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A growing concern: Arsenic poisoning and rice

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Arsenic is a metallic element that naturally occurs in the environment1. Whilst organic Arsenic is generally non-toxic, inorganic Arsenic (iAs) is a human carcinogen, and once absorbed into the body can cause symptoms ranging from nausea and diarrhoea to cancers of the lung; skin; and bladder, depending on the Arsenic concentration and duration of exposure2.

Mostly prevalent within groundwater3, the ability of Arsenic to assimilate itself within crops, such as rice, during irrigation and cooking means that it can be ingested daily4; particularly within Asian countries, where rice accounts for 50% of the daily caloric intake for the population5. Within iAs-contaminated grains, Arsenite is more prevalent (90%) than Arsenate (10%)6. The high affinity of Arsenite towards vicinal dithiol groups, together with seleno-enzymes7, makes Arsenite much more toxic than Arsenate8. With increased concern shown towards high consumers of rice per kg/bodyweight, the priority is to decrease the amount of iAs present in rice and rice-based products under the guidelines of the European Commission1 for safe consumption.

Extensive discovery has not been made into the prevention and treatment of Arsenic poisoning; but monitoring water quality used for daily household purposes can aid in decreasing the amount of iAs absorbed into the body4. Possible therapeutic methods such as dimercapto-propanesulfonate (DMPS) and dimercaptopropanol (BAL) can aid in treating acute, sub-acute and chronic Arsenic poisoning, as they have/exhibit a high affinity to iAs compounds and its derivatives9.

Arsenic Arsenic is an element present in the natural environment, from rocks, and soil, to water and even air. Also found in plants and animals, Arsenic can easily contaminate agriculture and industry2, and can be found in both inorganic and organic compounds based on its ability to assimilate with carbon and other elements1. Organic Arsenic has little to no toxic properties and tends to be found within seafood, however10, inorganic Arsenic (iAs) is highly toxic - with non-carbon components, it has been linked to major pathophysiological conditions like cancer2.

Arsenic and health

Through iAs-contaminated food and water, it is estimated that at least 140 million people from over 50 countries have been exposed to Arsenic above 10 µg/L, exceeding the recommended safety limit, with the national survey data estimating nearly 43,000 deaths annually linked to long-term iAs exposure at concentrations above 10 µg/L4.

High level, short-term exposure to iAs causes acute poisoning symptoms ranging from vomiting to diarrhoea, and toxic shock10. However, long-term exposure has produced cases of chronic poisoning, cardiovascular diseases, and in extreme cases multi-organ failure9 and cancers.

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Figure 1: Diagram showing symptoms of arsenic poisoning.

Arsenic and rice

With more than 51.4% (3.5 billion) of the global population depending on rice for over 20% of their daily calorie intake, particularly within low- and low-middle-income countries, rice has quickly become a worldwide staple food13. From 2009 to 2021, the rice consumption increased by 15.1% globally (504.309 million metric tons)14; now accounting for over 50% of the Asian population's daily caloric intake5. China is both the world's biggest rice consumer and producer, accounting for 142.7 million metric tons of rice, with India and Indonesia following closely.

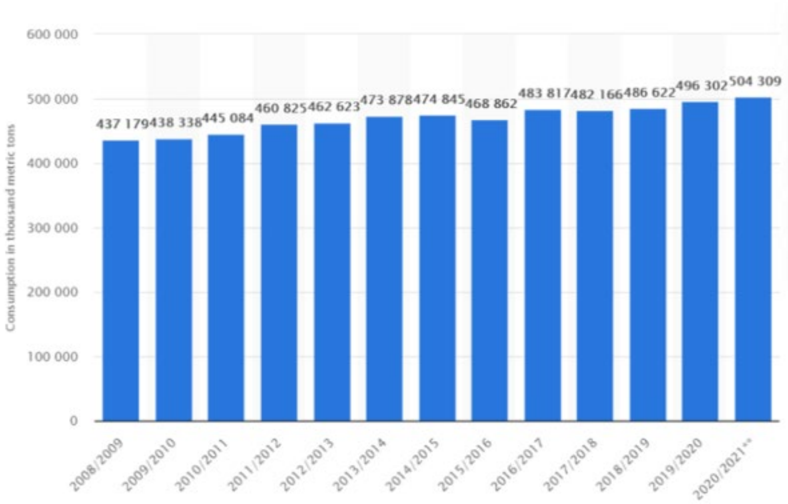

Figure 2: Consumption of rice in thousand metric tons globally from 2008 to 2021.

Rice (Oryza sativa) contains plenty of biomolecular components beneficial for human health. As a complex carbohydrate, it helps to increase blood sugar, regulate bowel movement, and decrease the risk of Diverticulosis15. However, rice is also a greater source of iAs than any other cereal crop grown in paddy fields16.

In 2014, the European Food Standards Agency (EFSA) published an Exposure Assessment regarding iAs intake across Europe, which included 28 surveys encompassing 17 European countries1. The study showed that a potential health risk was not associated with the amount of rice consumed, but rather for high consumers with regards to kg/bodyweight1. This is because young children generally consume a higher unit of food per bodyweight, resulting in a higher chance of iAs exposure1. To alleviate the risks of iAs exposure, the European Commission brought forth maximum limits for iAs in the production of rice and rice-based products, which was enforced in 20161.

Table 1: The maximum levels of inorganic arsenic (iAs) for rice and rice-based produced (mg/kg wet weight)

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Arsenic (inorganic)	Maximum levels (mg/kg wet weight)
Non-parboiled milled rice (polished or white rice)	0.20
Parboiled rice and husked rice	0.25
Rice waffles, rice wafers, rice crackers and rice cakes	0.30
Rice destined for the production of food for infants and young children	0.10

Maximum levels of inorganic arsenic in foodstuffs as detailed in Commission regulation (EU) 2015/1006 amending Regulation (EC) No 1881/2006

Table 2: The correlation between mean µg/kg bodyweight (b.w.) per day and the 95th percentile µg/kg b.w. per day (high consumers) for infants, toddlers and children and adults.

	Mean µg/kg b.w. per day	*95th percentile µg/ kg b.w. per day
Infant, Toddlers and children	0.20 to 1.37	0.36 to 2.09
Adults	0.09 to 0.38	1. 14

*Representing high consumers

Biological reasons

The direct or indirect intake of iAs-contaminated food and drink can lead to arsenic poisoning, due to high Arsenite and/or Arsenate levels[16]. These two anions are oxidative states of inorganic arsenic[17].

An experiment was conducted over a period of three days to show the toxicity levels of Arsenite and Arsenate in Lemna valdiviana plants[8]. The L. valdiviana plants showed a decrease in tolerance of absorption and toxicity as the iAs anion concentrations increased; with Arsenite requiring lower concentrations than Arsenate to achieve the same results[8]. Increased concentrations of superoxide anion levels were also observed from plants grown in Arsenite, whilst Arsenate-grown plants had increased hydrogen peroxide levels present within its tissues[8]. Overall, whilst both anions were toxic, Arsenite had much higher toxicity levels, with high solubility and mobility in aqueous environments, allowing for easy assimilation as well.

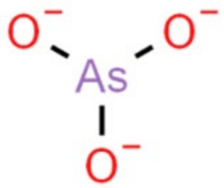

Figure 3: The 2D molecular diagram of Arsenite (also known as arsenic trioxide), AsO_3

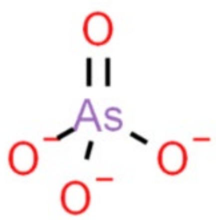

Figure 4: A 2D molecular diagram of Arsenate (also known as arsenic acid), AsO_4^{3-} [19].

Arsenate is taken into most cells via the phosphate pathway, whilst Arsenite uses aquaglyceroporins or sugar permeases to incorporate itself into cells[20]. The molecular structure of Arsenite allows for tight binding of itself to thiol groups, specifically vicinal dithiols such as dihydrolipoic acid (DHLA), and some seleno-enzymes, which results in Arsenic's toxic actions9. Once in the body, the high affinity of Arsenite-selenol compounds results in inhibition, along with ROS scavenging seleno-enzymes, leading to oxidative stress linked to Arsenic poisoning9.

Moving Forward Therapeutic dithiols such as dimercapto-propanesulfonate (DMPS), dimercaptopropanol (BAL), and in some cases, dimercaptosuccinic (DMSA), show promise as preventive treatments for Arsenic poisoning9. They target the binding properties of Arsenite compounds, and its derivatives, towards vicinal dithiols.

Education is a key factor in preventing further exposure to Arsenic, particularly for low-income countries and those exposed to Arsenic above the WHO recommended guidelines4. Using rainwater and treated surface water (low-arsenic concentrations) instead of groundwater (high-arsenic concentrations) to drink, cook and irrigate crops (e.g., rice) can be very effective in reducing the rate of arsenic absorption4.

Research by the FSA looked at cooking methods to help reduce Arsenic levels in rice1. On average, 10% of iAs was removed by rinse washing, with a 45% decrease in iAs content when cooking raw rice in a large volume of water1.

Conclusion

Arsenic-contaminated food and drinking supplies are increasing by the thousands each year and without a definite method on how to completely remove Arsenic from sources used in our daily lives, a big risk could be posed for the global population. For countries and communities that currently have cases of lifetime exposure to high levels of iAs (such as China, India, and Bangladesh)4, a huge spike may occur in the number of severe, and subsequently fatal cases. Continuous education and monitoring are key to controlling the rate of iAs exposure, but a long-term strategy is needed to effectively handle the level of iAs exposed to the human population21.

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