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Study of Arsenic Loading in the Grains of Rice When Irrigated Using Arsenic Contaminated Water in Eastern Uttar Pradesh, India - A Case Report

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ABSTRACT: Rice the staple food is a notable intake source of arsenic to the rural population of eastern India through food-chain. A field survey was carried out to study the variation of arsenic load in different parts of rice genotype Shatabdi (most popular genotype of the region) exposed to varying level of arsenic present in the irrigation water and soil. As irrigation is the primary source of arsenic contamination, a study was conducted to assess arsenic load in rice ecosystem under deficit irrigation practices like intermittent ponding (IP), saturation (SAT) and aerobic (AER) imposed during stress allowable stage (16–40 days after transplanting) of the crop (genotype Shatabdi). Present survey showed that arsenic content in water and soil influenced the arsenic load of rice grain. Variation in arsenic among different water and soil samples influenced grain arsenic load to the maximum extent followed by straw. Deviation in root arsenic load due to variation in water and soil arsenic content was lowest. Arsenic concentration of grain is strongly related to the arsenic content of both irrigation water and soil. However, water has 10% higher impact on grain arsenic load over soil. Translocation of arsenic from root to shoot decreased with the increase in arsenic content of water. Imposition of saturated and aerobic environment reduced both yield and grain arsenic load. In contrast under IP a marked decrease in grain arsenic content recorded with insignificant reduction in yield. Deficit irrigation resulted in significant reduction (17.6–25%) in arsenic content of polished rice and the values were lower than that of the toxic level (<0.2 mg kg^{-1}). In contrast the decrease in yield was to the tune of 0.9% under IP regime over CP in eastern Uttar Pradesh, India

KEYWORDS- rice, arsenic, grains, eastern Uttar Pradesh, soil, irrigation

I. INTRODUCTION

Arsenic (As) is a non-essential toxic metalloid whose elevated concentration in rice grains is a serious issue both for rice yield and quality, and for human health. The rice-As interactions, hence, have been studied extensively in past few decades. A deep understanding of factors influencing As uptake and transport from soil to grains can be helpful to tackle this issue so as to minimize grain As levels. As uptake at the root surface by rice plants depends on factors like iron plaque and radial oxygen loss. There is involvement of a number of transporters viz., phosphate transporters and aquaglyceroporins in the uptake and transport of different As species and in the movement to subcellular compartments. These processes are also affected by sulfur availability and consequently on the level of thiol (-SH)-containing As binding peptides viz., glutathione (GSH) and phytochelatins (PCs). Further, the role of phloem in As movement to the grains is also suggested in eastern areas of Uttar Pradesh.

Experimentation

Three regimes of deficit irrigation, viz. intermittent ponding (IP), saturation (SAT) and aerobic condition (AER) were tested against farmers practice, i.e. continuous ponding (CP). These four regimes were replicated five times and arranged in randomised complete block design (RCBD). Net area of each plot was 7 m 9 6 m = 42 m2 . The treatments were designed to impose stress up to tillering stage (15 DAT to 45 DAT) only. Out of various growth stages of rice, flowering stage is most sensitive to water stress (O'Toole 1982; Garrity and O'Toole 1995), and thus, imposing stress in tillering stage has minimum negative effect on yield. The crop received uniform submergence, in exception to this period. During the period of treatment consideration, in CP, 5 cm of water was applied at every 3-day interval, which simulated the local farmers' practice and was considered as control. At IP, 5-cm irrigation was only administered when hairline line cracks were found. The interval was normally 6 days. In SAT, 1-cm irrigation was provided everyday to keep the soil saturated. For maintenance of AER, 1 cm of irrigation was given on alternate days to AER. The treatments were designed with the philosophy of easy applicability for the farmers. Some of the irrigations were skipped due to receipt of 84 and 68 mm of rainfall during the study period of 2008 and 2009, respectively. Plots were irrigated from a submersible pump having depth of 70 m. Arsenic level of the irrigation water was 0.163 ± 0.02 mg As L-1 . Two-metrewide buffer zone was left surrounding the plots to minimise seepage from the neighbouring plots. Main and sub-channels were lined with polyethylene sheet to check the loss of irrigation water. Locally available cost-effective 62.5-micron-thick polythene sheets were used for this purpose. Bunds were reconstructed at regular interval. A locally popular rice variety Shatabdi was chosen for the study. This variety is medium statured, bold grained and of medium duration mainly suited for cultivation in medium land. Transplanting of thirty 2-day-old seedlings at 3–4 per hill was performed on February 14 and February 1 during 2008 and 2009 and harvested on May 18 and May 8, respectively. Standard package of cultivation practice including quick and eco-safe plant protection measure was followed.

Measurement of total arsenic in plant samples

GR-grade chemicals, class B glassware, calibrated micropipettes and double-distiled water (DDW) were used throughout the chemical analysis to maintain accuracy. Known amount of aliquot taken in a volumetric flask was acidified with 10 % v/v hydrochloric acid and reduced with 5 % potassium iodide and ascorbic acid. The mixture was kept for 45 min for completion of the reaction. Finally, it was measured for total arsenic in a Perkin Elmer AANALYST 200 Atomic Absorption Spectrophotometer (Perkin Elmer, USA) coupled with a same-make Hydride Generator (FIAS 400) in 720 nm wavelength. Measurement of arsenic was done according to Standard Methods 3114B (American Public Health Association 1995) by HG-AAS which has been recognised by United States Environment Protection Agency (USEPA) as a dependable and accurate process. In each analysis, matrix-matched standards were used for calibration. To assure the accuracy, 1568a rice flour obtained from National Institute Standards and Technology, USA, was used as standard reference material.

Computation

Irrigation water use efficiency (IWUE), i.e. the efficiency of water to produce grain has been calculated by the following equation where IWUE is irrigation use efficiency (kg m-3), GY is grain yield (t ha-1) and IW is amount of water irrigated (mm). IWUE ¼ ð Þ GY=IW : Yield and concentrations of arsenic values were statistically analysed for comparison of means by F test. Least significant difference (LSD) among treatment means was calculated at 5 % probability according to the method described by Gomez and Gomez 1984 where the difference was found significant. Data obtained from two consecutive years were pooled over years. All statistical analysis was done in computer with MSTATC (Massachusetts State University, USA) and Microsoft Excel 2007 (Microsoft Corporation, USA) programme.

II. DISCUSSION

Arsenic is a natural component of the earth's crust and is widely distributed throughout the environment in the air, water and land. It is highly toxic in its inorganic form.

People are exposed to elevated levels of inorganic arsenic through drinking contaminated water, using contaminated water in food preparation and irrigation of food crops, industrial processes, eating contaminated food and smoking tobacco.

Long-term exposure to inorganic arsenic, mainly through drinking-water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects.

Sources of exposure

Drinking-water and food

The greatest threat to public health from arsenic originates from contaminated groundwater. Inorganic arsenic is naturally present at high levels in the groundwater of a number of countries, including Argentina, Bangladesh, Cambodia, Chile, China, India, Mexico, Pakistan, the United States of America and Viet Nam. Drinking-water, crops irrigated with contaminated water and food prepared with contaminated water are the sources of exposure.

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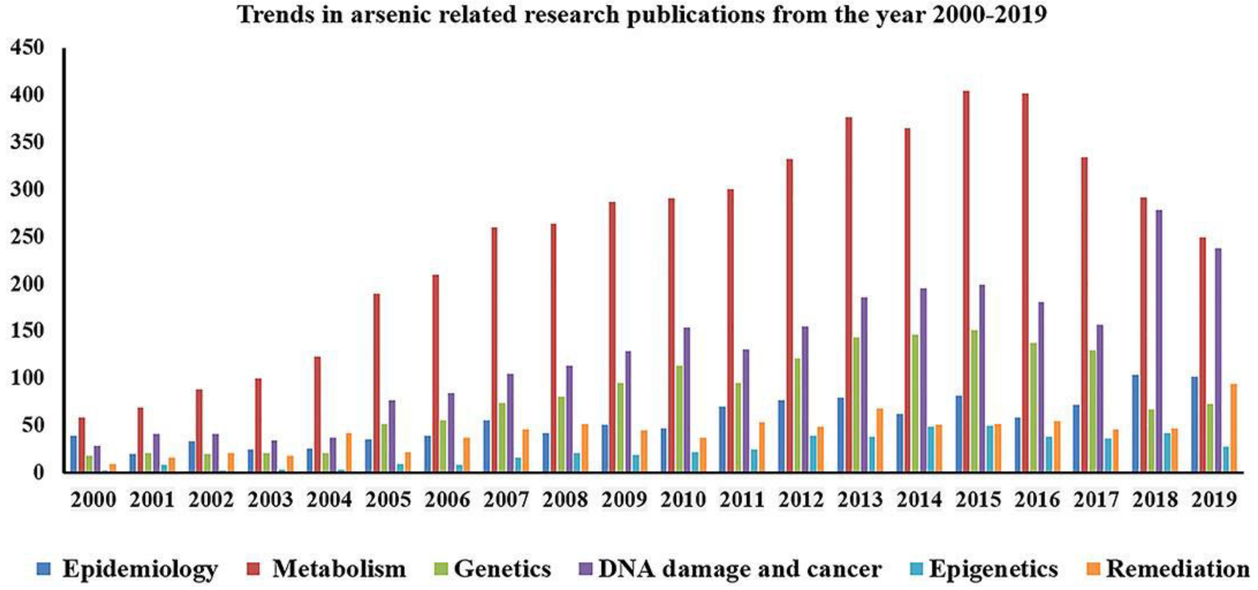

Fish, shellfish, meat, poultry, dairy products and cereals can also be dietary sources of arsenic, although exposure from these foods is generally much lower compared to exposure through contaminated groundwater. In seafood, arsenic is mainly found in its less toxic organic form.

Industrial processes

Arsenic is used industrially as an alloying agent, as well as in the processing of glass, pigments, textiles, paper, metal adhesives, wood preservatives and ammunition. Arsenic is also used in the hide tanning process and, to a limited extent, in pesticides, feed additives and pharmaceuticals.

Tobacco

People who smoke tobacco can also be exposed to the natural inorganic arsenic content of tobacco because tobacco plants can take up arsenic naturally present in the soil. The potential for elevated arsenic exposure was much greater in the past when tobacco plants were treated with lead arsenate insecticide.

Health effects

Inorganic arsenic is a confirmed carcinogen and is the most significant chemical contaminant in drinking-water globally. Arsenic can also occur in an organic form. Inorganic arsenic compounds (such as those found in water) are highly toxic while organic arsenic compounds (such as those found in seafood) are less harmful to health.

Acute effects

The immediate symptoms of acute arsenic poisoning include vomiting, abdominal pain and diarrhoea. These are followed by numbness and tingling of the extremities, muscle cramping and death, in extreme cases.

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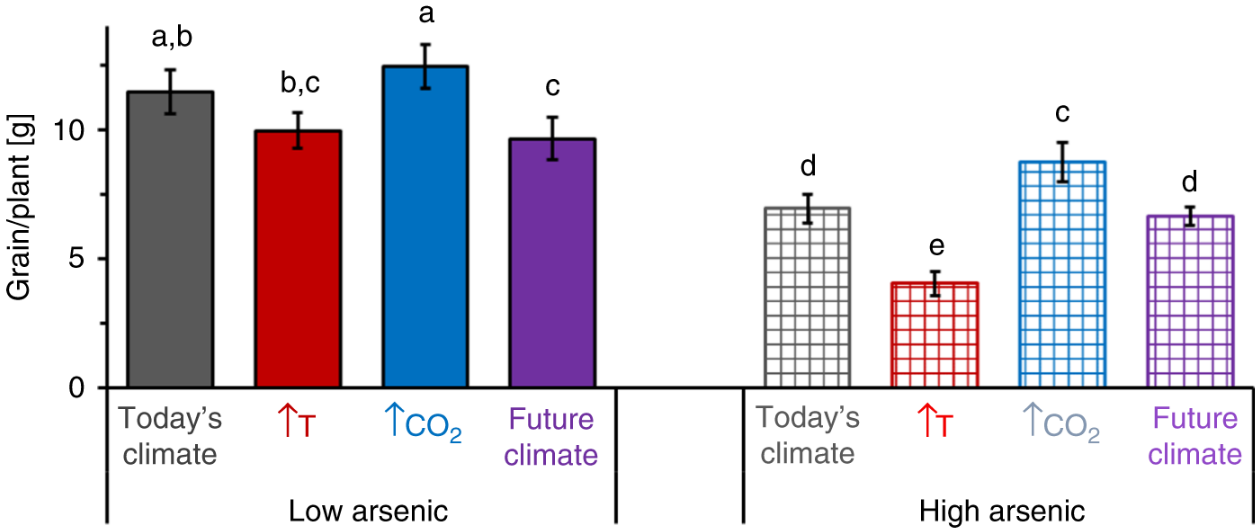

Long-term effects

The first symptoms of long-term exposure to high levels of inorganic arsenic (for example, through drinking-water and food) are usually observed in the skin, and include pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (hyperkeratosis). These occur after a minimum exposure of approximately five years and may be a precursor to skin cancer.

In addition to skin cancer, long-term exposure to arsenic may also cause cancers of the bladder and lungs. The International Agency for Research on Cancer (IARC) has classified arsenic and arsenic compounds as carcinogenic to humans and has also stated that arsenic in drinking-water is carcinogenic to humans.

Other adverse health effects that may be associated with long-term ingestion of inorganic arsenic include developmental effects, diabetes, pulmonary disease and cardiovascular disease. Arsenic-induced myocardial infarction in particular can be a significant cause of excess mortality.

Arsenic is also associated with adverse pregnancy outcomes and infant mortality, with impacts on child health (1), and exposure in utero and in early childhood has been linked to increases in mortality in young adults due to multiple cancers, lung disease, heart attacks and kidney failure (2). Numerous studies have demonstrated negative impacts of arsenic exposure on cognitive development, intelligence and memory (3).

Magnitude of the problem

Arsenic contamination of groundwater is widespread and there are a number of regions where arsenic contamination of drinking-water is significant. An estimated 140 million people in at least 70 countries have been drinking water containing arsenic at levels above the WHO provisional guideline value of 10 μg/L (4, 5). This is consistent with recent statistical modelling which suggests between 94 and 220 million people are at risk of exposure to elevated arsenic concentrations in groundwater (6).

The symptoms and signs caused by long-term elevated exposure to inorganic arsenic differ between individuals, population groups and geographical areas. Thus, there is no universal definition of the disease caused by arsenic. This complicates the assessment of the burden on health of arsenic.

Similarly, there is no method to distinguish cases of cancer caused by arsenic from cancers induced by other factors. As a result, there is no reliable estimate of the magnitude of the problem worldwide.

In 2010, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) re-evaluated the effects of arsenic on human health, taking new data into account. JECFA concluded that for certain regions of the world where concentrations of inorganic arsenic in drinking-water exceed 50–100 μg/L, there is some evidence of adverse effects. In other areas, where arsenic concentrations in water are elevated (10–50 μg/L), JECFA concluded that while there is a possibility of adverse effects. These would be at a low incidence that would be difficult to detect in epidemiological studies.

Prevention and control

The most important action in affected communities is the prevention of further exposure to arsenic by the provision of a safe water supply for drinking, food preparation and irrigation of food crops. There are a number of options to reduce levels of arsenic in drinking-water.

- Substitute high-arsenic sources, such as groundwater, with low-arsenic, microbiologically safe sources such as rainwater and treated surface water. Low-arsenic water can be used for drinking, cooking and irrigation purposes, whereas high-arsenic water can be used for other purposes such as bathing and washing clothes.
- Discriminate between high-arsenic and low-arsenic sources. For example, test water for arsenic levels and paint tube wells or hand pumps different colours. This can be an effective and low-cost means to rapidly reduce exposure to arsenic when accompanied by effective education.
- Blend low-arsenic water with higher-arsenic water to achieve an acceptable arsenic concentration level.
- Install arsenic removal systems – either centralized or domestic – and ensure the appropriate disposal of the removed arsenic. Technologies for arsenic removal include oxidation, coagulation-precipitation, absorption, ion exchange and membrane techniques. There is an increasing number of effective and low-cost options for removing arsenic from small or household supplies, though there is still limited evidence about the extent to which such systems are used effectively over sustained periods of time.

Long-term actions are also required to reduce occupational exposure from industrial processes.

Education and community engagement are key factors for ensuring successful interventions. There is a need for community members to understand the risks of high arsenic exposure and the sources of arsenic exposure, including the intake of arsenic by crops (e.g. rice) from irrigation water and the intake of arsenic into food from cooking water.

High-risk populations should also be monitored for early signs of arsenic poisoning – usually skin problems.

WHO response

Arsenic is one of WHO's 10 chemicals of major public health concern. WHO's work to reduce arsenic exposure includes setting guideline values, reviewing evidence and providing risk management recommendations. WHO publishes a guideline value for arsenic in its Guidelines for drinking-water quality. The Guidelines are intended for use as the basis for regulation and standard setting worldwide.

The current recommended limit of arsenic in drinking-water is 10 μg/L, although this guideline value is designated as provisional because of practical difficulties in removing arsenic from drinking-water. Every effort should therefore be made to keep concentrations as low as reasonably possible and below the guideline value when resources are available.

However, millions of people around the world are exposed to arsenic at concentrations much higher than the guideline value (100 μg/L or greater), and therefore the public health priority should be to reduce exposure for these people. Where it is difficult to achieve the guideline value, Member States may set higher limits or interim values as part of an overall strategy to progressively reduce risks, while taking into account local circumstances, available resources, and risks from low arsenic sources that are contaminated microbiologically.

The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene monitors progress towards global targets on drinking water. Under the 2030 Agenda for Sustainable Development, the indicator of "safely managed drinking water services" calls for tracking the population accessing drinking water which is free of faecal contamination and priority chemical contaminants, including arsenic.

III. RESULTS

About 150 million people are exposed to Arsenic contamination in the World with the largest percentage coming from Asia especially Uttar Pradesh, India. Also, an estimated 30 million people drink water from Arsenic-contaminated

Shallow Tube Wells (STWs) and approximately 900,000 STWs are used in irrigating 2.4 million out of 4 million ha under irrigation in Uttar Pradesh, mainly paddy fields. This has led to the accumulation of As in paddy soils and potentially have adverse effects on rice yield and quality. The present study reviews the damaging effects of As-contaminated irrigation water in rice production especially in Uttar Pradesh. The study highlights the causes of arsenic contamination in irrigation water, health and dietary hazards of rice consumers and its derivatives. The study suggested remedial measures from aerobic rice production to Phytoremediation for mitigating Arsenic contamination in food especially, As-free rice production and sustainable livelihoods.

Paired grain, shoot, and soil of 173 individual sample sets of commercially farmed temperate rice, wheat, and barley were surveyed to investigate variation in the assimilation and translocation of arsenic (As). Rice samples were obtained from Uttar Pradesh. Transfer of As from soil to grain was an order of magnitude greater in rice than for wheat and barley, despite lower rates of shoot-to-grain transfer. Rice grain As levels over 0.60 μg g-1 d. wt were found in rice grown in paddy soil of around only 10 μg g-1 As, showing that As in paddy soils is problematic with respect to grain As levels. This is due to the high shoot/soil ratio of ~0.8 for rice compared to 0.2 and 0.1 for barley and wheat, respectively. The differences in these transfer ratios are probably due to differences in As speciation and dynamics in anaerobic rice soils compared to aerobic soils for barley and wheat. In rice, the export of As from the shoot to the grain appears to be under tight physiological control as the grain/shoot ratio decreases by more than an order of magnitude (from ~0.3 to 0.003 mg/kg) and as As levels in the shoots increase from 1 to 20 mg/kg. A down regulation of shoot-to-grain export may occur in wheat and barley, but it was not detected at the shoot As levels found in this survey. Some agricultural soils in Uttar Pradesh had levels in excess of 200 μg g-1 d. wt, although the grain levels for wheat and barley never breached 0.55 μg g-1 d. wt. These grain levels were achieved in rice in soils with an order of magnitude lower As. Thus the risk posed by As in the human food-chain needs to be considered in the context of anaerobic verses aerobic ecosystems.

IV. CONCLUSION

In this study we investigated the effect of different levels of soil As contamination on rice (Shatabdi) and its management through irrigation practices. Our results revealed that rice growth and yield was significantly affected by soil arsenic contamination and AWD irrigation practice significantly increased rice yield compared to CF practice. Grain As concentration and uptake was significantly lower in AWD treatment as nonflooded condition did not facilitate As availability and mobilization compared to flooding management. Thus in high As-contaminated areas of Uttar Pradesh, AWD irrigation can be practiced to minimize As concentration and uptake for betterment of rice yield compared to CF.

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