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Inorganic arsenic in rice and rice-based diets: health risk assessment

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ABSTRACT

Total and inorganic arsenic (As) content in rice and rice-based diets (n=59) obtained from supermarkets in South Australia were studied to investigate the contamination levels and whether consumption of these products pose potential health risks to young children and adults. Results show that of the 59 rice-based products, 31 (53 %) exceeded the EU recommended value (100 µg/kg) of As for young children and 13 (22%) samples had higher than maximum level of 200 µg/kg recommended for adults. Arsenic content varies as rice crackers > baby rice > rice cakes > puffed rice > other rice-based snacks > ready-to-eat rice. Of the 6 categories of
rice-based products, except ready-to-eat rice, all others exceeded the EU recommended value for young children. Even manufacture recommended servings deliver significant amounts (0.56 to 6.87 µg) of inorganic As. These amounts are within the range of $\text{BMDL}_{01}$ values indicated by the European Food Safety Authority (EFSA), which means the risk cannot be avoided for young children and adults considering the levels of total and inorganic As in rice-based products.

**Keywords:** Rice-based products, Young children, Inorganic As, Health risk, BMDL

### 1. Introduction

Arsenic is a naturally occurring toxic element, which is ubiquitous in the environment and has been classified as a human carcinogen (group I), which with sustained exposure causes both carcinogenic and non-carcinogenic problems including nervous system disorder, developmental and reproductive issues, diabetes, heart disease and many more (IARC, 2004). Inorganic As [As(III) and As(V)] is more toxic compared to organic As [dimethylarsinic acid (DMA) and monomethylarsonic acid (MMA)]. Both As(III) and As(V) are potentially harmful to humans and animals, although As(III) is more toxic (Hindmarsh, et al., 1986; Vega, et al., 2001). Humans’ exposure to As mainly occurs through: firstly, drinking As-contaminated groundwater and consuming food crops grown in agricultural lands contaminated with As; and secondly, where contaminated irrigation water is used for cropping. Whenever, rice is the staple diet, As exposure from rice can be considerable and intake of inorganic As via this route is a significant risk factor, especially for populations who depend substantively on a rice diet.
Elevated concentrations of As have been detected in rice in several South-East Asian countries, which poses an additional risk to consumers (Correll, et al., 2006; Mondal, et al., 2010; Pal, et al., 2009; Rahman, et al., 2009; Williams, et al., 2005). In rice grown in the Bengal Delta, the predominant As species present are usually inorganic and a small portion of organic As also exists (Williams, et al., 2005). It was reported from West Bengal, India, that cooked rice with elevated As (>200 µg/kg) caused genotoxicity and it was found that As from cooked rice alone was responsible for the observed genetic effects in the study population (Banerjee, et al., 2013). Due to the global food trade, millions of consumers are likely to be potentially exposed to As from the imported foods, especially rice and rice-based food products (Rahman, et al., 2014).

In most cases, whole grain and polished rice, and bran are used to produce a variety of rice-based foods. These rice-based products are very popular worldwide especially for young children who are assumed to be the most vulnerable consumer group to As toxicity; they have a higher As body burden than adults (Rahman, et al., 2001). A study in the US suggests that rice is a potential source of As exposure for children (Davis, et al., 2012). The impact of a mother’s As consumption on fetal gene expression is evidenced by transcript levels in newborn cord blood (Fry, et al., 2007). Studies have also provided evidence that children are more susceptible to the toxic effects of inorganic As (Vahter, 2008, 2009).

Several studies have reported that rice and rice-based products used for infants contained high levels of both total and inorganic As (Ljung, et al., 2011; 2008; Signes-Pastor, et al., 2016; Sun, et al., 2009). Research has shown that at least 50% of rice-based food products in the UK have As levels which exceeded those being proposed by the European Union (EU); 179 different products were tested and 53% of these products had As higher than the maximum level of 100 µg/kg recommended for young children (Signes-Pastor, et al., 2016). The Commission Regulation (EU) 2015/1006 of 25 June 2015 has issued a limit value of 100 µg/kg
for rice destined for the production of foods for infants and young children and 200 μg/kg for adults. This regulation has been in force since January 1, 2016 (EFSA, 2014). In 2014, the European Food Safety Authority (EFSA) investigated the dietary exposure of people in 21 European countries to inorganic As, and the data show that grain-based processed products are the main contributors of inorganic As for all age groups except infants and toddlers (EFSA 2014). The mean dietary exposure to inorganic As among these groups ranged between 0.20 to 1.37 μg/kg bw per day (EFSA 2014). The mean dietary exposure to inorganic As according to surveys in the adult population (including adults, elderly and very elderly) ranged from 0.09 to 0.38 μg/kg bw per day (EFSA 2014).

A recent study on Australian rice, notably brown rice, found As content substantially higher than imported rice on sale in Australia which poses potential serious health risk to Asian adult immigrants (Rahman, et al., 2014). A few studies have been conducted on potential health risk of As to children from their rice-based food products in Europe and the US, but no information is available about the health risk of toxic inorganic As in products produced in Australia. This is especially so given that such products besides being consumed here are also exported to other countries, for example China and South Korea. For this reason, it is crucial to investigate the As levels in rice-based diets available in Australia and its associated health risk to both adults and young children. Considering that As is carcinogenic and highly toxic, reliable assessments of the health risks associated with the intake of As through rice-based products consumption are urgently needed, especially for children. In this study, we determine the levels of As (total and inorganic) in a variety of rice and rice-based products, and to assess inorganic As exposure and its associated health risks to both adults and young children.

2. Materials and methods

2.1 Selection of samples
Fifty-nine rice products in 6 categories commonly found in supermarkets were analyzed for total and speciated As. Samples of rice crackers [cracker is a baked food typically made from rice flour (n=10)], rice cakes [rice cake is a kind of food item made from puffed rice that has been shaped, condensed, or otherwise combined into a single object (n=11)], puffed rice [puffed rice is a type of puffed grain made from rice, commonly used in breakfast cereal or snack foods (n=6)], baby rice [ground rice cereals consumed by baby to young children (n=4)], ready-to-eat rice [cooked rice ready to eat, only need 2-3 minutes heat using microwave oven (22)] and other rice-based snacks [rice biscuits, rice hoops etc.(6)] of 25 different popular commercial brands were purchased from supermarkets in Adelaide, South Australia during February 2015. The samples’ expiry date (best before use) was between April, 2015 and March, 2016.

2.2 Sample preparations

With the exception of ready-to-eat rice, all rice-based products were oven dried (60 °C) and ground with mortar and pestle before microwave digestion for analysis. Between each samples, mortar and pestle were washed in tap water, deionised water and dried in a fan forced oven. For total As examination, the powdered samples were weighed accurately to 0.5 g into microwave digestion tubes to which 2mL MQ water (ELGA Labpure), 3 mL trace analytical grade HNO$_3$ (70%), obtained from Fisher Chemicals and 2 mL H$_2$O$_2$ (30%, Ajax Finechem) were added and allowed to sit overnight (12 hours). A microwave digestion system with 40 rotors (MARS 6, CEM) served for the digestion of the samples. Batches of 30 samples were prepared including a blank and a standard reference material (SRM 1568b rice flour) obtained from the National Institute of Standard and Technology (NIST), USA. Firstly, the temperature was raised to 55 °C, and held for 10 minutes, and then 75 °C, and again held for 10 minutes. Finally, temperature was lifted to 90 °C and held for 30 minutes. The ready-to-eat rice was directly weighed and followed the same digestion procedure as described above. The digests
were diluted to 10 mL using 0.1% HNO$_3$ and then passed through a 0.45 µm syringe filter (MCE, Agilent Technologies). Finally, 10 mL aliquot of the digest from each tube was transferred to a plastic tube for instrumental analysis.

Arsenic speciation analysis (inorganic As, MMA and DMA) was carried out with the procedure utilized by Signes-Pastor, et al. (2016). Briefly, the powdered samples were weighed accurately to 0.25 g into microwave digestion tubes to which 10 mL of 1% conc. HNO$_3$ (trace analysis grade) was added and allowed to sit overnight (12 hours). Batches of 30 samples were prepared including a blank and a SRM (1568b rice flour), which has inorganic As [As(III) and As(V)], DMA and MMA concentrations certified. The samples were then digested in the microwave digestion system. The digests were diluted to 10 mL and filtered by a 0.45 µm syringe filter. Lastly, 1 mL aliquot of the digest from each tube was transferred to a 2 mL HPLC glass vial (amber) for chromatographic analysis. For both total As and its speciation we have run three replicates of each samples.

2.3 Instrumentation

An Agilent 7500ce (Agilent Technologies, Tokyo, Japan) inductively coupled plasma mass spectrometer (ICP-MS) coupled with auto-sampler (ASX-520, CETAC Technologies) and integrated samples introduction system (ISIS) was used to determine the amount of As in the digested samples. An Agilent 1100 liquid chromatography system (Agilent Technologies, Tokyo, Japan) equipped with a guard column and a Hamilton PRP-X100 separation column, coupled with ICP-MS served to determine As species. The detection limit (DL) of the total As was 0.01 µg/L. The detection limit for speciation in As standard solutions [As(III), As(V), DMA and MMA] by the IC-ICP-MS ranged between 0.1 and 0.3 µg/l (Chen, et al., 2008).

2.4 Quality control: analysis of Standard Reference Materials (SRM)

We found the concentration of total As in rice flour was SRM 270±13 (n=6) µg/kg, which indicates 95% recovery of the certified value of 285±14 µg/kg. Similar SRM was used to
validate the results of As speciation in rice-based samples included in this study. Our results revealed that inorganic As recovery was around 98%. The certified values for inorganic As, MMA and DMA of SRM 1568b were 92±10 µg/kg, 11.6±0.3 µg/kg and 180±12 µg/kg, respectively. The observed values (n=6) were 90±20 and 176±10 µg/kg for inorganic As and DMA, respectively. We were unable to detect any MMA in rice SRM.

2.5 Statistical analysis

Data were analyzed by SAS Institute created statistical software JMP (the powerful statistical and analytic capabilities tool used for data explorers worldwide) version 11.1n. Statistical analysis was also done employing Microsoft Excel 2013.

2.6 Calculation of health risk of inorganic As

According to the Food and Agricultural Organization (FAO)/World Health Organization (WHO), three basic approaches can be used to determine the dietary intake of chemical contaminants from foods: (i) total diet study, (ii) duplicate diet method, and (iii) diary study (WHO, 1985). These approaches combine the concentration of specific contaminants in foods with individual consumption rates. In this study, the total diet study approach was used to determine the dietary intake of inorganic As from rice-based products.

Inorganic As intake per serving (µg) from rice-based products:

\[ EIPS = (C_{i\text{As}} \times RS_{\text{rice-based products}}) \]  
(1)

Where, EIPS represents estimated intake per serving (µg); \( C_{i\text{As}} \) represents inorganic As concentration in rice-based products (µg/kg); RS: Average recommended serving (g/person/day) by the manufacturer.

Estimated Weekly Intake (EWI; µg/kg body weight):

\[ EWI = (EIPS \times 7)/W_{AB} \]  
(2)
Where, EIPS is the estimated intake per serving (µg) and $W_{AB}$ is average body weight, assuming 10 kg for young children (WHO, 2014) and 60 kg for adults (Li, et al., 2011) in this study to calculate the As intake.

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) withdrew the provisional tolerable weekly intake (PTWI) of 15 µg/kg bw in 2010. Based on other epidemiological studies, JECFA identified a benchmark dose lower confidence limit for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$) of 3.0 µg/kg bw per day (2-7 µg/kg bw per day based on the estimated total dietary exposure range) (WHO, 2011). Prior to that, the EFSA Panel on Contaminants in the Food Chain concluded that the PTWI of 15 µg/kg bw was no longer appropriate and the panel established a $BMDL_{0.01}$ between 0.3 and 8 µg/kg bw per day for an increased risk of cancer of the lung, skin and bladder, and skin lesions (EFSA, 2009). The US Environmental Protection Agency (EPA) has also declared that there is no "safe" level of exposure to inorganic As. Total dietary intake and health risk of inorganic As species were estimated for two major consumer groups: (i) young children and (ii) adults (only for ready-to-eat rice).

3 Results and discussion

Mean total and inorganic As content in 6 categories of rice-based foods is shown in Fig. 1. The average As content in rice-based products ranging between 30 to 273 µg/kg (Table 1). Out of 59 rice-based products, 31 (53%) exceeded the EU recommended value (100 µg/kg) of As for young children, which is comparable with the previous study (Signes-Pastor, et al., 2016) conducted in Europe. It is also notable that As greater than 200 µg/kg (EU recommended value for rice-based product for adults) was detected in 13 (22%) rice-based products. Out of 6 categories of rice products, except ready-to-eat rice, all others exceeded the EU recommended value of As for young children. Variations in total As in rice-based products appear to be linked to their source as well as type of product. About 93% of rice-based products including rice
crackers, rice cakes and baby rice produced from Australian-grown rice contained significant
levels of total As (up to 456 µg/kg) and inorganic As (up to 270 µg/kg). For all rice products
investigated in this study, inorganic As was the predominant species and ranged from 35% to
100%, with the remainder being DMA. The inorganic As percentage in different rice products
differs and this may be due to the inherently found total As and their speciation (Williams, et
al., 2005).

Arsenic content in rice varied widely due to the geographical variation, low in Indian
Basmati and high in EU, US and Australian rice (Rahman, et al., 2014; Williams, et al., 2005;
2007; Zavala & Duxbury, 2008). The bioavailability of As species varied considerably and
inorganic As is more toxic than organic As and usually present in rice diet (Petrick, et al.,
2000), at around 90% which is high (Juhasz, et al., 2006). Processing of raw rice is likely to
influence the speciation in rice-based products. The main As components in both white and
brown rice are inorganic As and DMA (Laparra, et al., 2005; Williams, et al., 2006; Williams,
et al., 2005; 2007), while brown rice has high levels of inorganic As. This is due to the presence
of a brown layer. This study also confirms there is more As in brown rice-based products
compared to white or Basmati rice.

3.1 Rice crackers

Rice crackers are popular rice-based diets and are eaten by people of all ages. Out of 10
samples analyzed, all exceeded the EU recommended value (100 µg/kg) of As for young
children. Of much concern were 3 samples in which As exceeded 200 µg/kg. The average total
As in rice crackers produced from Australian rice was 239 µg/kg, while the highest inorganic
As content was 126 µg/kg, however, the Thai product contained 171 µg/kg of total As and 61
µg/kg of inorganic As (Table 1). Speciation of As in rice crackers (n=10) showed that inorganic
As species comprised the major portion ranging from 42% to 83% compared to the organic
species. These results are consistent with findings published in previous studies where
researchers found that inorganic As is the key species in rice crackers (average of 145 µg/kg ranging from 75-90% of the total As (Sun, et al., 2009) and 102 µg/kg ranging from 54-86% of the total As (Signes-Pastor, et al., 2016). The recommended serving is 30 g of rice crackers which was obtained from the product packet and one serving could deliver between 1.3 and 3.2 µg of inorganic As to consumers (Table 2). These values are within the current BMDL$_{01}$ range. Since all rice crackers had As greater than the EU recommended value (100 µg/kg) for young children, the risk cannot be excluded for consuming rice crackers. This is also higher than the previous provisional tolerable daily intake (PTDI) value of 2.1 µg/day/kg body weight, indicating that inorganic As species rice crackers may potentially pose considerable health risk to young children if this rice-based food is consumed on a daily basis.

3.2 Puffed rice

Rice constitutes the major ingredient for puffed rice, which is traditionally used as a snack food. Out of 6 puffed rice samples, half exceeded the EU recommended value (100 µg/kg) of As for young children and 2 samples had As greater than 200 µg/kg. The average total As content found in the puffed rice imported from New Zealand (213 µg/kg; n=3) was 3 times higher than that in Australian puffed rice (77 µg/kg; n=3). Speciation of As in puffed rice samples of this study showed inorganic As was the major species (32%-73%). Though the New Zealand rice contains total As 3 times higher than Australian rice, the average inorganic As content in puffed rice of Australian origin was 45 µg/kg, whereas it was 54 µg/kg in New Zealand origin puffed rice. According to the manufacturers’ recommendation, 20 to 30 g per day serving of puffed rice could deliver between 0.87 and 1.62 µg of inorganic As to consumers (Table 2). While these values are within the current BMDL$_{01}$ range, it should be noted that 50% of puffed rice crackers had As exceeding 100 µg/kg, so the health risk from consuming puffed rice cannot be neglected. Based on the results presented here, it is apparent that inorganic As levels in puffed rice is of concern although this value is substantially less than the
previous PTDI limit (2.1 µg/day/kg body weight). A previous study indicated that inorganic
As species was the major component (77% of the total As) in puffed rice with an average total
As content of 140 µg/kg (Sun, et al., 2009), which is 3 times greater than that found in this
study.

3.3 Rice cakes

The rice cake is a kind of food item made from rice that has been shaped, condensed, or
otherwise combined into a single object. Like other rice-based products, rice cakes are used for
light dinner or lunch, and in Australia they are made of 100% Australian-grown whole grain
brown rice. The concentrations of total As in rice cake in this study ranged from 58 to 384
µg/kg (Table 1), which is consistent with the results of total As concentrations in Australian-
grown organic brown, medium grain brown, and organic white rice of 438 ± 23, 287 ± 03, and
283 ± 18 µg/kg, dry weight, respectively (Rahman, et al., 2014). Nine and 4 out of 11 rice cakes
had As greater than 100 µg/kg and 200 µg/kg, respectively. The highest levels of inorganic As
was 105 µg/kg in Australian rice cakes. The manufacturer’s recommended serving is 15 to 20
g and therefore, one serving could deliver between 0.6 and 2.3 µg of inorganic As (Table 2)
indicating that the rice cake itself can satisfy the previous PTDI of inorganic As (2.1 µg/day/kg
body weight) for a consumer. This value is also within the BMDL<sub>01</sub> range. Since 82% and 36%
of the samples had As greater than the EU recommended values of 100 µg/kg (for children)
and 200 µg/kg (for adults), respectively, the risk cannot be avoided for children consuming
rice cakes on a daily basis.

3.4 Baby rice

Total As concentration in baby rice samples ranged from 59 to 357 µg/kg (n=4; Table 1).
Although we investigated only 4 samples from this category, 3 samples had As greater than
100 µg/kg. The average concentration of total As in Australian baby rice was 268 µg/kg,
whereas this value was 140 µg/kg in baby rice imported from other countries. The inorganic
As concentration in 4 baby rice samples of 4 different commercial brands ranged from 46 to 108 µg/kg (22% to 100%) (Table 1). This is consistent with the studies conducted in Spain by Carbonell-Barrachina, et al. (2012) and Signes-Pastor, et al. (2016). Baby rice of Australian origin contained less inorganic As (51%) than other countries (85%). The same trend regarding As speciation has been reported elsewhere (Meharg, et al., 2009; Torres-Escribano, et al., 2008). The manufacturer’s recommended serving of baby rice is 30 to 90 g. Therefore, one serving of baby rice per day could deliver between 1.9 and 6.9 µg of inorganic As (Table 2). This value is also within the BMDL\textsubscript{01} range. Considering the total As values detected in baby rice, the risk cannot be ignored for children consuming baby rice, thus indicating this rice-based food does pose a serious health risk to consumers.

3.5 Ready-to-eat rice

Total As concentration in ready-to-eat rice samples of 5 different commercial brands ranged from 14 to 90 µg/kg (Table 1). Out of 21 samples, all had As less than the EU recommended value of 100 µg/kg for young children. The average total As content in Australian ready-to-eat rice was 54 µg/kg (n=8), while it was 30, 39 and 32 µg/kg in Indian, Thai and UK ready-to-eat rice, respectively. While the inorganic As concentration ranged from not detectable (ND) to 94 µg/kg (Table 1), the percentage of inorganic As in ready-to-eat rice ranged from ND to 100% of the total speciated As. The ready-to-eat rice of Australian origin contained more inorganic As (77%) than that imported from other countries (57 to 73%). The recommended serving of ready-to-eat rice is 125 g. Therefore, one serving of ready-to-eat rice per day could deliver between 1.6 and 5.6 µg of inorganic As (Table 2), which is substantially higher than that of previous PTDI of 2.1 µg/day/kg bw set by the FAO/WHO Joint Expert Committee on Food Additives (JECFA). This value indicates consuming ready-to-eat rice does pose a serious health risk to the consumers.

3.6 Other rice-based snacks
We also analyzed 6 other rice-based snacks produced in Australia and imported from other
countries. Four of these 6 samples had As greater than the EU recommended value of 100
µg/kg for young children. On average, the snacks of Australian origin contained substantially
higher amounts of total As (273 µg/kg) than that of other countries (93 µg/kg). Inorganic As
content was also higher in Australian snacks (88µg/kg) compared to snacks imported from
other countries (28 to 44 µg/kg). Considering the recommended serving of 30 g snacks,
inorganic As intake from Australian snacks was 7.7 µg, which is substantially higher than the
previous PTDI (2.1 µg/day/kg body weight). This indicates the rice-based food is a health risk
to consumers. A comparison of the results of As content in rice-based products of this study
and other published studies is presented in Table 3.

3.7 Inorganic As intake and health risk for young children

In this study, young children’s health risk when exposed to inorganic As was determined
with a consideration of the dietary intake of inorganic As from rice-based products by using
equation numbers (1) and (2). The calculations of estimated weekly intake (EWI) and the
percentage of PTWI of inorganic As were based on: firstly, the manufacturer’s recommended
serving of rice-based products; and secondly, the average body weight for young children (10
kg) and adults (60 kg). Estimations of inorganic As exposure for young children from baby
rice, rice cakes, rice crackers, puffed rice and other snacks are presented in Fig. 2.

The results from Table 2 clearly indicate that young children are at risk of inorganic As
exposure from most rice-based products. Even manufacturers’ recommended servings deliver
significant amounts (0.56 to 6.87 µg) of inorganic As to consumers. These values were within
the range of BMDL_{0.01} identified by the EFSA, meaning the risk cannot be avoided for young
children and even adults when accounting for the levels of total and inorganic As in rice-based
products. On average, young children under 5 years of age eat three times more food than
adults on a body weight basis. Also, this sub-population is much more vulnerable than adults.
These facts may suggest young children face three times greater risk of exposure to inorganic As from the same food item. Children being exposed to As also associated with increased risk of respiratory infections (Gardner, et al., 2013). Early life chronic exposure to high levels of As is associated with poor growth and other long-term consequences such as increased blood pressure and compromised kidney function (Flanagan, et al., 2012; Gardner, et al., 2013; Hawkesworth, et al., 2012). One study found that an increase of 1/4-cup cooked rice consumption results in 14% increase of urinary As concentration in American children (Davis, et al., 2012). Vahter, et al. (2014) noted that the impact of early-life As exposure may constitute a major human health problem.

4 Conclusions

Rice-based food products are popular and half of the world’s population relies on rice-based diets. Some particular brands are favored by young children and eaten almost every day. This study shows that more than 53% of rice products had As greater than the EU recommended value of 100 µg/kg for young children and even 22% of samples had As greater than 200 µg/kg. Almost all rice-based products have been found to contain a good percentage of inorganic As, therefore the health risk posed by consuming rice-based products cannot be ignored for young children. It is crucial to minimize the inorganic As exposure from rice-based diets for young children. To reduce the risk of As, we recommend that young children eat no more than 1 serving of rice-based products per day on average and their diets should include cereals that contain significantly lower levels of As. When manufacturing rice-based products, rice varieties with much less inorganic As should be used to abate exposure to inorganic As.

As this preliminary study focuses on inorganic As exposure in rice-based products on sale in Adelaide supermarkets, the main limitation of this study is the sample size of each rice-based product. Future studies should investigate the other major rice-based products from all supermarkets of Australia. The main strength of this paper is that it provides useful data on
inorganic As concentration in food products sale in Australia and their associated health risks for young children who consume these products. The results will be of great interest to researchers, stakeholders, policy-makers, and agriculture managers. They will be able to develop management strategies to minimize young children’s exposure to inorganic As and curtail the risks associated with these rice-based products. Since Australia is recognized as an exporter of quality food products and China is the largest consumer market for them, we need to ensure that Australia’s international market access and trade interests are secure, and enhance its reputation as a reliable supplier of ‘clean and green’ foodstuffs.

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References


JECFA. (2010). (Food and Agriculture Organization/ World Health Organization), Joint FAO/WHO food standards committee of the Codex Alimentarius.


Figure Captions

**Fig. 1.** Mean of total and inorganic As content in 6 categories of Australian rice-based food products.

**Fig. 2.** Estimation of inorganic As exposure for young children from rice-based food products.
<table>
<thead>
<tr>
<th>Product category</th>
<th>Origin*</th>
<th>n</th>
<th>Inorganic As (µg/kg)</th>
<th>DMA (µg/kg)</th>
<th>∑Speciated As (µg/kg)</th>
<th>Inorganic As (%)</th>
<th>Total As (µg/kg)</th>
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<td>182±9 (125-326)</td>
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<td>35±3 (13-57)</td>
<td>96±6 (76-120)</td>
<td>66±15</td>
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<td>65±7b (55-83)</td>
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<td>55±11 (10-107)</td>
<td>161±13 (42-284)</td>
<td>68±12b</td>
<td>204±19</td>
</tr>
<tr>
<td></td>
<td>Belgium</td>
<td>1</td>
<td>94±0 (23-175)</td>
<td>18±0 (0-19)</td>
<td>112±0 (45-159)</td>
<td>84±0ab</td>
<td>170±0</td>
</tr>
<tr>
<td></td>
<td>Netherlands</td>
<td>3</td>
<td>96±3 (45-141)</td>
<td>12±2 (0-19)</td>
<td>108±6 (45-159)</td>
<td>92±7a</td>
<td>152±11</td>
</tr>
<tr>
<td>p-value</td>
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<td>0.94</td>
<td>0.20</td>
</tr>
<tr>
<td>Baby rice</td>
<td>Australia</td>
<td>2</td>
<td>73±6 (50-73)</td>
<td>99±1 (23-175)</td>
<td>173±9 (120-225)</td>
<td>51±41</td>
<td>268±6</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>&lt;0.04</td>
<td>0.74</td>
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</tbody>
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Table 1
Mean total and inorganic As concentration (µg/kg) in Australian produced and imported rice-based products (ranges are also given in the brackets).
<table>
<thead>
<tr>
<th></th>
<th>Others</th>
<th>Australia</th>
<th>8</th>
<th>45±5</th>
<th>11±2</th>
<th>55±5</th>
<th>77±29</th>
<th>54±5</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>(10-94)</td>
<td></td>
<td>(0-34)</td>
<td>(29-94)</td>
<td>(22-100)</td>
<td>(14-62)</td>
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<td></td>
<td></td>
<td>7</td>
<td></td>
<td>13±2</td>
<td>4±1</td>
<td>17±2</td>
<td>57±42</td>
<td>30±2</td>
</tr>
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<td></td>
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<td>(0-57)</td>
<td></td>
<td>(0-26)</td>
<td>(0-57)</td>
<td>(0-100)</td>
<td>(15-44)</td>
<td></td>
</tr>
<tr>
<td>Ready-to-eat</td>
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<td>India</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rice</td>
<td></td>
<td>Thailand</td>
<td></td>
<td>36±5</td>
<td>8±1</td>
<td>44±1</td>
<td>73±39</td>
<td>39±1</td>
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<td>(0-123)</td>
<td>(0-100)</td>
<td>(16-90)</td>
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</tr>
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<td></td>
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<td>UK</td>
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<td>41±0</td>
<td>0</td>
<td>41±0</td>
<td>100±0</td>
<td>32±0</td>
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<tr>
<td>p-value</td>
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<td>0.16</td>
<td>0.65</td>
<td>0.11</td>
<td>0.69</td>
<td>0.07</td>
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<tr>
<td>Other rice-based snacks</td>
<td></td>
<td>Australia</td>
<td>2</td>
<td>88±2a</td>
<td>128±4</td>
<td>215±2</td>
<td>49±24</td>
<td>273±6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(71-105)</td>
<td>(36-219)</td>
<td>(107-324)</td>
<td>(32-66)</td>
<td>(122-424)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others</td>
<td></td>
<td>33±6b</td>
<td>23±9</td>
<td>56±3</td>
<td>68±28</td>
<td>93±5</td>
</tr>
<tr>
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<td>(28-44)</td>
<td>(0-60)</td>
<td>(32-100)</td>
<td>(60-133)</td>
<td>(60-133)</td>
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<tr>
<td>p-value</td>
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<td>&lt;0.01</td>
<td>0.15</td>
<td>0.08</td>
<td>0.48</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*Origin of the samples based on label of the particular product. Values with the same letters were not significantly different at p-value < 0.05 for the variable studied.
Table 2
Estimated weekly intake of inorganic As and its potential health risk via consumption of Australian produced and imported rice-based products (ranges are also given in the brackets).

<table>
<thead>
<tr>
<th>Product category</th>
<th>Origin</th>
<th>n</th>
<th>Inorganic As (µg/kg)</th>
<th>Recommended serving (g)</th>
<th>Estimated inorganic As intake per serving (µg)</th>
<th>Estimated weekly intake (µg/kg body weight)</th>
<th>%PTWI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice crackers</td>
<td>Australia</td>
<td>5</td>
<td>126±11 (59-270)</td>
<td>25</td>
<td>3.16±2.09 (1.47-6.75)</td>
<td>2.21±1.46 (1.03-4.72)</td>
<td>14.74±9.70 (6.84-31.49)</td>
</tr>
<tr>
<td>Thailand</td>
<td>3</td>
<td>61±8 (58-63)</td>
<td>22 (20-25)</td>
<td>1.32±0.06 (1.28-1.38)</td>
<td>0.93±0.04 (0.90-0.97)</td>
<td>6.17±0.30 (5.97-6.46)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>2</td>
<td>77±4 (56-99)</td>
<td>25</td>
<td>1.94±0.75 (1.40-2.47)</td>
<td>1.35±0.53 (0.98-1.73)</td>
<td>9.03±3.53 (6.53-11.53)</td>
<td></td>
</tr>
<tr>
<td>Puffed rice</td>
<td>Australia</td>
<td>3</td>
<td>45±4 (37-61)</td>
<td>19 (5-30)</td>
<td>0.87±0.26 (0.69-1.16)</td>
<td>0.61±0.18 (0.49-0.81)</td>
<td>4.07±1.21 (3.24-5.39)</td>
</tr>
<tr>
<td>New Zealand</td>
<td>3</td>
<td>54±6 (43-61)</td>
<td>30</td>
<td>1.62±0.30 (1.28-1.83)</td>
<td>1.14±0.21 (0.90-1.28)</td>
<td>7.57±1.40 (5.97-8.55)</td>
<td></td>
</tr>
<tr>
<td>Rice cakes</td>
<td>Australia</td>
<td>7</td>
<td>105±8 (27-158)</td>
<td>22 (11-25)</td>
<td>2.32±0.94 (0.59-3.48)</td>
<td>1.62±0.66 (0.41-2.44)</td>
<td>10.81±4.40 (2.75-16.24)</td>
</tr>
<tr>
<td>Belgium</td>
<td>1</td>
<td>94±0</td>
<td>6</td>
<td>0.56±0.00</td>
<td>0.39±0.00</td>
<td>2.63±0.00</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>3</td>
<td>96±3 (45-141)</td>
<td>9 (8-12)</td>
<td>0.88±0.43 (0.40-1.27)</td>
<td>0.62±0.30 (0.28-0.89)</td>
<td>4.11±2.02 (1.89-5.90)</td>
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</tr>
<tr>
<td></td>
<td>Country</td>
<td>n</td>
<td>Total As (µg/g)</td>
<td>Provisional tolerable weekly intake (PTWI) of total As (15 µg/kg bw) (JECFA 2010)</td>
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<tr>
<td>------------------------</td>
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<td>---</td>
<td>----------------</td>
<td>---------------------------------------------------------------------------------</td>
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<td></td>
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</tr>
<tr>
<td>Baby rice</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Australia</td>
<td></td>
<td>2</td>
<td>73±6</td>
<td>1.90±0.86 (1.30-2.51) 1.33±0.60 (0.91-1.76) 8.84±3.99 (6.07-11.72)</td>
<td></td>
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<tr>
<td>Others</td>
<td></td>
<td>2</td>
<td>77±3</td>
<td>6.87±3.99 (4.10-9.73) 4.81±2.79 (2.87-6.81) 32.08±18.61 (19.11-45.42)</td>
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<tr>
<td>Ready-to-eat rice</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia (only for adult)</td>
<td></td>
<td>8</td>
<td>45±5</td>
<td>5.56±3.36 (1.20-11.76) 0.65±0.39 (0.14-1.37) 4.32±2.62 (0.94-9.15)</td>
<td></td>
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<tr>
<td>India</td>
<td></td>
<td>7</td>
<td>13±2</td>
<td>1.60±2.57 (0-7.07) 0.19±0.30 (0-0.82) 1.24±1.99 (0-5.50)</td>
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<tr>
<td>Thailand</td>
<td></td>
<td>6</td>
<td>36±5</td>
<td>4.50±3.92 (0-10.83) 0.52±0.45 (0.18-1.26) 3.50±3.05 (1.23-8.42)</td>
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<tr>
<td>UK</td>
<td></td>
<td>1</td>
<td>41±0</td>
<td>5.10±0.00 (0-5.50) 0.60±0.00 (0-1.26) 3.97±0.00 (1.23-8.42)</td>
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<tr>
<td>Other rice-based snacks</td>
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</tr>
<tr>
<td>Australia</td>
<td></td>
<td>2</td>
<td>88±2</td>
<td>2.64±0.71 (2.1-3.1) 1.84±0.50 (1.5-2.2) 12.28±3.31 (9.94-16.62)</td>
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<tr>
<td>Others</td>
<td></td>
<td>4</td>
<td>33±6</td>
<td>0.46±0.10 (0.39-0.61) 0.32±0.07 (0.27-0.43) 2.13±0.47 (1.83-2.84)</td>
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</table>
Table 3
Comparison of the results (As content in rice-based products) of this work and other published works (ranges are also given in the brackets).

<table>
<thead>
<tr>
<th>Rice Products</th>
<th>n</th>
<th>tAs (µg/kg)</th>
<th>iAs (µg/kg)</th>
<th>iAs (%)</th>
<th>References</th>
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</thead>
<tbody>
<tr>
<td>Baby rice</td>
<td>4</td>
<td>204±13 (59-357)</td>
<td>75±4 (46-108)</td>
<td>68 (22-100)</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>-</td>
<td>121 (56-268)</td>
<td>70 (51-85)</td>
<td>Signes-Pastor, et al. (2016)</td>
</tr>
<tr>
<td>Infant rice (without gluten)</td>
<td>13</td>
<td>126±26 (46-315)</td>
<td>69±8 (29-121)</td>
<td>64 (36-89)</td>
<td>Carbonell-Barrachina, et al. (2012)</td>
</tr>
<tr>
<td>Infant rice (with gluten)</td>
<td>9</td>
<td>33±6 (15-65)</td>
<td>26±5 (10-49)</td>
<td>98 (90-100)</td>
<td></td>
</tr>
<tr>
<td>Puffed rice</td>
<td>6</td>
<td>145±21 (62-228)</td>
<td>50±6 (37-61)</td>
<td>52 (32-73)</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>270±10</td>
<td>140±2</td>
<td>77</td>
<td>Sun, et al. (2009)</td>
</tr>
<tr>
<td>Rice crackers</td>
<td>10</td>
<td>215±23 (140-456)</td>
<td>97±8 (56-270)</td>
<td>64 (42-83)</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>390±10</td>
<td>210±10</td>
<td>76</td>
<td>Sun, et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>97</td>
<td>-</td>
<td>111 (18-211)</td>
<td>81 (45-100)</td>
<td>Signes-Pastor, et al. (2016)</td>
</tr>
<tr>
<td>Ready-to-eat rice</td>
<td>22</td>
<td>41±17 (15-90)</td>
<td>32±2 (0-94)</td>
<td>71 (0-100)</td>
<td>This study</td>
</tr>
<tr>
<td>Rice cakes</td>
<td>11</td>
<td>187±18 (58-384)</td>
<td>102±9 (27-158)</td>
<td>76 (52-100)</td>
<td>This study</td>
</tr>
<tr>
<td>Other rice-based snacks</td>
<td>6</td>
<td>153±8 (60-424)</td>
<td>51±5 (28-104)</td>
<td>62 (32-100)</td>
<td>This study</td>
</tr>
</tbody>
</table>
Highlights

- Significant level of arsenic (As) in all rice-based products.
- Arsenic content varies as crackers > baby rice > cakes > puffed rice > ready-to-eat rice.
- 75% of rice-based products had inorganic As greater than the EU recommended value.
- Manufacturer recommendation may lead to 0.56 to 6.87 μg inorganic As/serving.
- Young children are most at risk from ingestion of rice-based products.