Managing Arsenic for Production and Safety of Rice

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WHAT WE TESTED Our analysis found varying levels of arsenic in more than 60 rices and rice products—cereals, crackers, and more.

Arsenic in your food
Our findings show a real need for federal standards for this toxin
Outline

1. Health impacts and standards
2. As uptake and toxicity to rice
3. Strategies to prevent As toxicity and reduce As level in rice

ppb (parts per billion) = µg/kg or µg/L
ppm (parts per million) = mg/kg or mg/L
Health Impacts and Standards

• Inorganic As is highly toxic
  - acute & chronic toxin
  - carcinogen (lung, urinary tract, skin)
  - linked to circulatory problems, heart disease, diabetes and reduced mental and physical development

• As in water is inorganic (arsenate and/or arsenite)
  - WHO & US drinking water standard 10 ppb (µg/L)

\[
\text{for } 2\text{L} = \text{maximum daily intake of } 20 \mu g
\]
Inorganic Arsenic and Lung Cancer - $H_2O$

- Lifetime risk with US-FDA dose response model

<table>
<thead>
<tr>
<th>As Conc. (ppb)</th>
<th>Daily Intake (µg)</th>
<th>No. of Cases per $10^6$ People</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>340</td>
</tr>
</tbody>
</table>

Other risks in life (per $10^6$ people in USA):
- Annual road fatalities 100
- Annual road injury 800
- Lifetime - lightening strike 100
- Annual drowning 13
- Diet - high fructose corn syrup ??
Inorganic Arsenic and Lung Cancer - H$_2$O

- Lifetime risk with US-FDA dose response model

![Graph showing estimated number of lung cancers per million people vs. arsenic intake in micrograms per day. The graph highlights the lifetime risk with the US-FDA dose response model.]

- 10 ppb (WHO)
- 50 ppb (Bangladesh)
- 13-fold increase
- 6-fold increase
Bangladesh Household Tubewells

As (ppb)
- < 50
- 50-100
- 100-200
- 200-400
- > 400

From BGS/DPHE data
Health Impacts and Standards

- As exposure comes from water and food; As in food can be a mixture of $i$As and organic As species

- Organic As species considered much less toxic than $i$As
  - ppm (mg/kg) levels of As in seafood; mostly as arseonbetaine and arsenocholine; essentially non-toxic

- As in rice is a mixture of $i$As and organic (DMA) species (20-100% inorganic) in varying amounts (5-1000 ppb total As)

**Microbial Transformations of As in soils**

<table>
<thead>
<tr>
<th>$As(V)$ species</th>
<th>$As(III)$ species</th>
<th>Volatile Arsines</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AsO(OH)_3$</td>
<td>$As(OH)_3$</td>
<td>$AsH_3$</td>
</tr>
<tr>
<td>$CH_3AsO(OH)_2$ (MMA)</td>
<td>$CH_3As(OH)_2$</td>
<td>$MeAsH_2$</td>
</tr>
<tr>
<td>$(CH_3)_2AsO(OH)$ (DMA)</td>
<td>$(CH_3)_2As(OH)$</td>
<td>$Me_2AsH$</td>
</tr>
<tr>
<td>$(CH_3)_3AsO$ (TMAO)</td>
<td>$(CH_3)_3AsOH$</td>
<td>$Me_3As$</td>
</tr>
</tbody>
</table>
Health Impacts and Standards

• Health impact of As in rice depends on
  - speciation and iAs level
  - bioavailability of iAs in rice (not well studied, but high)
  - consumption of rice (USA 29 g/day; Bangladesh 470 g/day)

  6 µg As/day   94 µg As/day

• As standards for rice:
  - UN Codex commission set maximum limit for iAs in white rice at 200 ppb (20x water std)
  - China standard for iAs is 150 ppb

Why is Codex standard so high?
Inorganic As in Rice - UN Codex Commission

Japan

USA

DMA + MMA > Asi → Asi > DMA + MMA

Cumulative % of Samples

Inorganic As (%) 0 10 20 30 40 50 60 70 80 90 100

Australia 36
China 505
Japan 640
Thailand 182
USA 363
Bangladesh 46
Codex did not consider the rice eaters?

Average g dry rice/cap/day

- Bangladesh: 474
- Bhutan: 471
- Cambodia: 438
- China: 211
- India: 186
- Indonesia: 351
- Laos: 455
- Malaysia: 203
- Myanmar: 386
- Nepal: 219
- Philippines: 337
- Sri Lanka: 285
- Thailand: 364
- Vietnam: 386

(from IRRI, 2013)

China: 320 for 66% of pop.
India: detailed data by state
Inorganic As and Lung Cancer - $\text{H}_2\text{O} + \text{Rice}$

• Assumes 100% bioavailability of $i\text{As}$ in rice
• For Bangladesh, rice increases cancer incidence 1.5 to 1.9 times
• For USA, consumption of 1 cup cooked rice/day @100 ppb $i\text{As}$ increases cancer cases from 340 to 520 per million
As (III) & As (V) >> MMA & DMA

- As (III) uses phosphate transport system (competitive)
- As (III) & silicate (Lsi1) via aquaporin channels (non-competitive)

Si competitive

As (V) >> As (III) >> GSH >> As(GS)₃

Nodes restrict upward movement of As and partition As between leaf (40%) and stem (60%)

DMA movement to grain >> iAs

iAs(III) & iAs(V) >> MMA & DMA

- iAs(V) uses phosphate transport system (competitive)
- iAs(III) & silicate (Lsi1) via aquaporin channels (non-competitive)
High Resolution Secondary Ion Mass Spectrometry (Nano-SIMS) of Phloem Region in Rice Internode

Distribution of As Within a Rice Plant

Brown rice
- $i\text{As}$: 3%
- DMA: 50%

Straw + husk
- $i\text{As}$: 47%
- DMA: 50%

Root
- $i\text{As}$: 50%
- DMA: ? low
Several As Species are Toxic to Rice

Marin et al., Plant & Soil 139:175-183, 1992

DMA Interferes with Grain Formation

Zheng et al., Plant & Soil 365:227-238, 2013

Control        As(III)         MMA

0.8 ppm As
As Toxicity to Rice
Impact of Soil As on Rice Yield

Impact of Soil As on Rice Straw As

Strategies to Reduce As Toxicity and Grain As Content in Rice in Bangladesh

1. Low As Irrigation Water
2. Crop Management
   - varietal selection
   - water management to give less reduced soils
   - Si addition (not effective at practical addition rates)
3. Rice processing & preparation methods
   - milling
   - washing & cooking in excess water
   - washing and soaking
4. Reorganize where rice is grown
   - policy decision
Low As Irrigation Water
Irrigation Water Impact on Soil As
Crop Management: Varietal Tolerance to Arsenic

BRRI dhan 45

BRRI dhan 47

Winter Season Rice

Soil As mg/kg

Grain yield (t/ha)

Soil As (ppm)
<table>
<thead>
<tr>
<th>Soil As ppm</th>
<th>% of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>58</td>
</tr>
<tr>
<td>&gt;10</td>
<td>42</td>
</tr>
<tr>
<td>&gt;20</td>
<td>16</td>
</tr>
</tbody>
</table>
Variation in Varietal Tolerance to Arsenic

Summer Season Rice

<table>
<thead>
<tr>
<th>Variety</th>
<th>Yield Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BRRI dhan 47</td>
<td>y = -0.11x + 30.0</td>
</tr>
<tr>
<td>2. BRRI hybrid 4</td>
<td>y = -0.57x + 44.2</td>
</tr>
<tr>
<td>3. BRRI dhan 41</td>
<td>y = -0.59x + 54.6</td>
</tr>
<tr>
<td>4. BRRI dhan 39</td>
<td>y = -0.66x + 38.3</td>
</tr>
<tr>
<td>5. BRRI dhan 53</td>
<td>y = -0.83x + 42.1</td>
</tr>
<tr>
<td>6. BR 11</td>
<td>y = -0.87x + 50.4</td>
</tr>
<tr>
<td>7. Nijersail</td>
<td>y = -0.90x + 48.4</td>
</tr>
<tr>
<td>8. BRRI dhan 54</td>
<td>y = -1.03x + 44.0</td>
</tr>
<tr>
<td>9. Swarna</td>
<td>y = -1.06x + 49.4</td>
</tr>
<tr>
<td>10. BRRI dhan 49</td>
<td>y = -1.07x + 43.7</td>
</tr>
<tr>
<td>11. BRRI dhan 33</td>
<td>y = -1.18x + 41.2</td>
</tr>
<tr>
<td>12. Rajasail</td>
<td>y = -1.26x + 46.0</td>
</tr>
<tr>
<td>13. BINA dhan 7</td>
<td>y = -1.07x + 43.7</td>
</tr>
<tr>
<td>14. BR 25</td>
<td>y = -1.75x + 47.5</td>
</tr>
<tr>
<td>15= BRRI dhan 51</td>
<td>y = -1.79x + 50.5</td>
</tr>
<tr>
<td>15= BRRI dhan 52</td>
<td>y = -1.79x + 50.4</td>
</tr>
<tr>
<td>15= BRRI dhan 40</td>
<td>y = -1.79x + 50.5</td>
</tr>
<tr>
<td>18. BR 23</td>
<td>y = -2.23x + 42.0</td>
</tr>
<tr>
<td>19. BR 22</td>
<td>y = -2.59x + 48.2</td>
</tr>
</tbody>
</table>
Varietal Differences in Rice Grain As Concentration

**Boro**
Mean 329

- 23 varieties;
- 10 regional stations
- >10% variation from overall mean

**T. Aman**
Mean 140

- 27 varieties
- 5 regional stations
- >20% variation from overall mean

- 47 salt tolerant
- 56 & 57 drought resistant
- 37 & 38 aromatic
- 33 short duration
- 23 short duration; some salt tol.
  (after flood)
Crop Management: Water Management to Give Less Reduced Soils

1. Raised beds
2. Alternate wetting and drying (AWD) – IRRI technology with cycles of flooding and draining to 15 cm
3. Sprinkler and drip irrigation (aerobic)
Raised Beds and Alternate Wetting and Drying

Graphs showing the relationship between water management and arsenic levels in straw and grain yield with respect to soil arsenic concentration.
Relationship between As in Straw and grain

- **R² = 0.276**
- **R² = 0.5299**
- **R² = 0.5839**

**6 Varieties**

- **Straw As mg/kg**
- **Grain As mg/kg**

- **Conv**
- **Bed**
- **Linear (Conv)**
- **Linear (Bed)**
- **Log. (Bed)**

9-fold decrease straw As
2-fold decrease grain As
Crop Management: Sprinkler Irrigation for Aerobic Rice Production in Italy

37 genotypes (8 indica; 29 japonica)

<table>
<thead>
<tr>
<th></th>
<th>Sprinkler</th>
<th>Flooded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain Total As (ppb)</td>
<td>2.8 ± 2.5</td>
<td>163 ±23</td>
</tr>
</tbody>
</table>

Grain Total As

2.5 fold variation

Note different scales
Crop management: **Drip Irrigation for Aerobic Rice Production in USA**

Blue Moon Acres, NJ - Jim Lyons

<table>
<thead>
<tr>
<th>iAs</th>
<th>ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 varieties</td>
<td>14-18</td>
</tr>
<tr>
<td>1 variety</td>
<td>35</td>
</tr>
</tbody>
</table>

Arborio
Rice Processing: **Milling**

1. How much As is removed with progressive milling (5, 10, 15% mass removal)? (15, 30 and 45%)
2. Does % As removal vary with Level of As in brown rice? (No)

Used 5 varieties grown at 2 sites giving high and low grain As
3. Does As removal vary with variety? (No)

Milled 27 T. Aman and 23 Boro rice varieties from one site to 10% mass loss

- Milling preferentially removes iAs
Rice Preparation: Cooking in Excess Water

The combination of washing until water is clear and cooking in 5-6 times volume of As free water reduces As up to 50%.
Rice Preparation: **Washing (5x) & Soaking 8h**

### White Rice
- River
- Uncle Bens parboiled
- Lotus+bamboo...
- P&C Best Buy
- Wegmans Arborio
- Lotus Carnaroli
- Laxmi Basmati
- Thai Jasmine
- Texmati

### Brown Rice
- Lotus black
- Green Day black
- Lotus Sticky black
- Lotus Bhutan red
- Lotus Volcano
- River
- Tsuru Mai
- Texmati

**% As reduction**
- **Mean**: 49%
- **Range**: 35-79%

**Wash & Soak**
- **Lotus black**: 14%
- **Range**: 5-43%
Reducing Arsenic in Rice Grain

- **Arsenic removal**
  - 30%: Milling (10% mass loss)
  - 10%: Washing - arsenic free water
  - 23%: Cooking with excess (or soaking arsenic free water 8 h.)

- **Initial Concentration:** 200 ppb - brown rice
- **Intermediate Concentration:** 140 ppb - white rice
- **Final Concentration:** 95 ppb - cooked rice
Conclusions

• Arsenic in rice does pose a significant health threat to people who consume rice as their major staple food

• Codex limit of 200ppb iAs in white rice is too high and regulators need to consider intake from diets not just single sources when setting limits/standards

• Options exist to reduce iAs in rice through varietal selection, crop management, rice processing and rice preparation

• Aromatic white rice (basmati) from India, Pakistan and California has the lowest iAs levels (CR report Nov., 2014 has reasonable recommendations)