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Arsenic Biomagnifications in Rice Grain and Its Adverse Health Effect on Rice Consumers

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Use of arsenic-contaminated groundwater for irrigation purpose in crop fields increase arsenic concentration in surface soil and in the plants. Rice is reported to be one of the major sources of arsenic contamination in many arsenic-affected countries, including Bangladesh and India as Rice is much more efficient at accumulating arsenic into the grains than other staple cereal crops. Rice is generally cultivated in submerged flooded condition, where arsenic uptake and bioavailability is high in soil. Arsenic species are phytotoxic, they can also affect the overall production of rice, and can reduce the economic growth of a country. Once the food products are contaminated with arsenic, this local problem can gain further significance and may become a global problem, as many food products are exported to other countries. Use of rainwater for irrigation in large scal, bioremediation by arsenic-resistant organisms and hyperaccumulating plants, and the aerobic cultivation of rice are some possible ways to reduce the extent of bioaccumulation in rice.

Introduction

Rice, a dietary staple food for millions of people around the world and is often contaminated with arsenic, a naturally occurring element in soils that can cause cancer and other health effects. Although other foods also contain arsenic, rice is unusually efficient at absorbing this element from soil; it can absorb up to 10 times more arsenic than other crops, such as wheat. Moreover, rice flour and syrup are used in many processed foods, including baby foods, so exposures aren't limited to people eating the grain itself (Williams *et al.*, 2007). It's estimated that 95% of the average arsenic intake among Europeans comes from food, and half of that comes from rice and rice products. And in areas with high levels of arsenic in well water, the exposures via water and rice add up to a toxic double whammy .

Ground water of several states of India and Bangladesh was highly contaminated with arsenic (As), a non-threshold, class I human carcinogen. Situation was critical in several districts of West Bengal, located in eastern part of the river Bhagirathi where level of contamination reached 10 to 250 times higher than that of safe limit of 50µg/L (Mondal *et al.*, 1996). Rice, one of the major crops of West Bengal cultivated both at *kharif*, using rain water, and *boro*, completely dependent on groundwater. Being a staple crop of West Bengal, it represents a significant dietary source of arsenic, by accumulating above 0.3 mg/kg of grain.

Arsenic (As) Toxicity Mechanisms in Rice Plants

It has also been observed that arsenic can accumulate in the rice grains upto 7.5mg/kg even when the source of contamination is 2 km away. In general, plants take up As (V) through the phosphate transport channels. Because of their chemical similarity, arsenic competes with phosphate for root uptake and interferes with metabolic process like ATP synthesis and oxidative phosphorylation (Tripathi *et al.,* 2007). Recent studies have shown that in rice plants, arsenite is taken up at high rates of influx which follows the Michaelis–Menten kinetics (Abedin *et al.,* 2002). In rice, arsenic uptake shares the same pathway as silicon uptake. Rice is a strong accumulator of silicon which may allow efficient uptake and translocation of arsenite in the shoots.

Toxicity limit and mobility of arsenic in soil depend on the properties of soil such as particle size, texture, mineral nutrient content, pH, presence of other ions, moisture regimes, transformations by microbes, and the chemical form of arsenic (Bhattacharya *et al*., 2007). Arsenic is more mobile and bio-available in sandy soil than in clayey soil. The effect of arsenic toxicity in plants increase in low pH, but the uptake mechanism can enhance in higher pH soil. These properties of soil are very much relevant to evaluate the influence of arsenic on its accumulation and distribution in plants. Rice plants are generally grown in submerged soil condition, where arsenic bioavailability is generally high (Bhattacharya *et al.,* 2007). Rice roots can constitutively form aerenchyma and waterlogging or O2-deficient conditions can enhance the process.

Arsenate and arsenite two predominant forms of As present in paddy soil under aerobic and anaerobic condition respectively. Although most of the plants, usually, allow arsenate, an analogue of Phosphate, more readily into roots through Phosphate transporters but rice allow entry of both arsenate and arsenite efficiently and later form which was a dominant redox form under anaerobic conditions, entered through silicic acid efflux transporters. Arsenite remain as the predominant inorganic form found in xylem sap of rice plants fed with either arsenate or arsenite. It had been demonstrated that although majority of arsenic sequestered inside the vacuoles of the roots but grain uploading of As took place in the ovular vascular trace of rice grain, largely driven by mass flow (Carey *et al.,* 2010).

Arsenic Uptake and Accumulation in Plants

Uptake and accumulation of As in different plant parts affects the growth and productivity of the plants. Arsenic uptake, translocation and biomagnifications in various crop plants and vegetable species have increased the threat to humans. Accumulation of As in agricultural plants depends on two factors: As availability in the soil and the physiological properties of the plant. Arsenic uptake by plants occurs primarily through the root system. After uptake by the root system, As distribution is highly variable among various plant parts. Generally, roots and tubers are known to accumulate As in large amount, however, this varies among different plant species. Studies suggest that As is not readily translocated to the shoots and edible plant parts are generally low in As (2 mg/kg). However, some plants accumulate high levels (5–40 mg As/kg) of As even at soil concentrations near the background level.

In rice straw, As accumulates up to 149 mg/ kg which is a major cause of As related health hazards. Recently, Wilson *et al*., (2014) investigated the accumulation of antimony (Sb) and As in vegetable crops such as lettuce, spinach, raddish, carrot and silverbeet for the oral bioaccessibility of these toxic metalloids to humans. Analysis showed that fraction of metalloids was soluble under typical conditions of crop production and As was accumulated in all the glasshouse grown vegetable species.

Finding the Right Balance

Both the EPA and the WHO have adopted maximum limits of 10 µg/L for inorganic arsenic in drinking water (WHO 2008). However, most countries do not currently regulate arsenic in rice. The European Union—which sets centralized food safety standards for its member countries—has come out in favor of the Codex white rice standard, but it has yet to endorse it as law. According to Meharg, the European Union also plans to adopt a value of 0.1 mg/kg that would be specific to inorganic arsenic in rice-based baby food. Maximum inorganic arsenic levels in the submitted samples ranged between 0.16 and 1.8 mg/kg, but the mean values were all below 0.2 mg/kg. Thus, the 0.2-mg/kg value was selected in part because of its feasibility, with a relatively low exceedance rate of 2%.

Health Hazardous Effect of Arsenic Biomagnification in Rice

Ingestion of Arsenic is manifested in three ways in human beings, viz. As in urine (for recent exposure), As in blood (for instant exposure), as in skin and fingernails (for chronic exposure). High doses of As can be lethal, but chronic effects of lower levels of arsenic manifest quite slowly. Oral intake has a greater harmful effect than dermal or inhalation exposure. The effects of As toxicity due to oral intake are given below:

1. Skin-dark/light spots on skin, coms, on palm and soles may progress to skin cancer;
2. Increased risks of liver cancer, bladder cancer, kidney cancer and lung cancer;
3. Nausea, vomiting and diarrhaea;
4. Aggravated malnutrition;
5. Impaired nerve functioning, pins and needles feeling in palm and feet etc;
6. Fetal damage during pregnancy;
7. Abortion;
8. Respiratory tract infectio;
9. Loss of memory;
10. Lowering of the intelligence level of children.

Abdulla and Reis (1998) reported that there is a direct link between As toxicity and the nutritional status of the subject. Supplementation of protein in the diet and antioxidant like carotene, vitamin C, Vitamin E, etc. have been reported to have mitigated the severity of Arsenicosis.

How to Mitigation

1. Rice grains when accumulated with arsenic, it is very difficult to remove it properly. Cooking with high volume of arsenic-free water can help to some extent, but, it can also remove beneficial vitamins and thus can decrease the food value. Toxicity levels also depend on the cooking methods which vary in different regions. For example, in Hungary, rice is generally cooked with an excessive amount of water and the remaining water is discarded; on the other hand, in China, rice is generally cooked with aliquots of water in order to absorb it all.
2. Aerobic cultivation of rice can decrease arsenic bioaccumulation significantly, as in anaerobic submerged field conditions, the chances of arsenic bioavailability is high.
3. When rainwater used in irrigation in large scale, through proper water management systems, which, in turn can reduce the use of arsenic-contaminated water in irrigation in respective contaminated zones. Rainwater can also reduce the concentration of arsenic in surface soil, which, in turn, can reduce the accumulation of arsenic in rice and other edible plants.
4. Increase crop production under rain-fed conditions where soils are contaminated with arsenic as alternative safe irrigation supply cannot easily be provided, therefore, farmers should be encouraged rain fed cultivation where this is practical.
5. Applications of synthetic agglomerated nanoparticles materials like iron-zirconium, iron-titanium, cerium-manganese, and iron-chromium mixed oxides with arsenic sorption behavior from the aqueous solution for removing arsenic and other harmful contaminants from groundwater is very useful. These low cost and highly efficient materials have immense potentials in arsenic mitigation and can be used effectively to remove arsenic from irrigation and drinking water.

6. Use of phytoremediation for successful removal of heavy metals like arsenic from the contaminated soil, sediments, groundwater, and surface water as it is an emerging sustainable technology.
7. Considered for cultivation of arsenic-resistant genotypes of rice varieties to reduce the toxic effects of arsenic on plants is very practical. Some genotypes of rice varieties which can accumulate lesser amount of arsenic, specially the trivalent toxic form, can be used in breeding programs and genetic researches for identifying the beneficial genes which can decrease trivalent arsenic in grains.

Conclusion

Bioavailability of arsenic in rice and other edible plants must be considered to understand the importance of arsenic exposure from these food sources. The importance of rice in food security in India and Bangladesh and the high dietary intake of rice indicate that the impact of arsenic in groundwater on rice productivity and quality and it should be carefully monitored. Intensive investigation on a complete food chain is urgently needed in the arsenic-contaminated zones. Differences in environmental and socio-economic conditions within the contaminated regions and within countries need to be considered in a sustainable manner.

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