Mitigation strategies of arsenic accumulation in rice grain: minimizing human exposure

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Arsenic Exposure and Bengal Delta

Arsenic (As) is recognized as a toxic element and has been classified as a human carcinogen (group I) causing skin and lungs and bladder cancers.

Bangladesh and West Bengal are the two worst As-impacted areas in worldwide.

Arsenic exposure to humans mainly occurs via:

1. Drinking As-contaminated water and
2. Food crops grown in As-contaminated areas.

Currently, groundwater of 70 countries are affected by arsenic (As) contamination released from predominantly geological sources, posing a serious health hazard to an estimated 150 million people world-wide.

Ref: Brammer and Ravenscroft, Environ Int’l 2009, 35, 647-654; google map
1. Bangladesh
2. Cambodia
3. China: Inner Mongolia, Xingjiang and Shanxi
4. India: West Bengal, Bihar, Uattar Pradesh including Allahabad, Jharkhand, Manipur, Assam, Chattisgarh
5. Lao PDR
6. Myanmar
7. Nepal
8. Pakistan
9. Taiwan
10. Vietnam

Naturally occurring As in groundwater in the regions of south-east Asia

<table>
<thead>
<tr>
<th>Country / Region</th>
<th>Population at risk (million)</th>
<th>Level of As (µg/l)</th>
<th>Year of first discovery</th>
<th>National drinking water standard As (µg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>32</td>
<td>ND - 4730</td>
<td>1992</td>
<td>50</td>
</tr>
<tr>
<td>Cambodia</td>
<td>0.3</td>
<td>1-1610</td>
<td>2000</td>
<td>50</td>
</tr>
<tr>
<td>China</td>
<td>5.6</td>
<td>&lt;50-4440</td>
<td>1980</td>
<td>50</td>
</tr>
<tr>
<td>India</td>
<td>6.5</td>
<td>ND-3880</td>
<td>1983</td>
<td>50</td>
</tr>
<tr>
<td>Sumatra</td>
<td>Unknown</td>
<td>ND-65</td>
<td>2008</td>
<td>50</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>Unknown</td>
<td>ND-112</td>
<td>2001</td>
<td>50</td>
</tr>
<tr>
<td>Myanmar</td>
<td>3.4</td>
<td>ND-3880</td>
<td>1999</td>
<td>50</td>
</tr>
<tr>
<td>Nepal</td>
<td>0.5</td>
<td>ND-2620</td>
<td>1999</td>
<td>50</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Unknown</td>
<td>ND-906</td>
<td>2000</td>
<td>50</td>
</tr>
<tr>
<td>Taiwan</td>
<td>0.1</td>
<td>&lt;0.15-3590</td>
<td>1960s</td>
<td>10</td>
</tr>
<tr>
<td>Vietnam</td>
<td>10</td>
<td>1-3050</td>
<td>2001</td>
<td>10</td>
</tr>
</tbody>
</table>

Arsenic induced health effects

- Melanosis
- Leucomelanosis
- Keratosis, hyper-keraosis and dorsal keratosis
- Bowen’s
- Gangrene

Dermal effects

- Respiratory effects
- Diabetes mellitus
- Obstetric problems
- Neurologic involvements
- Cardiovascular diseases and hypertension
- Cancers including skin, lung, bladder and kidney

Other effects

Current focus of As research

(a) extent and severity of As contamination,,
(b) source and mobilization of As,
(c) human health effects and food chain,
(d) social and socioeconomic aspects of arsenicosis patients, and mitigation options.

Very limited effort has been given to mitigation As uptake in rice grain.
Arsenic exposure – food chain link

- Groundwater is used for drinking, cooking and other purposes in many areas of southeast Asian countries.
- Groundwater is also used for irrigating crops during the dry season, particularly for paddy rice (Oryza sativa).
- Rice and vegetables are the main foods of population in Bengal delta. Transfer of As from groundwater into crops has been well documented.

Groundwater – soil – plant transfer of As – food chain issue

- Irrigation with As contaminated water
- As in soil
- Groundwater
- Root Uptake
- Translocation to tops
- Harvest
- As(soil) ⇔ As(soln)
- Human Uptake
- Groundwater
Chemical forms and toxicity of arsenic

Inorganic arsenic compounds
1. Arsenite, AsIII
2. Arsenate, AsV

Organic arsenic compounds
1. Monomethylarsonic acid, MMA
2. Dimethylarsinic acid, DMA
3. Trimethylarsine, TMA
4. Trimethylarsinic oxide, TMAO
5. Arsenobetaine, AB
6. Arsenicholine, AC
7. Arsenosugars, AS

Toxicity: Inorganic arsenic compounds > Inorganic arsenic compounds
### Arsenic in rice grain of Bengal delta: published results

<table>
<thead>
<tr>
<th>Regions</th>
<th>No. of samples</th>
<th>Arsenic concentrations (µg/kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>14</td>
<td>153</td>
<td>74-302</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>214</td>
<td>143</td>
<td>2-557</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>4</td>
<td>11.3</td>
<td>&lt;5-20.2</td>
</tr>
<tr>
<td>Bangladesh (boro)</td>
<td>78</td>
<td>183</td>
<td>108-331</td>
</tr>
<tr>
<td>Bangladesh (boro)</td>
<td>72</td>
<td>117</td>
<td>72-170</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>10</td>
<td>136</td>
<td>40-270</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>15</td>
<td>130</td>
<td>30-300</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>13</td>
<td>496</td>
<td>58-1835</td>
</tr>
<tr>
<td>Bangladesh (boro)</td>
<td>133</td>
<td>-</td>
<td>40-910</td>
</tr>
<tr>
<td>Bangladesh (boro)</td>
<td>189</td>
<td>-</td>
<td>&lt;40-920</td>
</tr>
<tr>
<td>Jalangi, West Bengal, India</td>
<td>11</td>
<td>232</td>
<td>40.8-605</td>
</tr>
<tr>
<td>Domkal, West Bengal, India</td>
<td>23</td>
<td>233</td>
<td>78.8-546</td>
</tr>
</tbody>
</table>

Total and inorganic As contents (µg/kg) in raw rice

Mean In-As: 113 µg/kg (dw), Range: 51-237 µg/L, In-As in raw rice: 68-78%

Mean As: 153 µg/kg (dw), Range: 74-302 µg/L
Cereal killers? More than half of rice products including Rice Krispies and Heinz baby rice exceed new EU limits for ARSENIC

- Experts warn some popular rice products contain high levels of arsenic
- Tests found 58% exceeded new recommended arsenic limits for children
- Scientists say high levels over time could lead to cancer or heart disease
- People in Britain consume five times more rice today than 40 years ago

Although there are strict limits for the amount of arsenic level allowed in water, there are currently no maximum levels in food - and now some scientists are speaking out as they are concerned about the effects of long-term exposure.
Arsenic and rice cereal: How safe is our food

% Above new proposed arsenic limits in food

- 168% Above recommended levels for children and babies
- 88% Above recommended levels for children and babies
- 62% Above recommended levels for children and babies
- 61.5% Above recommended levels for adults

Arsenic in rice is an important issue as about 3 billion people around the world consume rice as staple food.

Recent study from West Bengal shows that high level of arsenic in cooked rice (>200 µg/kg) is associated with genotoxic effects. Volunteers were exposed to very low level of arsenic through drinking and cooking water (4.1 µg/L), it is concluded that arsenic from cooked rice alone was responsible for the observed genetic effects (Banerjee et al. 2013).
Arsenic and rice: health risk issue

• Much of the global rice supply is sourced from Asian countries;
• Risk: elevated levels of As in groundwater used for irrigation
• contaminated rice is one of the major exposure pathways of As to humans worldwide.

Arsenic in rice and the associated risks to human health can thus no longer be considered just a regional issue but an important global one.
# Arsenic and Australian grown and imported rice

<table>
<thead>
<tr>
<th>Origin</th>
<th>Local name and type of rice</th>
<th>Total</th>
<th>Arsenic species</th>
<th>% of total arsenic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inorganic</td>
<td>MMA</td>
</tr>
<tr>
<td>Australia</td>
<td>Brown rice (organic, medium grain)</td>
<td>438 ± 23</td>
<td>276 ± 25</td>
<td>&lt;dl</td>
</tr>
<tr>
<td></td>
<td>Brown rice (whole, medium grain)</td>
<td>287 ± 03</td>
<td>178 ± 22</td>
<td>&lt;dl</td>
</tr>
<tr>
<td></td>
<td>Brown rice (long grain)</td>
<td>198 ± 41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>White rice (organic, long grain)</td>
<td>283 ± 18</td>
<td>165 ± 08</td>
<td>&lt;dl</td>
</tr>
<tr>
<td></td>
<td>Clever rice (long grain)</td>
<td>257 ± 05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>White rice (long grain)</td>
<td>241 ± 07</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sushi rice (sticky, Japanese style)</td>
<td>188 ± 06</td>
<td>177 ± 13</td>
<td>&lt;dl</td>
</tr>
<tr>
<td>All rice</td>
<td></td>
<td>270</td>
<td>199</td>
<td></td>
</tr>
</tbody>
</table>

Estimated daily dietary intake of total, inorganic, and methylated As speciation by three consumer groups (average Australian and Asian and European immigrants) from Australian grown (A) and imported (B) rice on sale in Australia.

What can be done?

Breeding of arsenic resistant rice varieties: productivity is crucial and need long time (5-6 years).

Cultivation of upland/aerobic rice varieties which require less water: yield is crucial

Identification of existing rice cultivars which accumulate low arsenic or genotype selection, and

Development of effective water management strategies provide important opportunities to reduce As uptake in rice.
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