Arsenic in Rice: An Emerging Challenge in Context of Food Security

Rebia Ejaz¹*, Mian Kamran Sharif², Aysha Sameen¹, Rizwana Batool¹, Saima Tehseen¹, Mahwash Aziz¹
¹Department of Food Science and Technology, Government College Women University, Faisalabad, Pakistan;
²Faculty of Food, Nutrition and Home Science, National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan
*Corresponding author: rebiaejaz.2500@gmail.com

Abstract: Arsenic speciation in food and diet was assessed for human exposure through dietary approaches because it seems as a critical public health issue all over the world. Globally, rice is a vital commodity in world hunger and vastly important for survival of human race. Rice is widely used for the formulation of baby formulas, breakfast cereals, bread, cookies, cakes, rice drinks and other foodstuff. Arsenic is concentrated at higher rates in rice grains and containing more than 85% of total arsenic forms that poses serious health ailments o human as well as animal life on the planet. Meanwhile, Arsenic contaminated water and soil may induce hazardous affects to humans through water-soil-plant pathway.

Keywords: Rice; Arsenic; Health Threat; Food Safety; Metabolic Disorders

1. Introduction

Elemental composition of food is an effective approach to establish an suitable pattern of consuming nutrients as well as identifying their toxic limits of exposure. Total concentration of any metal present in our daily diet or food could not measure its level of toxicity. In some regions of Pakistan, presence of arsenic above acceptable limit (10ppb) has demonstrated in drinking water and thus is a potentially critical concern regarding public health[1].

2. Arsenic

Arsenic a pure elemental crystal comprised of different minerals especially in conjunction with sulphur and other metals. It was first documented by Albert Magnus in 1250 and exists in various allotropes. It is 53rd most abundant element and making 1.5ppm of earth crust. Contribution of arsenic in soil and seawater is 10ppm and 1.6ppb, respectively. Arsenic ubiquitous in the environment as trivalent arsenate and pentavalent arsenite that are more hazardous irrespective to monomethyarsonae (MMA) as well as dimethylarsonate (DMA). Arsenic is notorious poison to all living organisms, although a few bacterial species respire in presence of arsenic metabolites. Geological conditions, genetic factors along other manmade activities like more use of vehicles, production of smoke, application of agrochemicals and deposit of industri-
al effluents leads to the contamination of underground water and soil that ultimately deteriorate the agriculture commodities [2,3].

3. Presence of Arsenic in Soil, Water and Plants

Total As concentration varies from 10 ppm to several thousand ppm in soils according to specific area whereas in terrestrial plants it depends on soil As contents and plant ability to uptake or accumulate. Moreover, plants grown on contaminated site have upto 1000 ppm As while uncontaminated plants contain 0.2 to 0.4 ppm. Inorganic arsenic dominates in foods that are originated form terrestrial while minor in marine food [4].

It is reflected as most critical type for creating and assessing the hazards of dietary arsenic. Arsenic, a toxic metalloid is present in irrigated water upto a certain safe limit i.e. 10ug/L and 100ug/L proposed by WHO and FAO, respectively. The occurrence of arsenic due to natural and artificial processes above safe level is crucial to food security and creates an alarming situation now days [5,6].

Arsenic toxicity affects the photosynthesis of plant ultimately decreases plant growth and yield in promising rice varieties. The plant roots are most efficient accumulator of arsenic than rice straw and leaf while the husk or outer protective covering contains more arsenic than the full rice grain. Byproducts of rice milling industry rice straw are found to be an major agricultural source and used as main ingredient in cattle feed. Hence, cattle feed rich in arsenic poses a direct threat to animal life and indirectly affect the humans via their associated meat, milk and other foods [7].

Edible plants are well recognized sources of As contamination among Asian countries like India Bangladesh and Pakistan as well as Latin America, thus posing health risk to inhabitants. It is obvious that long term exposure to As intake through water and plants adversely affect production and quality of food. Cultivation methods, plant composition, morphology, soil physiology and identification of arsenic form are essential factors contributing towards As uptake in food [7].

4. Rice

Agriculture is the major profession among masses around the globe and occupies 37% of the land area. Rice production is used as staple diet to feed half of the world population. Rice is a water loving plant and requires groundwater as irrigated source from just its establishment till further operations at the fields. Rice is one of the staple foods for more than half of the world population. It is one of the major sources of carbohydrates (70%), proteins (6-9%) and vitamins (1%). Rice grains have strong potential as anti-oxidant, anti-inflammatory and anti-allergic agents and widely consumed for health promotion and wellbeing. Rice has developed a circular breathing system of taking oxygen in through direct surface leaves, provides to the stalks and leaves under water for the growth of root system and releases carbon dioxide into the water. Globally, rice is a vital commodity in world hunger and vastly important for survival of human race. Rice consumption among Asians population has been exceeding 100
kg/capita annually. Rice contributes about 50% of global energy supply to persons. Rice is widely used for the formulation of baby formulas, cakes, rice milk, beverages and other foodstuff for vulnerable groups having metabolic disorders. Meanwhile, such products may contain As and enhance the severity of diseases among individuals rely on these food items\(^8\).

**5. Arsenic in Foods**  
Cereal and cereal based products are chief contributors for its exposure to humans. According to data collected on population exposure arsenic is nominated as class I human carcinogen\(^9\). Naturally occurring organ arsenic compounds are non-toxic\(^10\). Arsenic speciation in food and diet was evaluated and assessed for human exposure through dietary approaches\(^11\).

**5.1 Arsenic in Rice**  
Approximately, 90% of Arsenic present in rice plant in various forms i.e. As III, As V and DMA all these forms are responsible for cancer propagation due to specific routes for their entry through silicic and phosphate transporters\(^12\). Firstly, arsenic accumulated in roots and then move towards shoots, leaves and grains due to formation of photochelatin complexes between metals and sequestration within cell vacuoles of rice. Anaerobic system for rice cultivation under flooded conditions is one of the major reasons for higher arsenic concentration up to ten folds in rice grains as compared to other cereal grains like wheat, barley and maize that grow best in aerobic environment\(^13,14\).

It is obvious from previous findings that total As concentration was depends on rice cultivar. Brown rice contains more arsenic as compared to polished one. Endosperm fraction of rice contains the least amount of arsenic as compare to bran and husk. Brown rice was a famous food for individuals due to all natural tendencies and nutritional benefits but at the same time these are not known safe to use in infant diet. However, quality and safety of designer foods should be wisely monitored before consumption\(^15\). It is concluded that only white rice with lower As contents should be incorporated for the manufacturing of baby foods\(^16,17\).

Arsenic accumulation in food crops has becoming as serious public health problem. In 2014, CODEX/FAO has established maximum limit for polished rice (0.2mg/kg). In 2016, CODEX has recommended that brown rice or cargo rice (rice without husk only) should not contain more than 0.35mg/kg arsenic. Foods prepared from rice and its flour are gluten free and alternatively consumed by celiac patients or gluten intolerant persons along with people suffering from severe allergies as well as lactose intolerants. In western population, upto 1% of individuals including children and old aged (over 65 years) are celiac patients. Celiac disease is an immune mediated allergy linked with malabsorption of nutrients and vitamins due to an abnormal response to gluten that harms the small intestines lining of children during the infancy and adolescence. Rice and its products are the main edible alternate for wheat based products because of lacking gluten. Pre-
cooked milled rice is commonly used for weaning purpose owing to its blended taste, discoloration, low allergenic and scare nutrition value\textsuperscript{18}.

Rice samples\textsuperscript{(12)} were collected from local markets of Australia for the determination of Arsenic by ICP-MS. Mean concentrations of As were ranged from 0.026 to 0.464 ppm in all rice samples. Variation among As concentration was observed due to differences in geographic origins. American rice contained the highest Arsenic (0.25mg/kg) followed by Thai rice (0.20 mg/kg), Pakistani rice (0.14 mg/kg), Indian rice (0.10 mg/kg) and Egyptian rice (0.09 mg/kg), respectively. Some varieties under study contained hazardous concentration of toxic elements. There is a dire need for concerned authorities to regulate and monitor the Arsenic contents in paddy for the improvement and protection of public health. Millions of subjects were exposed to As toxicity through water in Bangladesh and West Bengal. Skin diseases, cancer risks and potential effect on development of children have become the basis for arsenic regulation. According to Codex, maximum permissible limit (0.2mg/kg) was established for fresh milled rice\textsuperscript{19}.

Approximately, 75-90% arsenic found in rice products demonstrated the inorganic species during analysis. Liquid rice products including oil, rice milk and vinegar contained 0.01 to 0.03ppm of As which was lower than solid rice products. Reduction in arsenic was probably due to dilution of rice As with water during processing. Rice milk is used as beverage in contrast to cow milk, thus monotonous intake can lead to elevated dietary As among subjects.

As toxicity in irrigated groundwater used for rice cultivation is more prevalent among South and Southeast Asian countries. Asian rice contains the highest fraction of inorganic As species due to its more toxicity, bioavailability and bio accessibility. Therefore, Asian rice is considered to be a serious health hazard for local population as well as for others who consume imported rice from these regions. Higher levels of As was found in rice grains grown in contaminated soil. Cooked rice contains more As concentration if cooking is done in contaminated water\textsuperscript{20}.

### 5.2 Baby Foods and Arsenic

Rice is the complementary ingredient in many baby foods as well as first food for American babies. In an internal analysis, 200 rice samples for baby foods were examined for their arsenic contents and compared to substitutes as oatmeal. Infants fed with 2 or 3 serving of rice per day could prone to cancer risk twice their acceptable level. It was suggested that babies are no more fed on rice cereal than one serving per week, diversify their child diet and endorse the consumption of other food made from oat and corn grits due to their lower Arsenic content\textsuperscript{21}.

Long grain rice (8 varieties) and baby foods prepared from rice (n=10) were evaluated for inorganic and total arsenic contents by using HPLC-ICP-MS system in Finland market. Mean values for inorganic As levels were varied from 0.09 to 0.28mg/kg and 0.11 to 0.13mg/kg for long grain rice and baby foods, respectively. The total
arsenic concentration was ranged from 0.11 to 0.65 mg/kg and 0.02 to 0.29 mg/kg for long grain rice and baby foods. It was indicated that in each age group the intake is quite close to the lowest detection limit in body i.e. 3 μg/kg body weight/day set by EFSA[22].

In another study among US children, it was found that every 1/4th cup increase in cooked rice consumption enhanced the urinary arsenic concentration by 14 folds. Arsenic toxicity in early life was connected with deprive growth and other harmful consequences including high blood pressure and kidney malfunctioning. According to FDA, there was no authentic evidence that rice cereal is not superior to other grains as the first solid food[23]. Total As concentration present initially in rice has not changed during processing for production of rice foods and ultimately reach the end consumers. There is a need to paid special extraordinary attention to infants and kids due to their weak and under develop immune system towards arsenic toxicity. Children with celiac disease are more prone to As contamination due to more intake of baby formulas and weaning foods[24].

In a research, 103,773 food samples were collected form European countries and analyzed for estimation of As exposure through food intake by the European Food Safety Authority (EFSA). After conducting analysis, EU has established the maximum legal threshold of As in white rice (0.2 mg/kg), parboiled rice (0.25 mg/kg), wafers, cookies or cakes (0.30 mg/kg) and baby foods (0.1 mg/kg), respectively. Furthermore, FDA also proposed the same legal limits of As for infant rice cereals (0.1 mg/kg). Govt. of China has set the maximum value for inorganic arsenic in rice i.e. 0.15 mg/kg[25].

Rice cooking in As contaminated water improves the complexity of soil and crop contamination. In some countries, rice fortification with iron, zinc and folate involves no rinsing and water drainage before cooking to prevent nutrients loss. On the other hand, rice is washed thrice and then cooked with plenty of water and drained as well which significantly increases the human exposure to As due to strong binding between rice proteins and inorganic rice[26]. Rice grown in flood conditions accumulated higher levels of As in grains than other plant species. In a study, it was suggested that bioavailability of iron and zinc in milled rice grains significant effects the heavy metal contents. Many other researchers are trying to improve the bioavailability of minerals and other staple foods to maintain nutritional profile of individuals which could also reduce As accumulation[27,28].

In a Japanese study, effect of polishing, cooking and storing on total As contents in rice were evaluated. Total As was reduced to 65% in white rice polished by 10% bran removal whereas 50% removal of As was observed in brown rice with bran layer. Moreover, As levels in white rice after three washing with deionized water were decreased to 80% and 75% of raw rice without washing. Effects of rinsing on As was quite similar for brown rice. Rice cooked in low volume of water (2:1 water to rice ratio) to dryness did not remove As while stored brown rice for one year
exhibited stable As contents[29]. The level of As was very heterogeneous in rice ranging from 0.01 to 0.8 ppm according to transfer coefficient of As from grain to soil 0.1[30]. Rice and bulgar (parboiled wheat product) samples (5g) were analyzed for arsenic speciation through HPLC–ICP-MS system followed by collection of exposure related information among participants (14-75 years) in Turkey. Both samples were dominated with inorganic arsenic but more concentration was found in rice samples (160mg/kg) than bulgar (30 mg/kg). Persons with more consumption of rice, exposures were higher resulting in carcinogenic risks. Average rice intake by an individual was 9 and 278g/d, in Europe and Asia[31]. rice cooked in abundant water and discarding extra water has shown lower As level than raw rice while cooking with limited water (steaming) do not affect the As concentration. Rice bran and its products contain 10-20 folds of As of whole grain concentration possess more detrimental effects when used as healthy food[32]. It was reported that As intake through rice was as high in some Indian areas because of presence of arsenic in drinking water that indicates the off-flavors developed in rice grains due to significant arsenic content among Indian population. Rice crops cultivated on soil enriched with arsenic and irrigated media was also source of arsenic have accumulated elevated levels of As than normal soil and water. Rice products from various categories were analyzed for average As level and showed that mean values for arsenic were ranged from 0.14 to 0.28 mg/kg for solids foods and 0.12 to 0.47mg/kg for baby foods due to extensive geographic differences among Indian, EU and US rice.

6. Measurement of Arsenic

High Performance Liquid Chromatography was a versatile and rapid monitoring method for measurement of total inorganic and organic arsenic in rice flour samples. It was further equipped with Inductively Coupled Plasma Mass Spectrometry. Various forms of arsenic were identified and eluted at same retention time and completely separated by a isocratic elution program set on reverse phase column. This was a latest and reliable analytical procedure for efficient estimation of arsenic from biological tissues of rice based on Hydride Generation Atomic Absorption Spectrometry. Now a day, non-chromatographic methods are also introduced for determination of inorganic arsenic due to ease of working and simplicity[33,34].

7. Strategies for Mitigation of Arsenic

For the purpose, screening of rice cultivars with low As accumulation should be fully implemented with other workable solutions to mitigate the threat. Furthermore, simple recommendations should be revised for rice processing of infant food which significantly reduce As exposure[35]. Rice grown in unsaturated soils has lower contents of arsenic compared to flooded conditions in Mediterranean climates. Rice production was increased through efficient water management
system. Successive sprinkle irrigation for 7 years decreased total As concentrations to one sixth its initial value in flooded irrigation (0.55 to 0.09 ppm) whereas one cycle of sprinkle irrigation reduced 0.20 ppm of As. Moreover, both irrigation techniques have not affected the crop yields (3000kg/ha). It was suggested that changes in water regimes of rice fields seems to be beneficial against excessive arsenic accumulation as well as had valuable impact on food safety and water resources conservation\textsuperscript{[36,37]}. Best demonstrated technologies for treatment of heavy metals contaminated sites are immobilization, soil washing and phytoremediation. Low cost and sustainable options are required to restore contaminated land in countries with greater population index and scarce funds available to enhance food security. Due to diverse soil chemistry, heavy metals exerted low to severe toxic effects on plants according to their concentration in soil. Arsenic a metalloid as well as a hazardous element in soil. Arsenic toxicity was accessed on the basis of its impact on plant and human health (Vodyanitskii, 2016). Silica and phosphate fertilization in soil is suggested to deceased the uptake of arsenic through soil and irrigation water to rice plants\textsuperscript{[38]}. Arsenic accumulation in rice plants can be reduced by specific genes system that performs functions such as uptake, transport and detoxification. Therefore, genetic modifications are of much importance for crop improvement in terms of breeding resistant varieties and reveal that how these metabolized. By using effective and practical approaches like genetic engineering rice crops with low arsenic content are produced. Additionally, other strategies including methylation and volatilization are employed for minimize the exposure of arsenic in rice cultivars because these processes sequestered the arsenic in plant vacuoles and detoxify the plants parts. Some biological active rice cultivars have minimum amount of arsenic i.e. 20-30 fold less than other due to development of blockage pathways for uptake, translocation and accumulation of this toxic element in the rice grains\textsuperscript{[14,39]}. In a recent Korean symposium existing techniques for lowering heavy metals and their pros and cons in rice cropping system, paddy soils, rice cultivars and irrigation process was evaluated. An integrated approach is established that involves a combination of remedial options and water management system with economically and technologically feasible methods for mitigation of As levels. Filtration through absorbents (iron oxide coated sand material) represented as an emerging and effective way to treat arsenic contaminated aqueous solutions without any drawbacks. Important parameters for absorption were pH, contact time, adsorbent dose and initial As concentration. It is suggested that 5g/L iron oxide coated sand could efficiently remove the 100ug/L arsenic from solution due to availability, low cost and better performance\textsuperscript{[40]}.

8. Conclusion

Rice is a major dietary source as well as a staple food for many populations. Rice produced multiple processed foods including syrups, bars,
breakfast cereals, cookies and crackers as well as vital component of baby cereals i.e. first solid food at infancy. Meanwhile, epidemiological studies reported the strong association between rice consumption and human health ailments due to presence of higher arsenic concentrations. Additionally, higher rice intake may increase the risk of certain chronic diseases such as diabetes, cancers, cardiovascular conditions and skin lesions. Thus, it is important to address the health challenges and impacts originated from arsenic ingested food and drinking water especially in remote areas. In future studies should be more focused to measure the arsenic levels in biological specimens to further understand the health effects of dietary arsenic and protect the masses from rice heavy diets.

Conflict of Interest

The authors of the article have no conflicts of interest to declare.

Reference


