Research conducted by Professor Andrew Meharg at the University of Aberdeen and colleagues, with funding from BBSRC, has revealed that rice grown in certain parts of the world contains relatively high levels of inorganic arsenic. As a result, UK and international policy-makers are reviewing guidelines for arsenic levels in food and have published health warnings for consumers.

Arsenic is highly toxic, and continuous exposure to relatively low levels in the diet can result in serious illness and death. In particular, long-term research by Professor Andrew Meharg and others has shown that rice contains about ten times more arsenic than other crops, and that rice from some regions, such as Bangladesh, India, China and the USA, often contains even higher levels of arsenic as it is grown on contaminated land. At the moment, however, there are no EU or US regulations governing the arsenic content of food.

Meharg’s findings have led to a major EU review of arsenic levels in food. The UK Food Standards Agency (FSA) recommends that children under the age of four should not be given rice milk. In addition, the World Health Organisation has withdrawn their maximum tolerable daily intake level for arsenic and is currently considering how to regulate arsenic levels in food.

“If you look, for example, at the European Food Safety Authority (EFSA), about two years ago they produced a scientific comment on arsenic in food. There are nine individual references from Andy in the reference list,” Polya adds.

“The fundamental research into arsenic contamination in rice conducted by Professor Andrew Meharg and colleagues at the University of Aberdeen has highlighted to policy-makers the need to set arsenic standards in food:

- The UK Food Standards Agency issued guidance to parents suggesting children between one and four and a half years old should not be given rice milk, due to its arsenic content.
- The European Food Safety Authority conducted its own review of arsenic exposure in Europe and found that levels of arsenic were “unacceptable”.
- The World Health Organisation withdrew its maximum tolerable daily intake level for arsenic and is currently considering how to regulate arsenic levels in food.
- Ten Bangladeshi researchers spent time in Meharg’s laboratory in Aberdeen. Most are now working in Bangladesh, building research capability in the country.
- Meharg also wrote a popular science book, “Venomous Earth”, which was longlisted for the 2006 Aventis prize for popular science writing.
The results are also of interest to the food industry, and Meharg has recently been approached by baby food manufacturers concerned about the levels of arsenic in their rice milk products.

The research has received BBSRC funding, including three PhD studentships, two grants from the Research Equipment Initiative, a project supported by the SARID programme (Sustainable Agricultural Research for International Development3, co-funded by DFID) and a current responsive mode grant4.

**The arsenic problem**

In some parts of the world, such as Bangladesh, groundwater is naturally contaminated with high concentrations of highly poisonous and carcinogenic arsenic (see ‘Arsenic Poisoning’, below). As this groundwater is often extracted for drinking water, local communities can be exposed to dangerously high levels of arsenic. For instance, in 1993 researchers found that a large number of tube wells in Bangladesh had elevated arsenic levels, leading to what the World Health Organisation (WHO) described as “...the largest mass poisoning of a population in history...”.

According to Polya, water is by far the most important exposure route for tens of millions of people. “And that’s what the focus has been on. But it’s clear, particularly from Andy’s work, and from other people, that arsenic in rice is also an important exposure route.”

“As water remediation programmes are put in place, its relative importance is increasing,” he adds.

This is a particular problem in countries where rice is a staple crop. For instance, rice makes up 73 per cent of the calorific intake of 140 million Bangladeshis4. “Bangladeshis eat, globally, the most rice per capita... in Britain we take an average of 16 grams of rice a day. In Bangladesh they take an average of 450 grams of rice a day,” says Meharg. “The EFSA found that arsenic in rice was problematic in terms of cancer risks for the EU population. Then work out what that’s going to be doing if you eat twenty times more rice,” he warns.

Despite this, there are few regulations governing acceptable levels of arsenic in food, and none in the EU or USA (although arsenic levels in water are tightly regulated). Instead, old and almost certainly inadequate national standards may be invoked. For instance the UK government ultimately set an arsenic limit of one milligram per kilogram in food7 in response to the Manchester Beer Epidemic in 1900, where brewers inadvertently contaminated their beer with large quantities of arsenic, leading to 70 deaths8. However, the historical one mg per kg limit is much higher than existing UK regulations for arsenic levels in water.

**Arsenic Poisoning**

Arsenic, which occurs naturally in a number of forms, or ‘species’, is classified as a class one carcinogen by the World Health Organisation’s International Agency for Research on Cancer (IARC).

High levels of arsenic intake can raise the risk of developing lung, bladder and skin cancer, cardiovascular disease, diabetes, skin lesions, gastrointestinal illness and other serious health problems, eventually leading to death9.

It is a major public health concern in parts of the world with contaminated groundwater. “There’s a recent study by Maria Argos that suggests as many as 20 per cent of deaths in arsenic-impacted areas in Bangladesh are attributable to arsenic exposure,” says Polya10.
**Surveys and standards**

Meharg’s research into arsenic contamination of rice began when he moved to Aberdeen in 1989. Here he supervised a Bangladeshi PhD student on a Commonwealth Scholarship studentship studying the physiological aspects of arsenic uptake in rice. Following that project, a second Commonwealth Scholarship student surveyed rice from Bangladesh and found that the elevated arsenic levels were caused by watering rice paddies with contaminated groundwater\(^\text{11}\).

Meharg and BBSRC-funded PhD student Paul Williams then conducted surveys of arsenic levels in rice from around the world, including the USA, India, the EU, and Bangladesh. The results were published in 2005 in what has been recognised as an important and highly-cited paper\(^\text{12,13}\).

The 2005 study used a chemical analysis technique called HPLC-ICP-MS to determine which form of arsenic was present in the rice. “It’s really modern analytical methods that have enabled these conclusions. Our paper in 2005 was the first to widely speciate arsenic in rice grain using HCLP-ICPMS. People had done this before but they had used less robust techniques, or with only limited sample numbers” says Meharg. “The actual core equipment in our laboratory is BBSRC- and NERC-funded. The HPLC-ICP-MS was BBSRC-funded,” he adds. Two more BBSRC-funded PhD studentships followed, including one that used synchrotron radiation to determine where inorganic arsenic was localised in the rice grain.

Meharg’s group then turned their attention to rice products such as rice grain, baby rice and rice milk. They found that, when they considered consumption patterns, the levels of arsenic exceeded EU exposure limits for arsenic in water\(^\text{14}\).

“Off the back of our work, the UK FSA commissioned a study of their own on baby rice milk and found very similar results,” says Meharg. As a result, the FSA recommended that children between one and four-and-a-half years of age should not be given rice drinks (or ‘rice milk’) as a substitute for cows’ milk, infant formula milk or breast milk\(^\text{15}\).

Following this, the EFSA conducted a further investigationii. Once again, the findings reiterated Meharg’s earlier results. “They basically said there were unacceptable arsenic levels in the EU diet. They also found that rice was the dominant source. Currently they’re considering setting standards at an EU level for arsenic in food.... we published the original research papers which have triggered this,” says Meharg.

The EU report prompted the World Health Organisation (WHO) to withdraw its Potential Maximum Tolerable Daily Intake (PMDTI) standard for arsenic. The PMDTI was not a legal limit, but indicated an upper limit for substances such as arsenic beyond which they would have a negative impact on health. Meharg’s results and publications, and the EFSA review, indicated the existing PMTDI was too high; the WHO is now considering its approach to arsenic levels in food.

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Bangladeshi man suffering from skin lesions caused by arsenic poisoning. Credit: Andrew Meharg/University of Aberdeen
“Certainly in the UK and Europe, Andy has been particularly influential in getting these organisations to look at revisions of policy,” says Polya.

**Low-arsenic rice**

The researchers have also explored the genetic basis of arsenic uptake in rice through locally-grown rice cultivars in Bangladesh, India and China, funded through a recently-completed SARID grant, as well as a larger BBSRC responsive mode grant that has just started. Their ultimate aim is to enable breeders to develop low-arsenic rice that could be grown in contaminated areas.

“[From the SARID grant] we found there was a large genetic basis to arsenic in rice grain, which is what we were interested in. We also found there was a large genotype and environment interaction, so there were different genes acting on grain arsenic in different habitats, which makes it more complicated,” explains Meharg16.

The researchers found significant differences in arsenic uptake between different rice cultivars, and that local Bangladeshi varieties had the highest arsenic uptake17. Rice grain arsenic concentrations also varied significantly within a single field, and farming practices such as alternate wetting and drying resulted in far lower rice grain arsenic levels than the usual practice of flooding rice fields to help control pests and weeds.

Throughout the work Meharg has collaborated with researchers from Bangladesh, India and China to access unique field sites, local materials and expertise. “They’re extraordinarily good collaborators because they have the field sites, a deep local knowledge of rice cultivation practices and the nature of paddy soil, and an understanding and access to locally-relevant germplasm. We can contribute high-end analytical equipment,” says Meharg. “It can only be done through true partnership, which has naturally led to infrastructure building in Bangladesh and elsewhere,” he adds.

For Professor Rafiqul Islam from Bangladesh Agricultural University, who collaborated with Meharg on the SARID project, the collaboration helped to improve his understanding of arsenic in the interactions between the rice plants, soil and water. It also gave him the opportunity to work with scientists from the UK and elsewhere. Without the financial support of the SARID programme, the research and capacity building in Bangladesh could not have taken place.

The collaboration builds on long-term interactions between Meharg’s group and the Bangladeshi researchers. Meharg has trained five Bangladeshi PhD students, including four who were Commonwealth Scholarship funded. Five senior Bangladeshi research fellows, also with Commonwealth Association funding, have spent time working and training in Aberdeen. The majority of these researchers are now working in Bangladesh, where they are helping to build capacity and have successfully won further funding for research into arsenic in rice.

**Future impact**

Once the results are published, the genetic markers identified by the SARID programme will be used by rice breeders to produce varieties with low levels of arsenic in the rice grain and which can be grown in contaminated soils. “We will have the markers to show, for each particular environment we’re interested in, which ones to select for low-arsenic rice and what are the genetic characteristic of that low-arsenic rice,” says Meharg. “So breeders can go straight to that information and lift it and start breeding from it.”

However, the most important impact of the research is likely to be on public health, once arsenic levels in food are reduced. This is currently being considered in the UK and Europe, according to a recent discussion in the UK House of Lords18. “The real impacts and drive for change will come once the EU and US regulators, and the WHO, start putting standards in place,” says Meharg.
Notes and references

1) See: [Reference/webpage no longer available – Feb 2016]


3) See: [Reference/webpage no longer available – Feb 2016]

4) Grant references: Responsive mode - BB/J003336/1; SARID - BB/F004184/1; REI - REI18479, REI20492; Studentships - BBS/S/P/2003/10279, 02/B1/E/08011, 01/B1/E/07008. details can be found on BBSRC’s Portfolio Analyser at: http://www.bbsrc.ac.uk/df/1/grants/

5) See: [Reference/webpage no longer available – Feb 2016]

6) According to the Bangladesh Rice Foundation, a non-profit organisation: http://www.asiarice.org/sections/chapters/Bangladesh/BRF-About.html


12) See: [Reference/webpage no longer available – Feb 2016]


18) See question asked by Lord Bradley: http://www.publications.parliament.uk/pa/lrd201212/ldhansrd/text/120227w0003.htm#12022745003647