Kim, S., & Lim, S. (2016). Enhanced antioxidant activity of rice bran extract by
 287 carbohydrase treatment. *Journal of Cereal Science*, *68*, 116–121.
 288 <http://doi.org/10.1016/j.jcs.2016.01.006>
 289 Lakkakula, N. R., Lima, M., & Walker, T. (2004). Rice bran stabilization and rice
 290 bran oil extraction using ohmic heating. *Bioresource Technology*, *92*(2), 157–
 291 161. <http://doi.org/10.1016/j.biortech.2003.08.010>
 292 Meharg, A. A., Lombi, E., Williams, P. N., Scheckel, K. G., Feldmann, J., Raab, A.,
 293 ... Islam, R. (2008). Speciation and localization of arsenic in white and brown
 294 rice grains. *Environmental Science & Technology*, *42*(4), 1051–1057.
 295 <http://doi.org/10.1021/es702212p>
 296 Meharg, A. A., & Zhao, F. J. (2012). *Arsenic & Rice*. Berlin: Springer-Verlag.
 297 Nagendra Prasad MN, N. P., Kr, S., & Khatokar M, S. (2011). Health Benefits of Rice
 298 Bran - A Review. *Journal of Nutrition & Food Sciences*, *1*(3), 1–7.
 299 <http://doi.org/10.4172/2155-9600.1000108>
 300 Patil, S. S., Kar, A., & Mohapatra, D. (2016). Stabilization of rice bran using
 301 microwave: Process optimization and storage studies. *Food and Bioproducts*
 302 *Processing*, *99*, 204–211. <http://doi.org/10.1016/j.fbp.2016.05.002>
 303 Qureshi, A. A., Sami, S. A., & Khan, F. A. (2002). Effects of stabilized rice bran, its
 304 soluble and fiber fractions on blood glucose levels and serum lipid parameters in
 305 humans with diabetes mellitus Types I and II. *Journal of Nutritional*
 306 *Biochemistry*, *13*(3), 175–187. [http://doi.org/10.1016/S0955-2863\(01\)00211-X](http://doi.org/10.1016/S0955-2863(01)00211-X)
 307 R Core Team. (2014). *R: A Language and Environment for Statistical Computing*, *R*
 308 *Foundation for Statistical Computing*. Vienna. Retrieved from [http://www.r-](http://www.r-project.org/)
 309 [project.org/](http://www.r-project.org/)
 310 Sun, G., Williams, P. N., Carey, A.-M., Zhu, Y. G., Deacon, C., Raab, A., ... Meharg,
 311 A. A. (2008). Inorganic arsenic in rice bran and its products are an order of
 312 magnitude higher than in bulk grain. *Environmental Science and Technology*,
 313 *42*(19), 7542–7546. <http://doi.org/10.1021/es801238p>
 314 The Lancet. (2016). Obesity: we need to move beyond sugar. *The Lancet*.
 315 [http://doi.org/10.1016/S0140-6736\(16\)00091-X](http://doi.org/10.1016/S0140-6736(16)00091-X)

316 Tuncel, N. B., Yilmaz, N., Kocabiyik, H., & Uygur, A. (2014). The effect of infrared
317 stabilized rice bran substitution on B vitamins, minerals and phytic acid content
318 of pan breads: Part II. *Journal of Cereal Science*, 59(2), 162–166.
319 <http://doi.org/10.1016/j.jcs.2013.12.005>

320 Wang, J., Suo, G., de Wit, M., Boom, R. M., & Schutyser, M. A. I. (2016). Dietary
321 fibre enrichment from defatted rice bran by dry fractionation. *Journal of Food*
322 *Engineering*, 186, 50–57. <http://doi.org/10.1016/j.jfoodeng.2016.04.012>

323 WHO. (2014). *WHOCodex Alimentarius Commission—Geneva 14–18 July 2014*.
324 Retrieved from <http://www.fao.org/news/story/en/item/238558/icode/>

325 Williams, P. N., Villada, A., Deacon, C., Raab, A., Figuerola, J., Green, A. J., ...
326 Meharg, A. A. (2007). Greatly enhanced arsenic shoot assimilation in rice leads
327 to elevated grain levels compared to wheat and barley. *Environmental Science*
328 *and Technology*, 41(19), 6854–6859. <http://doi.org/10.1021/es070627i>

329 Zhang, H.-J., Zhang, H., Wang, L., & Guo, X.-N. (2012). Preparation and functional
330 properties of rice bran proteins from heat-stabilized defatted rice bran. *Food*
331 *Research International*, 47(2), 359–363.
332 <http://doi.org/10.1016/j.foodres.2011.08.014>
333
334

335 **Table 1:** Inorganic arsenic and DMA concentration in commercial rice bran, and
 336 percentage of inorganic arsenic (median (min – max)). *RB = Pure rice bran and RB
 337 WS = Rice bran water-soluble.

Commercial RB	N	i-As (mg/kg d.w.)	DMA (mg/kg d.w.)	i-As %
RB	14	0.561 (0.376 - 0.818)	0.025 (0.013 - 0.032)	95.5 (93.4 - 97.7)
RB_WS	2	0.916 (0.753 - 1.079)	0.041 (0.028 - 0.055)	95.6 (95.0 - 96.3)
RB_1	3	0.668 (0.664 - 0.818)	0.016 (0.013 - 0.018)	97.6 (96.5 - 97.7)
RB_2	4	0.570 (0.535 - 0.626)	0.025 (0.024 - 0.025)	95.6 (95.4 - 95.9)
RB_3	2	0.533 (0.504 - 0.562)	0.027 (0.024 - 0.030)	94.5 (94.3 - 94.7)
RB_4	1	0.583 (0.583 - 0.583)	0.027 (0.027 - 0.027)	94.8 (94.8 - 94.8)
RB_5	1	0.561 (0.561 - 0.561)	0.030 (0.030 - 0.030)	94.1 (94.1 - 94.1)
RB_6	2	0.521 (0.484 - 0.559)	0.030 (0.029 - 0.032)	93.5 (93.4 - 93.6)
RB_7	1	0.376 (0.376 - 0.376)	0.017 (0.017 - 0.017)	95.6 (95.6 - 95.6)
RB_8_WS	1	1.079 (1.079 - 1.079)	0.055 (0.055 - 0.055)	95.0 (95.0 - 95.0)
RB_9_WS	1	0.753 (0.753 - 0.753)	0.028 (0.028 - 0.028)	96.3 (96.3 - 96.3)

338

339

Table 2: Arsenic speciation (i-As and DMA), and total calcium, copper, potassium, iron, manganese, phosphorus, sulfur, and zinc in raw and cooked rice bran according to the cooking time (median (min – max)).

Water:Rice ratio	N	i-As (mg/kg)	DMA (mg/kg)	Ca (mg/kg)	Cu (mg/kg)	K (mg/kg)
Uncooked	7	0.601 (0.535 - 0.818) ^a	0.025 (0.013 - 0.030) ^a	515.0 (402.0 - 769.0)	10.60 (9.350 - 13.90) ^a	15,300 (14,000 - 19,700) ^a
75:1	7	0.374 (0.277 - 0.526) ^b	0.012 (0.006 - 0.020) ^b	379.0 (299.0 - 787.0)	6.980 (6.380 - 10.00) ^b	8,430 (8,030 - 12,000) ^b
150:1	7	0.212 (0.032 - 0.376) ^c	0.007 (0.003 - 0.014) ^b	489.0 (228.0 - 661.0)	6.860 (5.090 - 11.10) ^b	6,720 (4,040 - 10,800) ^b
300:1	4	0.167 (0.028 - 0.260) ^c	0.006 (0.003 - 0.011) ^b	445.5 (389.0 - 567.0)	6.195 (5.850 - 9.890) ^b	4,805 (1,890 - 10,500) ^b
<i>p</i> -value		<0.001	<0.001	0.543	0.002	<0.001

Water:Rice ratio	N	Fe (mg/kg)	Mn (mg/kg)	P (mg/kg)	S (mg/kg)	Zn (mg/kg)
Uncooked	7	84.90 (79.90 - 131.0)	276.1 (214.7 - 417.1)	18,679 (17,131 - 20,703) ^a	1,530 (1,340 - 1,830)	60.60 (46.00 - 73.50)
75:1	7	71.50 (62.30 - 91.40)	291.2 (231.4 - 408.6)	16,238 (14,649 - 17,376) ^{ab}	1,390 (1,250 - 1,840)	52.90 (38.60 - 56.00)
150:1	7	75.50 (53.40 - 149.0)	303.5 (233.5 - 427.1)	14,776 (11,064 - 17,237) ^b	1,450 (1,090 - 2,120)	54.30 (35.90 - 84.50)
300:1	4	67.25 (51.00 - 118.0)	382.8 (319.4 - 424.8)	14,494 (11,151 - 16,536) ^b	1,235 (1,010 - 2,090)	48.50 (34.50 - 77.40)
<i>p</i> -value		0.504	0.362	<0.001	0.635	0.601

Figure 1: Inorganic arsenic and DMA concentration in rice bran, and removal percentage according to water-to-rice bran ratio.

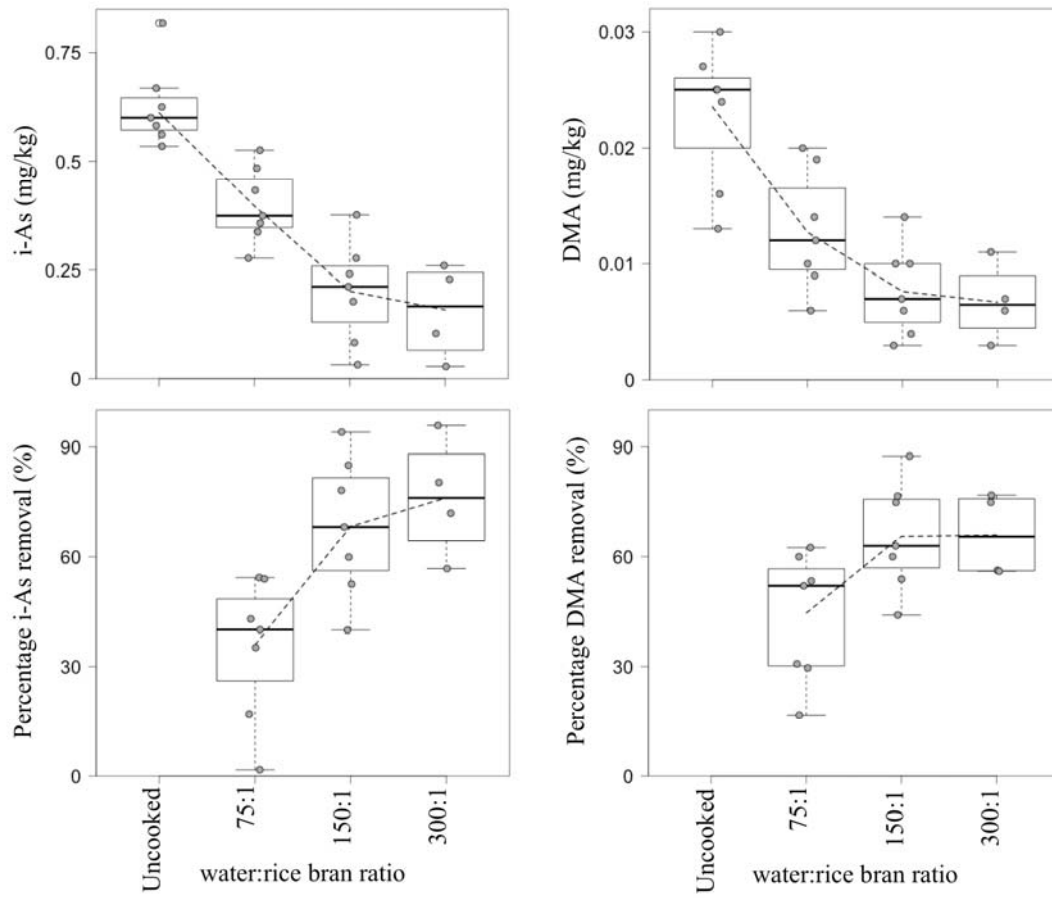


Figure 2: Percentage of compositional variation according to the water-to-rice bran ratio. Each point at 75:1 and 150:1 ratios shows the median percentage obtained from 7 rice bran samples, respectively. Each point at 300:1 ratio shows the median percentage obtained from 4 rice bran samples.

