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

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Arsenic Exposure and Bengal Delta

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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.

Ref: Rahman ….Naidu 2009, EGAH, 31, 189-200.

Present world scenario: Arsenic contamination in groundwater

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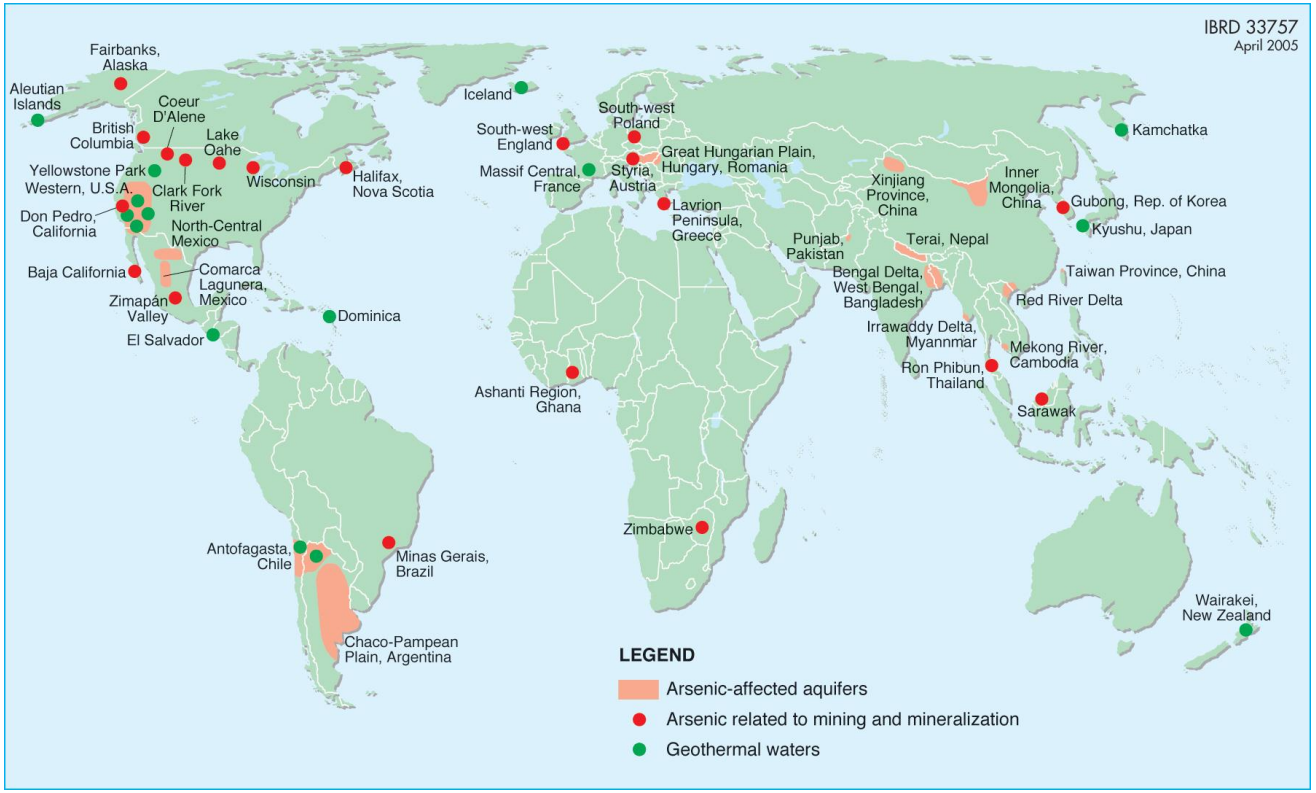

Currently, groundwater of 70 countries are affected by arsenic (As) contamination released from predominantly geological sources, posing a serious health hazard to an estimated 150 million people world-wide.

Ref: Brammer and Ravenscroft, Environ Int'l 2009, 35, 647-654; google map

Arsenic in groundwater of south-east Asia

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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

Ref: Rahman MM .... & Naidu R 2009, EGAH, 31, 189-200.

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

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

Ref: Rahman MM …. & Naidu R, 2009, EGAH, 31, 189-200 and references therein.

Arsenic induced health effects

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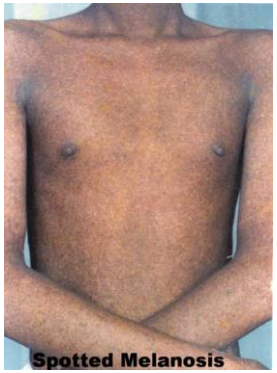
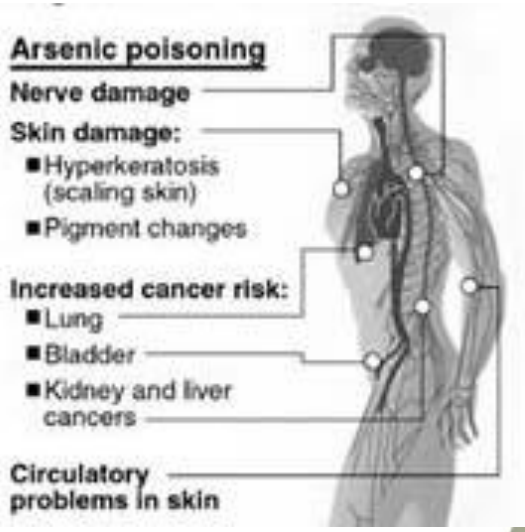
Dermal effects →

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





Other effects →

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

Ref: IARC 2004; NRC 1999; Rahman et al. 2009, EGAH, 31, 189-200.

Current focus of As research

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(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

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- 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

Ref: Rahman MM……. & Naidu R, 2009, EGAH, 31, 179-187.

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

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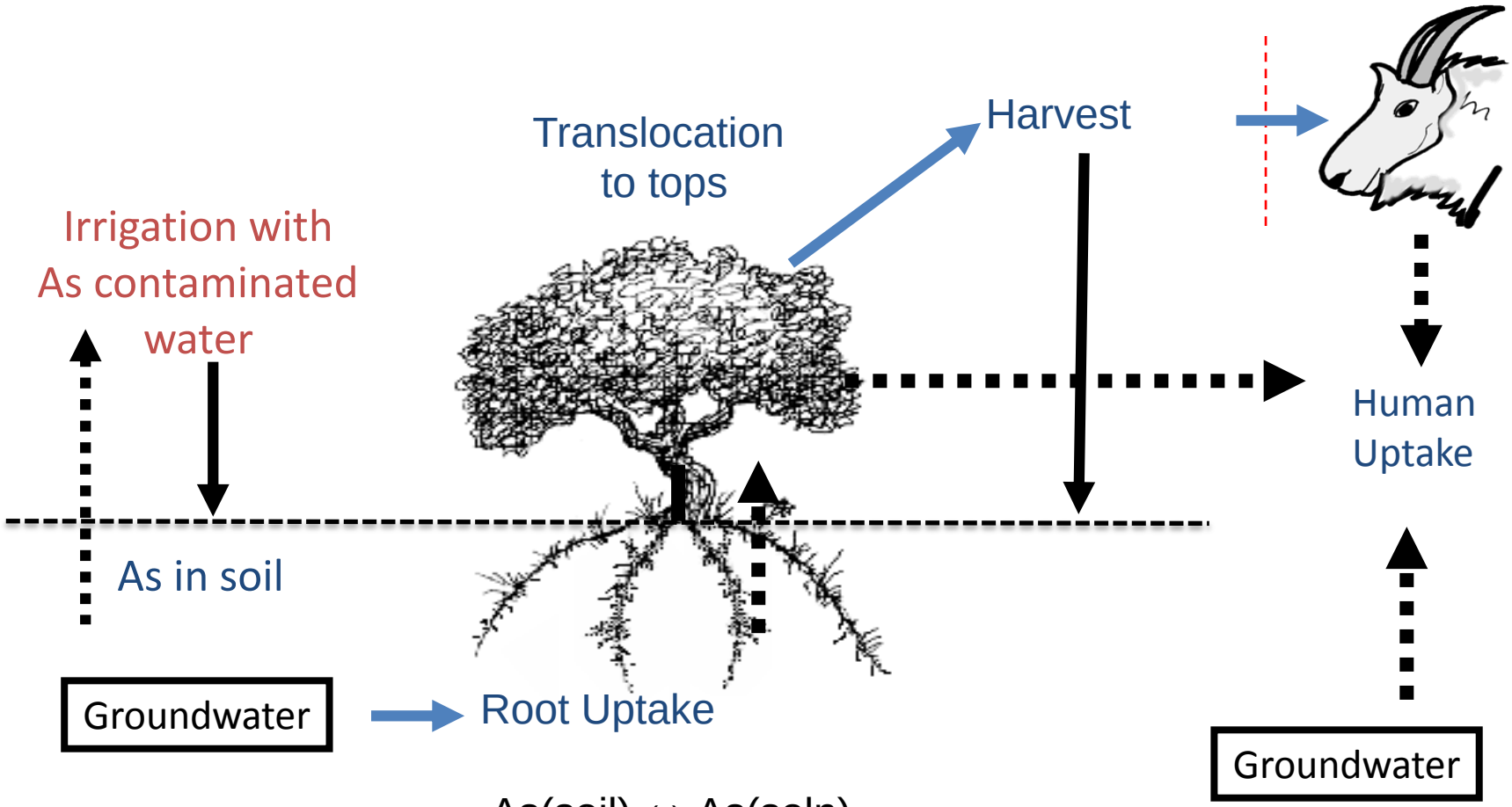

As(soil) ⇔ As(soln)

Chemical forms and toxicity of arsenic

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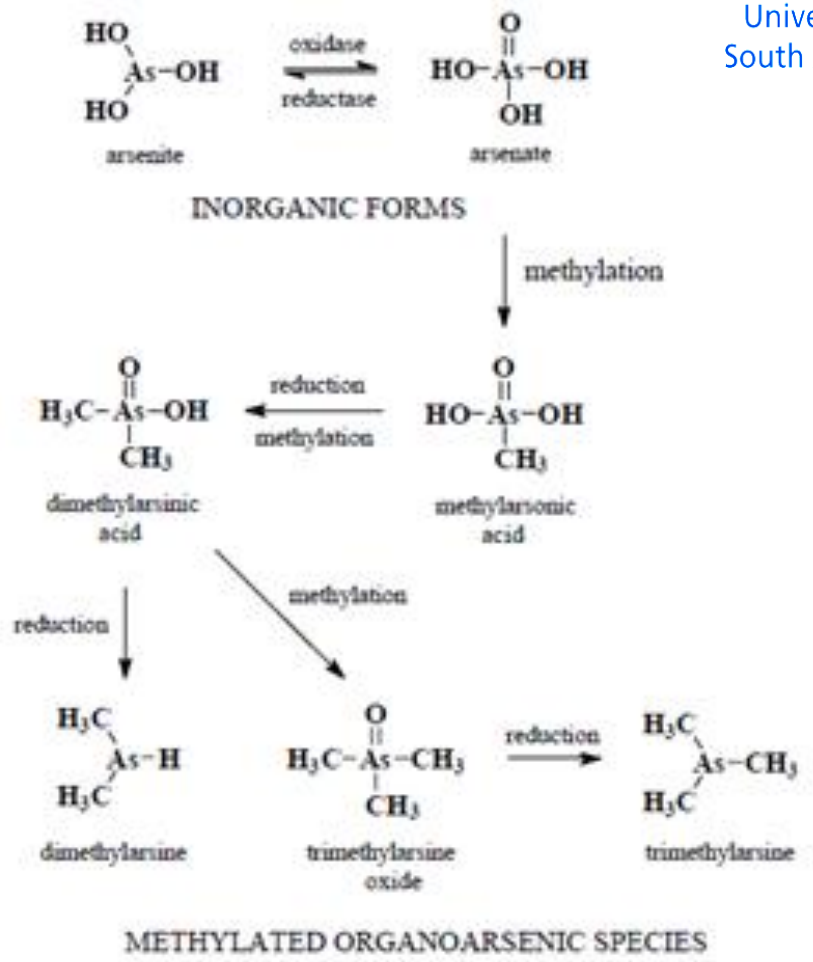
Inorganic arsenic compounds

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

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Regions	No. of samples	Arsenic concentrations (μg/kg)		Reference
		Mean	Range	
Bangladesh	14	153	74-302	Rahman et al. 2011
Bangladesh	214	143	2-557	Rahman et al. 2009
Bangladesh	4	11.3	<5-20.2	Al Rmalli et al. 2005
Bangladesh (boro)	78	183	108-331	Duxbury et al. 2003
Bangladesh (aman)	72	117	72-170	Duxbury et al. 2003
Bangladesh	10	136	40-270	Das et al. 2004
Bangladesh	15	130	30-300	Williams et al. 2005
Bangladesh	13	496	58-1835	Meharg & Rahman 2003
Bangladesh (boro)	133	-	40-910	Williams et al. 2006
Bangladesh (aman)	189	-	<40-920	Williams et al. 2006
Jalangi, West Bengal, India	11	232	40.8-605	Roychowdhury et al. 2003
Domkal, West Bengal, India	23	233	78.8-546	Roychowdhury et al. 2003

Ref: Rahman MM .... & Naidu R, 2009, EGAH, 31, 179-187.

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

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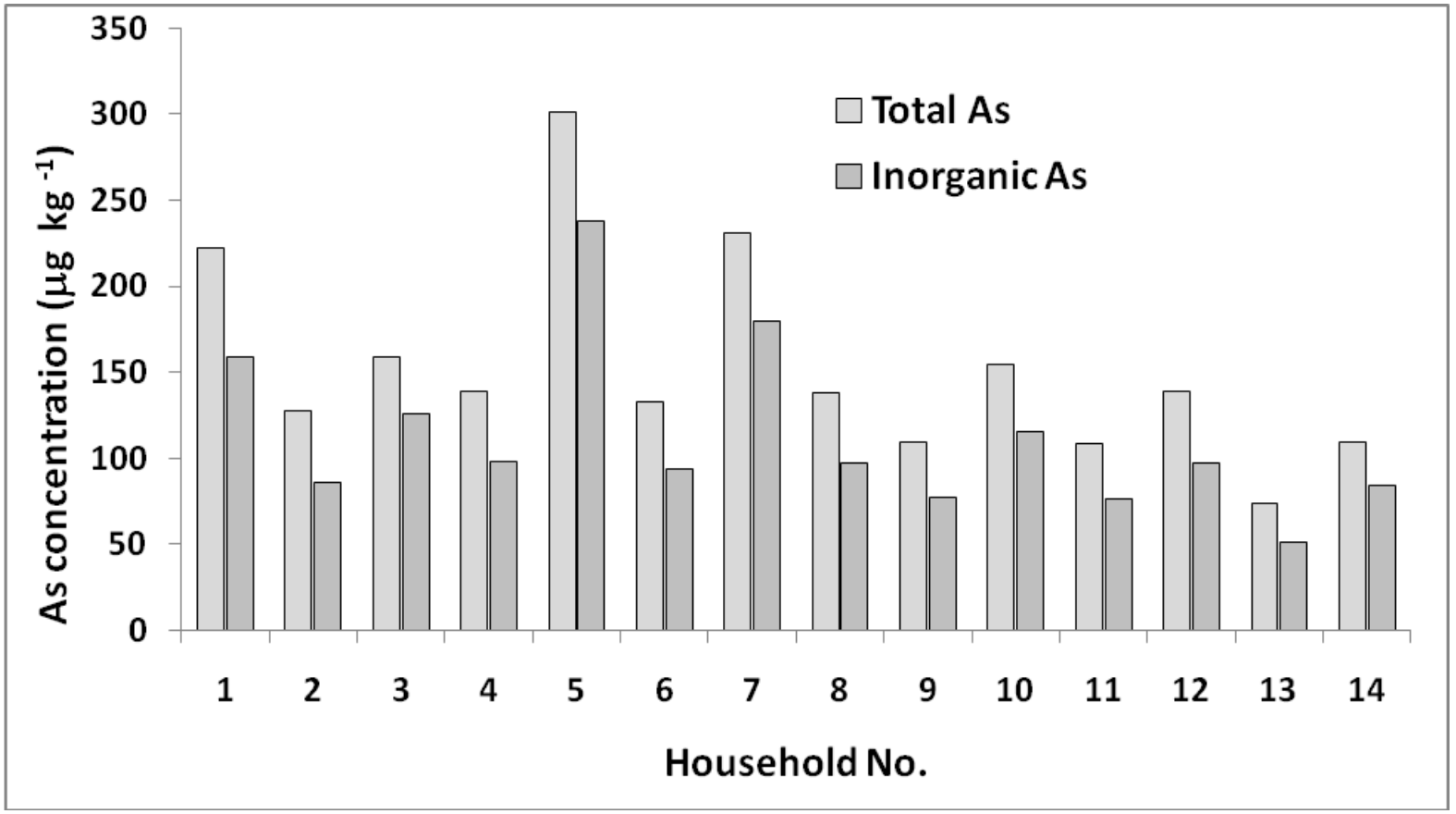

Mean As: 153 µg/kg (dw), Range: 74-302 µg/L

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

Arsenic and rice cereal: How safe is our food

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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.

Daily Mail, UK 02 Nov 2014, http://www.dailymail.co.uk/news/article-2817542/More-half-rice-products-exceed-new-EU-limits-ARSENIC.html

Arsenic and rice cereal: How safe is our food

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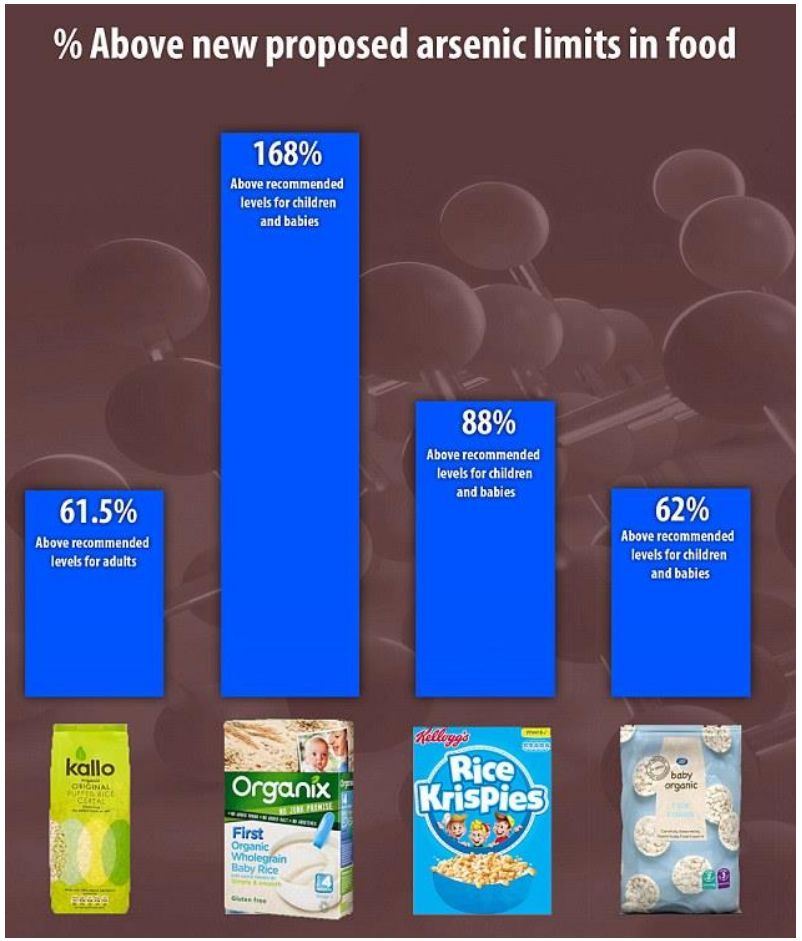

Daily Mail, UK 02 Nov 2014, http://www.dailymail.co.uk/news/article-2817542/More-half-rice-products-exceed-new-EU-limits-ARSENIC.html

Arsenic and rice: health risk issue

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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

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- 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

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Origin	Local name and type of rice	Total	Arsenic species			% of total arsenic		
			Inorganic	MMA	DMA	Inorganic	Methyl	Species
Australia	Brown rice (organic, medium grain)	438 ± 23	276 ± 25	<dl	115 ± 02	63	26	89
	Brown rice (whole, medium grain)	287 ± 03	178 ± 22	<dl	68 ± 03	62	24	86
	Brown rice (long grain)	198 ± 41						
	White rice (organic, long grain)	283 ± 18	165 ± 08	<dl	52 ± 01	58	18	77
	Clever rice (long grain)	257 ± 05						
	White rice (long grain)	241 ± 07						
	Sushi rice (sticky, Japanese style)	188 ± 06	177 ± 13	<dl	<dl	94		94
	All rice	270	199					

Ref: Rahman MM……. & Naidu R, 2014, J Agric Food Chemistry.

Arsenic and Australian grown and imported rice

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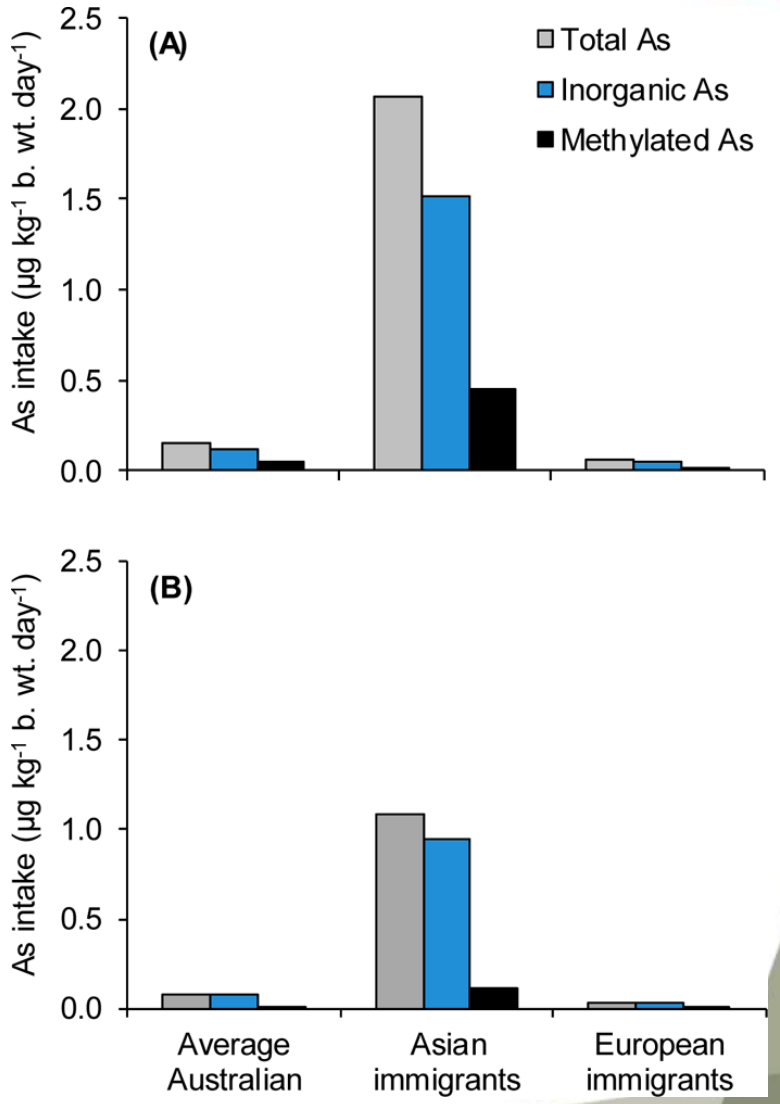
Estimated daily dietary intake of total, inorganic, and methylated As speciation by three consumer groups (average Australian and Asian and European immigrants) from Australian grown (A) and imported (B) rice on sale in Australia.



Ref: Rahman MM……. & Naidu R, 2014, J Agric Food Chemistry.

What can be done?

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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.

Acknowledgements

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