INVESTIGATING THE CURRENT ARSENIC CONTAMINATION SCENARIO IN PADDY AND SEARCH FOR REMEDIATION OF ARSENIC IN RICE BY COOKING PRACTICES: A STUDY FOCUSING ON MURSHIDABAD DISTRICT OF WEST BENGAL, INDIA

MD ZAMAN HATEEF

Roll Number: 002230904014

Exam Roll Number: M4EBT24010B

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL BIOTECHNOLOGY

SCHOOL OF ENVIRONMENTAL STUDIES

FACULTY OF INTERDISCIPLINARY STUDIES, LAW AND MANAGEMENT (F.I.S.L.M)

JADAVPUR UNIVERSITY

JADAVPUR, KOLKATA-700032

INVESTIGATING THE CURRENT ARSENIC CONTAMINATION SCENARIO IN PADDY AND SEARCH FOR REMEDIATION OF ARSENIC IN RICE BY COOKING PRACTICES: A STUDY FOCUSING ON MURSHIDABAD DISTRICT OF WEST BENGAL, INDIA

A thesis

Submitted in Partial Fulfilment of the Requirements for the

Award of the degree of

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL BIOTECHNOLOGY

BY

MD ZAMAN HATEEF

Roll Number: 002230904014

Under The Esteemed Guidance Of

DR. TARIT ROYCHOWDHURY

SCHOOL OF ENVIRONMENTAL STUDIES (SOES)

JADAVPUR UNIVERSITY, 188, RAJA S. C. MALLICK ROAD,

KOLKATA – 700032 (INDIA)

DECLARATION

I, **MdZamanHateef** hereby declare that this term paper titled **“Investigating the current arsenic contamination scenario in paddy and search for remediation of arsenic in rice by cooking practices: a study focusing on Murshidabad district of West Bengal, India”** submitted to the School of Environmental Studies (SOES), Jadavpur University, Kolkata – 700032 is record of original work done by me under the guidance of Dr. Tarit Roychowdhury.

This term paper is written in my own words, with reference to several published scientific papers which have been adequately cited from the original sources. It is also to be declared that this term paper does not contain any fictional or misreported data or result.

The term paper is not submitted to any other University or Institution for the award of any degree, diploma or fellowship or published any time before.

I understand that any violation of the above will be a cause for disciplinary action against me.

MdZamanHateef

Date: 14/11/2024

CERTIFICATE

This is to certify that the thesis report titled " Investigating the current arsenic contamination scenario in paddy and search for remediation of arsenic in rice by cooking practices: a study focusing on Murshidabad district of West Bengal, India", submitted by MdZamanHateef (Registration Number 163795 of 2022-2023; Class Roll No. 002230904014 and Exam Roll no: M4EBT24010B), to Jadavpur University, Kolkata for the award of the degree of Master of Technology in Environmental Biotechnology in Environmental Biotechnology is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the constituents of this report, in full or in parts, have not been submitted to any Institute or University for the award of any degree or diploma.

Dr. Tarit Roychowdhury

Thesis supervisor

School of Environmental Studies,

Jadavpur University

TO WHOM IT MAY CONCERN

It is hereby notified that this thesis titled " Investigating the current arsenic contamination scenario in paddy and search for remediation of arsenic in rice by cooking practices: a study focusing on Murshidabad district of West Bengal, India", is prepared and submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology course of Jadavpur University by MdZamanHateef (Registration Number 163795 of 2022-2023; Class Roll No. 002230904014 and Exam Roll no: M4EBT24010B), a student of the said course for session 2022-2024. It also declared that no part of this thesis has been presented or published elsewhere.

Dr. Tarit Roychowdhury
Tarit Roychowdhury Ph.D.
Associate Professor
School of Environmental Studies
Jadavpur University
Kolkata - 700 032 INDIA

Dr. Tarit Roychowdhury
Thesis Supervisor School of Environmental Studies,
Jadavpur University

Director
School of Environmental Studies
JADAVPUR UNIVERSITY
Kolkata - 700 032

Prof.Joydeep Mukherjee,
Director, School of Environmental Studies,
Jadavpur University

Dean
Faculty of I.S.L.M., Jadavpur University
Kolkata - 700 032

Dean, Faculty of Interdisciplinary Studies, Law & Management,
Jadavpur University

CERTIFICATE OF APPROVAL

This certifies that MdZamanHateef thesis, " Investigating the current arsenic contamination scenario in paddy and search for remediation of arsenic in rice by cooking practices: a study focusing on Murshidabad district of West Bengal, India**"** is an authentic documentation of his work completed between September 2022 and November 2024, partially fulfilling the requirementsfor the Master of Engineering in Environmental. Biotechnology degree from the Department of Environmental Studies (Registration Number 163795 of 2022-2023; Class Roll No. 002230904014 and Exam Roll no: M4EBT24010B).It is acknowledged that the undersigned only approves the thesis for the purpose for which it has been presented and that by granting this approval, they do not necessarily support or approve any statements made, opinions stated, or conclusions drawn within.

……………………………………

Final examination for evaluation of thesis

………………………………..

Signature of Examiner

ACKNOWLEDGEMENT

With my most sincere gratitude, I would like to acknowledge the support of my supervisor **Dr. Tarit Roychowdhury** for his valuable assistance and constant guidance throughout preparation of this term paper.

The knowledge imparted by professors **Dr. Joydeep Mukherjee**, **Dr. Reshmi Das**, **Dr. Subarna Bhattacharyya** was quite helpful for me during selection of the topic for my term paper.

Finally, I would like to thank **Jadavpur University** for providing me this opportunity to pursue the course of Environmental Biotechnology at their esteemed organisation.

MdZamanHateef

Date: 14/11/2024

Place:Jadavpur,Kolkata-700032

ABSTRACT

Arsenic contamination is not only affecting drinking water but also staple food such as rice. It has become a global issue as a dietary risk among humans. Naturally occurring arsenic in paddy soils gets magnified several folds by irrigating with arsenic contaminated groundwater, which further intensifies the problem. Numerous research is ongoing to reduce the arsenic in drinking water. After a review of various works of literatures, it was found that very little research has been conducted to remediate the As in household level through cooking of rice. To initiate the work as a background knowledge this study will conduct the paddy cultivation and post-harvesting practices in Murshidabad district of West Bengal. The objectives of this study will be to monitor the current arsenic exposure scenario in soil-paddy system, to explore the possibility of reducing Arsenic toxicity in the cooked rice by various pre-cooking and cooking methods.

KEYWORDS – Arsenic, paddy, phase-wise cultivation, translocation, cooked rice, rice fermentation

TABLE OF CONTENTS

Index

LIST OF FIGURES

1. INTRODUCTION

Arsenic (As) is an extremely toxic metalloid scattered through the environment. Groundwater As contamination has recently grabbed popular attention and its deadly exposure is a global concern now. The areas of Indo-Gangetic and Ganga–Meghna–Brahmaputra plains are the worst suffering parts of the world considering this contamination scenario (Chakraborty et al., 2013).

Being a carcinogenic heavy metal, As could be found in minerals of earth's crust in different concentration in different geographical regions. The release of as from the surface of the Earth into groundwater happens mostly via natural geological and hydrological processes and causes groundwater as contamination (Koley et al., 2021; Kumar et al., 2021).

The heavy metal enters the human body mainly through contaminated drinking water, which is a major threat for the human population. On the other hand, when the same polluted groundwater is used for cultivation purposes the problem increases and leads to as bioaccumulation and toxicity through the cultivated crops (Roychowdhury et al., 2003; Ruiz-Huerta et al., 2017).

Contaminated groundwater in many regions of India, especially in West Bengal, used for cultivation specially that of rice in dry seasons (Islam et al., 2017; Roychowdhury, 2008).

It has been reported earlier that the exposure to As through drinking water and consumption of contaminated food stuffs for a longer period can adversely affects the human health and may cause several diseases including cancers, Melanosis, skin lesions, Hyperkeratosis, lung disease, and Peripheral vascular disease (Podgorski et al., 2017; Upadhyay et al., 2019).

In view of as contamination, rice is one of the most severely affected crops in comparison with other staple crops like wheat and maize. The reason behind that is the flooded cultivation practice of rice. Thus, it puts the staple rice consuming population in grave danger due to high consumption rate in as contaminated areas (Awasthi et al., 2017).

Rice is a dominant source of inorganic as through dietary intake for people who consume rice as staple food. Global agricultural ecosystem is getting contaminated day by day with growing anthropogenic pollution of As and in turn increasing human health risks. (Li et al. 2011; Meharg et al. 2013; Meharg et al. 2009).

It has been well established that from the first stage of rice cultivation to the final harvesting stage the prevalence of as toxicity results in reducing root-shoot length in paddy plants (Majumdar & Bose, 2017).

Asian countries have been reported for 90% of global rice production, using irrigational groundwater as the main source (Islam et al., 2016; Yu et al., 2020).

It can be easily said that, identification of food chain as dominanceespecially in paddy and rice is an essential part of determining present and future human health risks. (Rehman et al., 2021; Santra et al., 2013).

Health hazard through rice as contamination is not a regional problem any longer. Since rice is traded all over the world, thus, leads to consumption of As through daily diet for the people living far from different rice production regions (Meharg et al., 2009).

Persistent exposure to as causes many forms of cancer, skin cancer being the most dominant amongst them. Other forms include lung, liver, bladder, and kidney cancer. It has also been linked with variety of other adverse health conditions like cardiovascular, hematological, renal, endocrine, and hepatic diseases. Continuing dietary exposure through water, rice and other food stuffs in turn leads to bioaccumulation of as within the human body. Hence, the rice As contamination is especially concerning for almost half of the world's population who consumes rice as a staple (Rahaman at al., 20011; Islam et al., 2017; Mondal et al., 2019; Farrell et al., 2021).

That is why it became necessary to understand the accumulation scenario of as in paddy from different regions and its severe exposure in view of rice grain as staple crop.

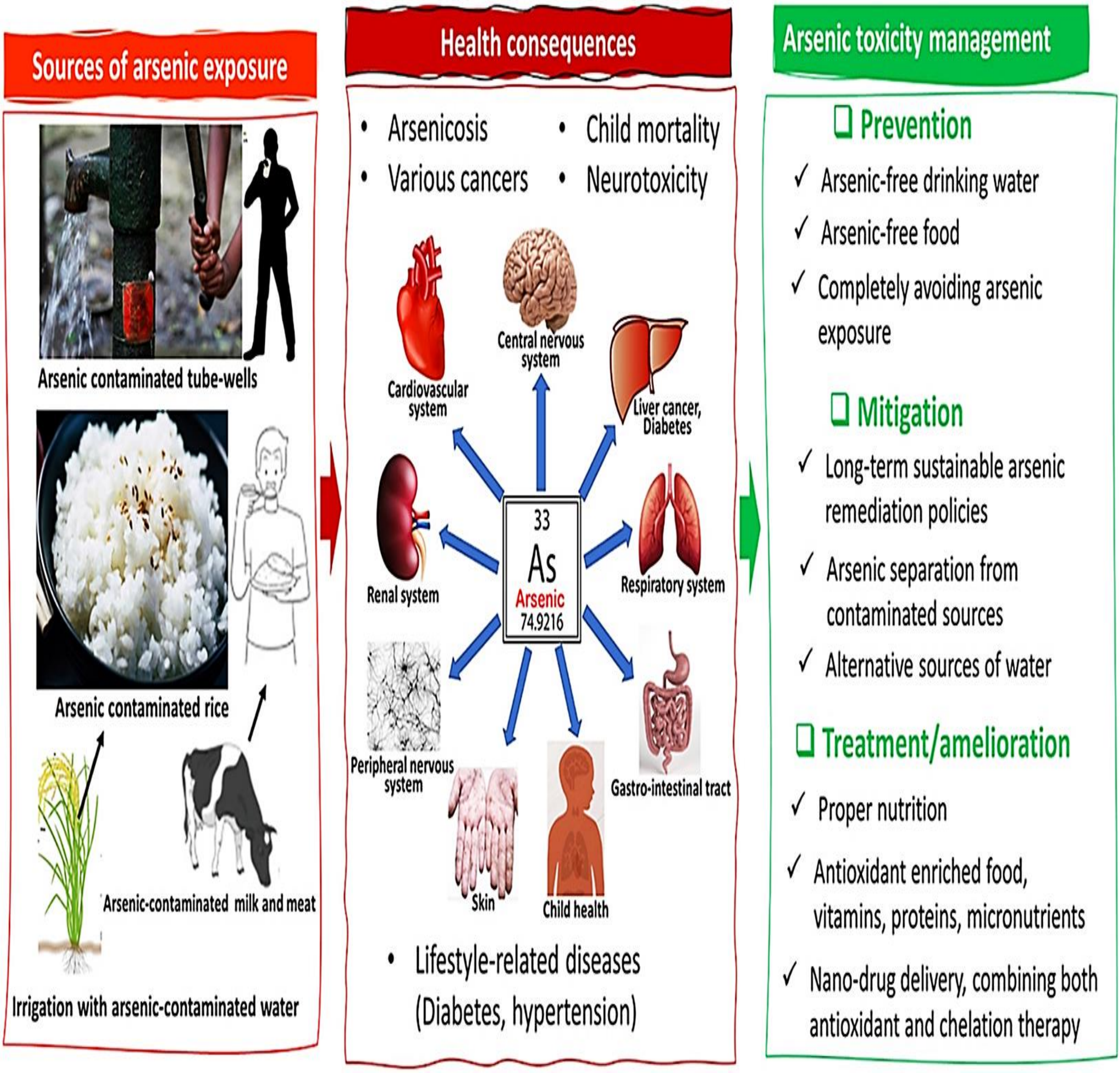


Fig 1. Sources of arsenic exposure, health consequences and arsenic toxicity management (Rahaman et al., 2021)

1.1 Arsenic ingroundwater

Arsenic groundwater pollution is a serious environmental and public health problem. Natural geological formations that contain arsenic in rocks and sediments are frequently the source of arsenic in groundwater. Arsenic pollution can also result from human activities such as mining and industrial operations. Consuming water tainted with arsenic can result in major health issues such as diabetes, cardiovascular disorders, skin lesions, and several types of cancer. Bangladesh, India, China, and the United States are just a few of the nations that are impacted by arsenic poisoning, which is a worldwide problem. The usage of deep tube wells for water delivery has a particularly negative impact on the Ganges Delta in Bangladesh and India. Rainwater collection systems, community water purifiers, and different filtration methods are ways to eliminate arsenic from groundwater. But getting rid of arsenic entirely can be difficult. To stop more contamination, sustainable water management techniques and the use of less contaminated water sources for consumption and irrigation are essential(Jomova et al., 2011).

1.2 Arsenic in paddy

Arsenic is harmful to human health, poisoning of paddy fields is a serious concern. Groundwater used for irrigation is the main source of arsenic in rice fields. As rocks weather bio-geochemically, arsenic is released into groundwater. Arsenic tends to build up in rice grains in paddy fields, particularly those that are flooded. This is brought on by alterations in soil chemistry and the development of iron plaques on the surfaces of paddy roots. Arsenic's mobility and toxicity are influenced by microorganisms in paddy soil, which are essential to its transformation. They have the ability to methylate arsenic, increasing its mobility and possibly increasing its toxicity. To lessen arsenic levels in rice, sustainable agricultural methods are crucial. These include creating rice varieties with lower arsenic uptake and utilizing less contaminated water for irrigation. (Rahman et al., 2007).

1.3 Cooked rice arsenic contamination

Because of its growing environment, particularly in flooded fields, rice has a tendency to acquire more arsenic than other crops. The main issue is the more hazardous inorganic form of arsenic. Using a high water-to-rice ratio and properly washing rice before cooking will help lower arsenic levels. It also works well to cook rice in clean, low-arsenic water.Research indicates that cooking rice can lower its arsenic content by roughly 60–80%. But some arsenic still exists, so it's crucial to employ these techniques regularly.Over time, eating rice tainted with arsenic might increase your risk of developing skin lesions, cardiovascular conditions, and several types of cancer. (Mondal et al. (2010)

2. ARSENIC CONTAMINATION OF GROUND WATER

2.1 literature review

Drinking water contaminated with arsenic is a major public health issue.Natural geological formations that contain arsenic in rocks and sediments are the main source of arsenic in drinking water. Arsenic levels in groundwater can also be caused by human activities such as mining, industrial operations, and the use of tainted water for irrigation. Prolonged exposure to drinking water tainted with arsenic can cause major health problems, such as diabetes, heart disease, skin lesions, and many types of cancer. The biggest danger is from inorganic arsenic, which is more toxic.Bangladesh, India, China, the United States, and portions of South America are among the numerous nations impacted by arsenic poisoning. In Bangladesh and India.Remediation Techniques: Rainwater collection systems, community water purifiers, and different filtration methods are ways to eliminate arsenic from drinking water. But getting rid of arsenic entirely can be difficult(Andrew et al 2006).

Tube well water contamination by arsenic is a serious problem, particularly in areas like Bangladesh and the Indo-Gangetic plain. Although tube wells are a common drinking water source in many places, they frequently draw from groundwater that has a high arsenic content. This is especially true in areas with soft soils where groundwater naturally contains arsenic. Consuming water from tube wells tainted with arsenic can result in major health issues such as diabetes, cardiovascular disorders, skin lesions, and several types of cancer. Exposure over an extended period is very dangerous.Testing tube wells for arsenic levels is crucial to lowering exposure to arsenic. While wells with high levels of arsenic should be utilized for other purposes, such as washing, safe wells should be used for drinking water. Arsenic can also be eliminated from water with the use of filtration devices and community water purifiers (Nadakavukaren et al., 1984; Hindmarsh& McCurdy, 1986).

3. ARSENIC IN PADDY CULTIVATION

3.1 Literature review

Arsenic contamination is a global concern and it has affected almost every country like western USA, Mexico, Chile, Argentina, Hungary, Romania, Mongolia, Nepal, China, Bangladesh, Taiwan, Vietnam, Thailand, and India. According to the latest report by the Central Ground Water Board (CGWB), 21 states across the country have As levels higher than the specified permissible limit of 10 µg/l (BIS, 2012). The most affected regions are around the Ganga-Meghna-Brahmaputra (GMB) plains along with states like Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Assam. The contamination is not only limited to drinking water but it also has entered our food chains. The usage of groundwater for irrigation along these regions has intensified the situation as the crops will uptake As and make it bioavailable.Different crucial mechanisms influence the mobility, bioavailability, and toxicity of arsenic in paddy cultivation.

Oxidation and Reduction: Arsenic can exist in a variety of oxidation states, although its most common forms are arsenite (As(III)) and arsenate (As(V)). Arsenite, which is more mobile and poisonous, is frequently produced when arsenate is flooded.

Iron Plaque Formation: By adsorbing arsenic and altering its uptake, iron plaques that develop on the roots of rice plants impact the dynamics of arsenic.

Microbial Activity: The methylation, reduction, and volatilization of arsenic are all significantly influenced by microorganisms in the soil. Arsenic may become more mobile and possibly more dangerous as a result of these activities.Inorganic arsenic is methylated by microorganisms to produce organic forms, such as dimethylarsinic acid (DMA) and monomethylarsonic acid (MMA), which can be more mobile and toxic.

Translocation from Root to Shoot: Arsenic is absorbed by paddy roots and moved to the grains and shoots, causing buildup in rice grains.

The pH, redox potential, and organic matter content of the soil are some of the variables that affect these changes. Developing ways to reduce arsenic contamination in rice requires an understanding of these mechanisms (Majumdar et al., 2019).

The buildup of arsenic in paddy grains poses a serious risk to human health and food safety. Contaminated irrigation groundwater is the main source of arsenic in paddy grains. Arsenic is released into groundwater by the biogeochemical weathering of rocks, and rice plants subsequently absorb it. Rice roots absorb arsenic, which is then transferred to the shoots and grains. Arsenic dynamics in the soil-water-rice system are influenced by variables such as redox potential, soil pH, and iron plaque formation on roots. Eating rice tainted with arsenic can cause a number of illnesses, such as cancer, diabetes, heart disease, and skin blemishes.

Mitigation Strategies: To lessen arsenic levels in rice, it is crucial to create rice types with lower absorption of the metal, use less contaminated irrigation water, and use sustainable farming methods. Arsenic's mobility and toxicity are influenced by microorganisms in paddy soil, which are essential to its transformation. They have the ability to methylate arsenic, increasing its mobility and possibly toxicity (Majumdar et al., 2019)

4. ARSENIC IN COOKED RICE

4.1 Literature review

Arsenic contamination is a global concern and it has affected almost every country like western USA, Mexico, Chile, Argentina, Hungary, Romania, Mongolia, Nepal, China, Bangladesh, Taiwan, Vietnam, Thailand, and India. According to the latest report by the Central Ground Water Board (CGWB), 21 states across the country have As levels higher than the specified permissible limit of 10 µg/l (BIS, 2012). The most affected regions are around the Ganga-Meghna-Brahmaputra (GMB) plains along with states like Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Assam. The contamination is not only limited to drinking water but it also has entered our food chains. The usage of groundwater for irrigation along these regions has intensified the situation as the crops will uptake As and make it bioavailable.(Jomova et al., 2011).

Ingestion, inhalation, and skin absorption are some of the critical routes for arsenic entering human body. Both pentavalent and trivalent arsenic compounds are extensively and rapidly absorbed from the gastrointestinal tract. Several health problems are related to arsenic exposure, ranging from the development of cancer, inducing epigenetic changes, to skin diseases (Ozturk et al., 2022).

Rice is the most common food item found to be heavily contaminated with As. Being the second most rice consuming country among the South and Southeast Asian countries, India is highly vulnerable to arsenic exposure through rice (Baldwin et al., 2012). In the eastern part of India, specifically in rural West Bengal rice constitutes 51% of daily diet, which can step up to 70% during shortage of non-vegetarian food items (signes and pastor et al., 2008). Rice grown in arsenic contaminated areas, near industrial areas, cotton fields, etc., accumulates more amount of inorganic as from soil than other crop (seyfferth et al., 2014; williams et al., 2007). In general, the phosphate transporter mechanism is responsible for as uptake in plants, but the multiple transport mechanisms are also active in rice which results in excessive accumulation of inorganic as in this crop (sarkar et al., 2022).

Indian subcontinent is known for erratic and irregular rainfall which compels the farmers to go for irrigation using groundwater and results in higher inorganic as accumulation in topsoil as well as in growing plants and their produce (brammer and ravenscroft, 2009).

There are studies which emphasize that the brown rice retains more amount of As (70-80% higher) than the polished white rice due to presence of high amount of arsenic in germ layer in the former (Sun et al., 2008). Williams et al. (2005) reported inorganic As concentration in different varieties of rice such as basmati (0.02-1 mg/kg), brown basmati (0.04 mg/kg), long red rice (0.05 mg/kg), but higher concentrations in Thai (0.11-0.51 mg/kg) and Jasmine (0.11 mg/kg) rice. Further, unlike many other foods, inorganic arsenic constitutes about 27-93% of total arsenic in rice that increases its food safety risk.Hassan et al. (2017) emphasized that the consumption of rice with 0.08 mg/kg of arsenic on regular basis have similar impact like intake of drinking water with 10 ppb of inorganic As.

West bengal is one of the major rice producing states in india with 5,900,000 ha used for cultivation of rice alone (signes et al., 2008). However, prolonged use of as contaminated groundwater for cultivation purpose has led to high deposition of as in irrigated soil (meharg and rahman, 2003; roychowdhury et al., 2005). Groundwater with as concentrations in the range of 600–3700 μg/l and 19–68 μg/l, respectively have been reported from nine highly and five moderately as affected districts of west bengal (chakraborti et al., 2009), where rice cultivation is a regular process. During dry season groundwater is used for cultivation and flooding the soils to give rise to anaerobic condition in paddy cultivation.

In india, rice is the staple food crop for eastern and southern people and a large population lives on a subsistence diet of rice and its derivatives (rahman et al., 2008). The rate of evaporation of water during cooking process had an increased effect on as accumulation in the boiled rice.

Considering higher accumulation of as in raw rice grain, dietary intake of as and related health hazards come through consumption of cooked rice. In terms of chronic as toxicity, the consumption of cooked rice plays a significant health threat. Several factors like raw rice grain as, cooking water as, cooking practice of the inhabitants, rice cultivars, role of micronutrients or other heavy metals and as species distribution, if any, might influence as accumulation in cooked rice (chowdhury et al., 2020).

Halder et al., 2014 reported that water low in as (< 10 μg/l) used for cooking rice grain, significantly decreased the total and inorganic as content in cooked rice compared to raw rice. So, content of as in cooking water might play some important role behind as accumulation in cooked rice.Sengupta et al (2006) revealed that the traditional method of cooking (at rice water ratio of 1:6) with less As-contaminated water and discarding gruel removes approximately 57% of As in the cooked rice while cooking rice with As contaminated water of 50 μg/L enhances up to 35%–40% of As in cooked rice. According to Mridha et al (2021), cooking rice with As-safe water significantly releases As into the gruels. Similar trend have been established by Chowdhury et al (2020) which supports this finding.Gray et al (2016) demonstrated a decreasing trend of grain inorganic As accumulation while cooking As contaminated brown long grain, white medium grain, and parboiled rice with deionized water at a ratio of 2:1, 6:1 and 10:1 (water: grain) with increasing the volume of water. Cooking with a low amount of water does not eliminate As content, however, increasing water volume reduces up to 45% of iAs. A similar trend has been reported with As water by Jitaru et al (2016).Liu K L et al (2018) and Liao et al (2019) revealed an insignificant change in As concentration in cooked rice cooking in pressure cooker and stainless steel pot with deionized water.

A number of variables, such as the type of rice and cooking techniques employed, can affect the amount of arsenic present in various cooked rice fractions. Higher amounts of inorganic arsenic (As(III) and As(V)), the most hazardous type of arsenic, are present in raw rice. Although cooking can lower its levels, some are still present. Monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) are examples of organic forms of arsenic that are also found. Although less harmful, these versions can nonetheless be harmful to one's health. Arsenic levels can be considerably decreased by utilizing a high water-to-rice ratio and properly rinsing rice before cooking. Arsenic concentration can be lowered by up to 83% by boiling rice in extra water and then discarding the water.Because the outer layers of polished rice are removed, brown rice often has greater amounts of arsenic than polished rice.

5. **REMIDIATION APPROCHES**

5.1 Cooking methods

Rice's arsenic content can be decreased by using various cooking techniques. Use a lot of water to rinse the rice well. Before cooking, this can aid in removing some of the surface arsenic. Parboiling is the process of partially boiling rice while it is still in its husk, followed by grinding and drying. Arsenic levels may be lowered by this procedure. Cook rice in a lot of water (six to ten parts water to one part rice), and then after cooking, drain the extra water. Arsenic levels can be lowered by up to 57% with this technique. Cook the rice in new water after soaking it in water for an hour and discarding the soaking water.Although the additional water approach is more efficient, some research indicate that pressure cooking rice can lower arsenic levels.The role of rice cultivar that is being cooked is also an important factor. Several other factors like washing of rice grain, rice grain-water ratio might influence cooked rice as accumulation. The interaction of as between rice grain and water during cooking process have been investigated (rokonuzzaman et al., 2022).

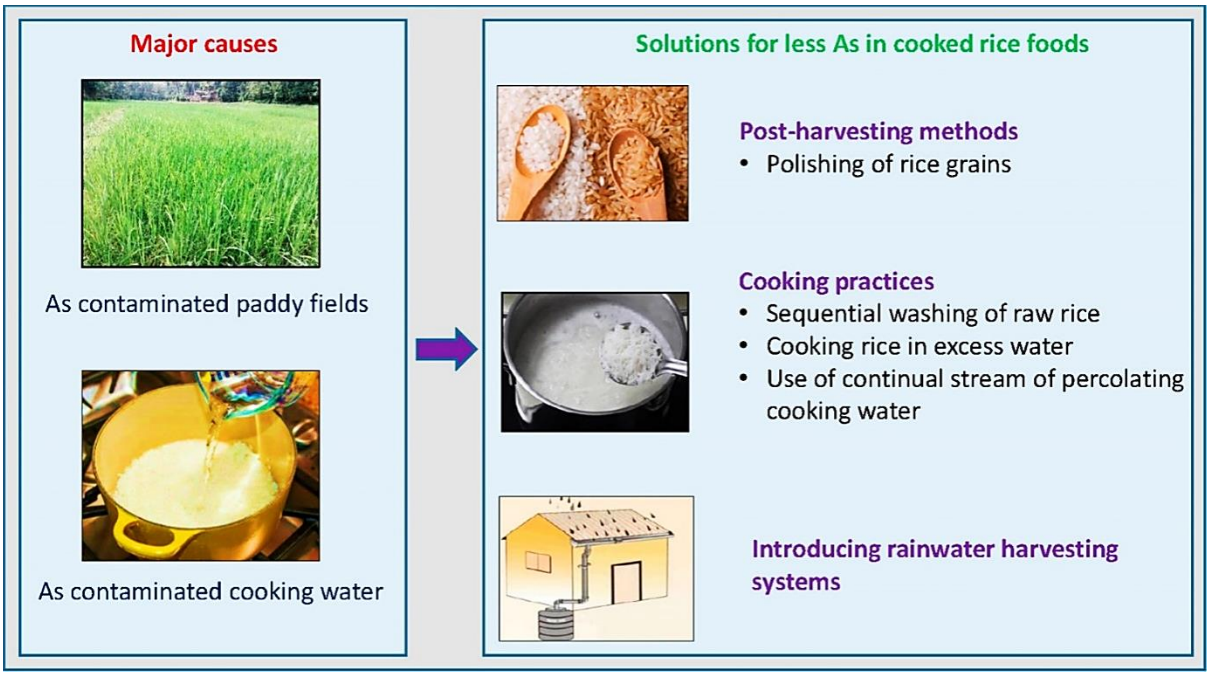


Fig 2. Major causes and remediation of arsenic toxicity through cooking practices (Kumarathilaka et al., 2019)

In India, rice is the staple food crop for eastern and southern people and a large population lives on a subsistence diet of rice and its derivatives (rahman et al., 2008). The rate of evaporation of water during cooking process had an increased effect on as accumulation in the boiled rice.Considering higher accumulation of as in raw rice grain, dietary intake of as and relatedhealth hazards come through consumption of cooked rice. In terms of chronic as toxicity, theconsumption of cooked rice plays a significant health threat. Several factors like raw ricegrain as, cooking water as, cooking practice of the inhabitants, rice cultivars, role ofmicronutrients or other heavy metals and as species distribution, if any, might influence asaccumulation in cooked rice (chowdhury et al., 2020).Halder et al., 2014 reported that water low in as (10 μg/l) used for cooking rice grain,significantly decreased the total and inorganic as content in cooked rice compared to raw rice.So, content of as in cooking water might play some important role behind as accumulation incooked rice.

So, it is of great importance right now to investigate the food chain arsenic contamination properly specially through staple rice grain in daily diet. Highly exposed blocks of West Bengal is a matter of concern regarding paddy cultivation and post-harvesting procedures.

This proposed study will investigate the arsenic contamination in paddy from cultivation to cooking,focusing on Murshidabad district, one of the worst arsenic exposed part of West Bengal to create awareness among the stakeholders. This study will also try to establish some arsenic remediation methods through cooking practices which will help to combat the effects of this heavy metal in daily life for the community.

5.2 Aims and objectives

The objectives of this study are as follows:

1. Investigating the phase wise cultivation of paddy in Baligram Village, Lalgola block of Murshidabad district of West Bengal to identify the trend of arsenic contamination.
2. Comparison between cultivated rice grains in exposed and unexposed sites with respect to the collected rice grains of non-cultivation sites of West Bengal.
3. Experiment on arsenic remediation methods in terms of pre-cooking and cooking practices

6. METHODOLOGY

6.1 Study area

Baligram Village, Lalgola block, Murshidabad district of West Bengal.

6.2Sample collection and preparation arsenic in food chain through paddy:

Rice is the most common food item found to be heavily contaminated with As. Being the second most rice-consuming country among the South and Southeast Asian countries, India is highly vulnerable to arsenic exposure through rice (Baldwin et al., 2012). In the eastern part of India, specifically in rural West Bengal rice constitutes 51% of daily diet, which can step up to 70% during a shortage of non-vegetarian food items (signes and pastor et al., 2008). Rice grown in arsenic-contaminated areas, near industrial areas, cotton fields, etc., accumulates more amount of inorganic as from soil than other crops (seyfferth et al., 2014; williams et al., 2007). In general, the phosphate transporter mechanism is responsible for uptake in plants, but the multiple transport mechanisms are also active in rice which results in excessive accumulation of inorganic as in this crop (sarkar et al., 2022).

Indian subcontinent is known for erratic and irregular rainfall which compels the farmers to go for irrigation using groundwater and results in higher inorganic as accumulation in topsoil as well as in growing plants and their produce (brammer and ravenscroft, 2009).

There are studies which emphasize that the brown rice retains more amount of As (70-80% higher) than the polished white rice due to presence of high amount of arsenic in germ layer in the former (Sun et al., 2008). Williams et al. (2005) reported inorganic As concentration in different varieties of rice such as basmati (0.02-1 mg/kg), brown basmati (0.04 mg/kg), long red rice (0.05 mg/kg), but higher concentrations in Thai (0.11-0.51 mg/kg) and Jasmine (0.11 mg/kg) rice. Further, unlike many other foods, inorganic arsenic constitutes about 27-93% of total arsenic in rice that increases its food safety risk.Hassan et al. (2017) emphasized that the consumption of rice with 0.08 mg/kg of arsenic on regular basis have similar impact like intake of drinking water with 10 ppb of inorganic As.

West Bengal is one of the major rice producing states in India with 5,900,000 ha used for cultivation of rice alone (Signes et al., 2008). However, prolonged use of as contaminated groundwater for cultivation purpose has led to high deposition of as in irrigated soil (Mehargand Rahman, 2003; Roychowdhury et al., 2005). Groundwater with as concentrations in the range of 600–3700 μg/l and 19–68 μg/l, respectively have been reported from nine highly and five moderately as affected districts of West Bengal (Chakraborti et al., 2009), where rice cultivation is a regular process. During dry season groundwater is used for cultivation and flooding the soils to give rise to anaerobic condition in paddy cultivation.

6.3 Post harvesting of paddy:

The cereal rice is marketed either as raw (non-parboiled rice) which is directly prepared by dehusking the whole grain of paddy or parboiled rice which undergoes a light boiling of the whole grain followed by mechanical dehusking to obtain the boiled rice grain. Preparation of parboiled rice using As contaminated water during post harvesting is a common practice in parts of Bengal delta, including West Bengal, India and Bangladesh (Chowdhury et al., 2018b). A comparative analysis of drinking water, raw rice and cooked rice by Mondal et al. (2010) during their on-site studies in West Bengal showed that the concentration of as in parboiled rice was higher than that in raw rice. A study on distribution of as in different fractions of parboiled and non-parboiled rice grains in Bangladesh revealed the order of as concentrations as rice hull > bran-polish > brown rice > raw rice > polished rice (Rahman et al., 2007).

It has been observed that, parboiled rice of different strains showed much higher as concentrations than that of raw rice strains. Analyses of as concentrations of paddy whole grains at various stages of parboiling have also showed an overall increase in finally parboiled grain from that of initial raw grain signifying accumulation of as from water during parboiling (Chowdhury et al., 2018b).

6.4 Quality control and quality assurance

A quality control study was done by digesting 30% of the solid samples through the hot plate digestion method. The protocol of hot plate digestion was the same as that of Teflon-Bomb digestion except that the samples were collected in a glass beaker and placed on a hot plate at 90 °C without the involvement of pressure during digestion. Arsenic concentrations obtained through this process were compared to those obtained by Teflon bomb digestion for the same samples. To validate and assure the quality of the results obtained, As concentration of a standard reference material [Rice Flour 1568a (National Bureau of Standards. Gaithersburg, MD, USA)] was analysed via both digestion protocols.

The SRM sample (Rice flour: 1568a, Certified value of As: 0.29 μg/g) showed a recovery of 92–94% and 80–82% of total As concentration when digested by Teflon bomb and the hot plate methods, respectively. Quality control tests were also performed by analyzing duplicates and calculating the recovery of spiked digested samples.

6.5 Analysis

Arsenic was analyzed by an atomic absorption spectrophotometer (Varian AA140, USA) coupled with Vapor Generation Accessory (VGA 77, Agilent technologies, Malaysia) using software version 5.1 in the hydride generation-atomic absorption (Das et al., 2024)

7. RESULT AND DISCUSSION

7.1 Arsenic in groundwater

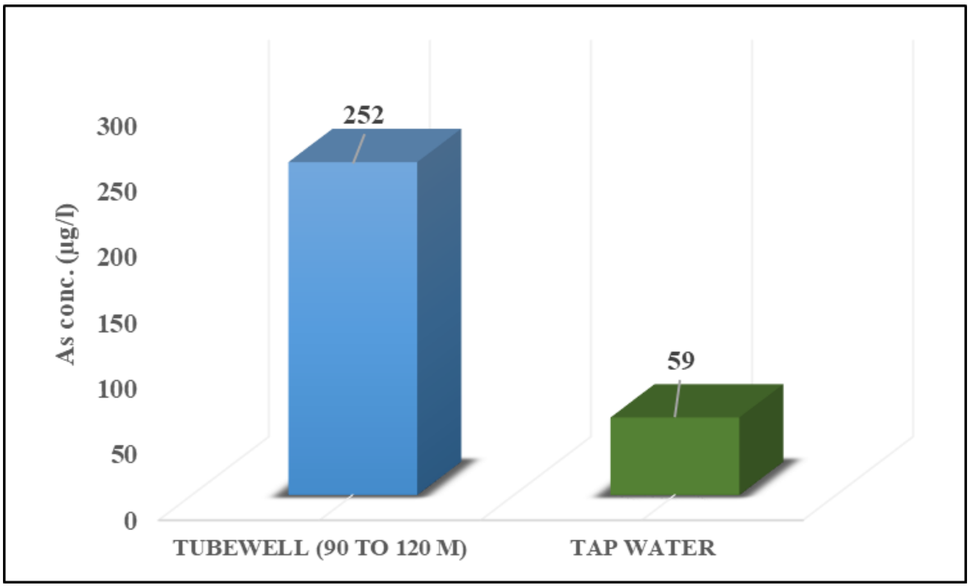
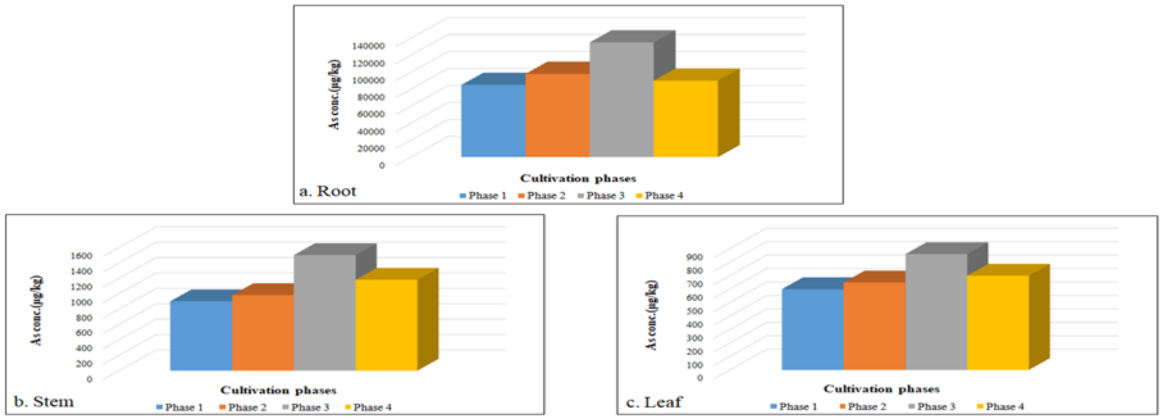


Fig. 3 Water arsenic concentration in tube well and tap water, Baligram village, Lalgola, Mursidabad

7.2 Phrase wise cultivation of paddy and arsenic translocation



As conc.(µg/kg) in various parts of the paddy plant (a. Root, b. Stem and c. Leaf) during 4 different monsoonal cultivation phases in Bhagwangola, Murshidabad

Fig. 4 Arsenic in various parts of paddy plant

7.3 Arsenic in cooked rice

RG: Rice grain

CRG: Cooked rice grain

TDW: Total discarded water

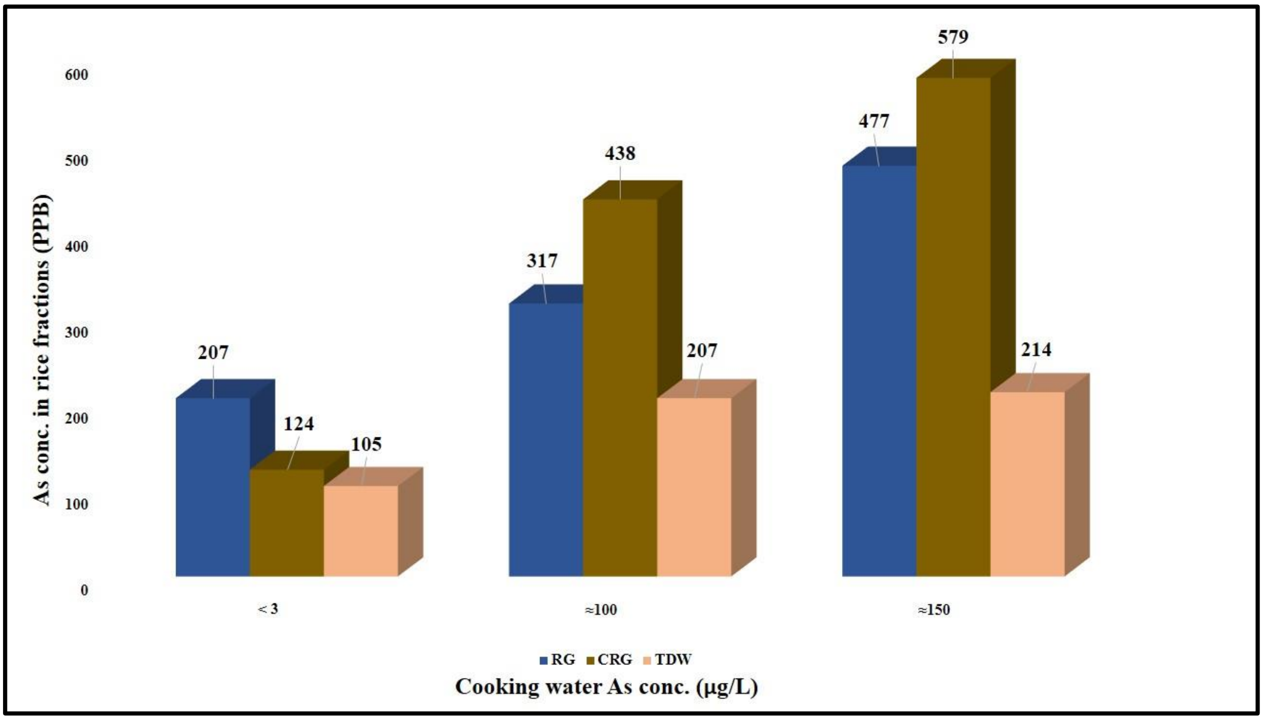


Fig. 5 **Arsenic in different fractions of cooked rice**

7.4Remediation approaches by rice fermentation

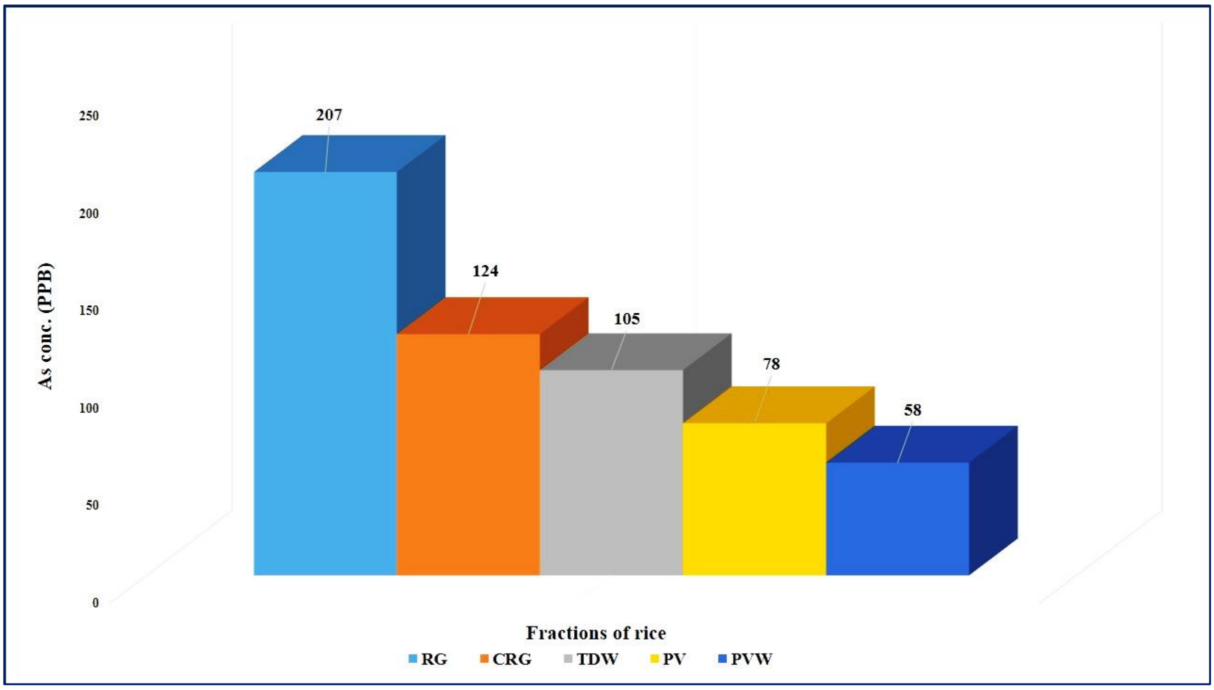


Fig 6.Arsenic in different fractions of rice and fermented rice (Pantavaat)

RG: Rice grain

CRG: Cooked rice grain

TDW: Total discarded water

PV: Pantavaat (Fermented rice)

PVW: Pantavaat water (Fermented rice water)

Based on collected samples from families (n=15)

	RG	CRG	TDW	PV	PVW
Mean As conc. (µg/kg)	207	124	105	78	58
SD	52	72	30	32	25
Range	141-285	52-267	55-150	31-139	30-112

8. Conclusion

Naturally occurring arsenic in paddy soils gets magnified several folds by irrigating with arsenic contaminated groundwater, which further intensifies the problem. Numerous researches is ongoing to reduce the arsenic in drinking water. Cooking has a high impact on the arsenic load of cooked rice grain. So remediation of arsenic could be done by proper cooking methods and some pre and post-cooking modification or practices like fermentation of rice commonly known as making pantavaat. For conclusion, this study showed the current scenario of arsenic accumulation in paddy plant parts and cooking and fermented methods to remediate arsenic. Promoting best method and monitoring could result in arsenic remediation.

REFERENCE

[1] Baldwin, K., Childs, N., Dyck, J., & Hansen, "Southeast Asia's rice surplus" *Outlook No.(RCS-121-01). USDA ERS*, 2012.

BIS. (2012). Indian Standard Specifications for Drinking Water. IS: 10500. Bureau of Indian Standards, New Delhi, India.

Brammer, H., & Ravenscroft, P. (2009). Arsenic in groundwater: a threat to sustainable agriculture in South and South-east Asia. *Environment international*, *35*(3), 647-654.

CGWB (Central Ground Water Board). (2019). *National Compilation on Dynamic Ground Water Resources of India, 2017*. Department of Water Resources, RD & GR, Ministry of Jal Shakti, Govt. of India.

Chakraborti, D., Das, B., Rahman, M.M., Chowdhury, U.K., Biswas, B., Goswami, A.B., Nayak, B., Pal, A., Sengupta, M.K., Ahamed, S. and Hossain, A. (2009). Status of groundwater arsenic contamination in the state of West Bengal, India: A 20-year study report. *Molecular nutrition & food research*, *53*(5), 542-551.

Chowdhury, N. R., Ghosh, S., Joardar, M., Kar, D., & Roychowdhury, T. (2018b). Impact of arsenic contaminated groundwater used during domestic scale post harvesting of paddy crop in West Bengal: arsenic partitioning in raw and parboiled whole grain. *Chemosphere*, *211*, 173-184.

Chowdhury, N.R., Das, A., Joardar, M., De, A., Mridha, D., Das, R., Rahman, M.M. and Roychowdhury, T. (2020). Flow of arsenic between rice grain and water: Its interaction, accumulation and distribution in different fractions of cooked rice. *Science of the Total Environment*, *731*, 138937.

Gray, P. J., Conklin, S. D., Todorov, T. I., &Kasko, S. M. (2016). Cooking rice in excess water reduces both arsenic and enriched vitamins in the cooked grain. *Food Additives & Contaminants: Part A*, *33*(1), 78-85.

Halder, D., Biswas, A., Šlejkovec, Z., Chatterjee, D., Nriagu, J., Jacks, G., & Bhattacharya, P. (2014). Arsenic species in raw and cooked rice: implications for human health in rural Bengal. *Science of the total environment*, *497*, 200-208.

Hassan, F. I., Niaz, K., Khan, F., Maqbool, F., &Abdollahi, M. (2017). The relation between rice consumption, arsenic contamination, and prevalence of diabetes in South Asia. *EXCLI journal*, *16*, 1132.

Jitaru, P., Millour, S., Roman, M., El Koulali, K., Noël, L., &Guérin, T. (2016). Exposure assessment of arsenic speciation in different rice types depending on the cooking mode. *Journal of Food Composition and Analysis*, *54*, 37-47.

Jomova, K., Jenisova, Z., Feszterova, M., Baros, S., Liska, J., Hudecova, D., Rhodes, C.J. and Valko, M. (2011). Arsenic: toxicity, oxidative stress and human disease. *Journal of Applied Toxicology*, *31*(2), 95-107.

Kumarathilaka, P., Seneweera, S., Ok, Y. S., Meharg, A., &Bundschuh, J. (2019). Arsenic in cooked rice foods: assessing health risks and mitigation options. *Environment International*, *127*, 584-591.

Liao, W., Wang, G., Li, K., Zhao, W., & Wu, Y. (2019). Effect of cooking on speciation and in vitro bioaccessibility of Hg and As from rice, using ordinary and pressure cookers. *Biological Trace Element Research*, *187*, 329-339.

Liu, K., Zheng, J., & Chen, F. (2018). Effects of washing, soaking and domestic cooking on cadmium, arsenic and lead bioaccessibilities in rice. *Journal of the Science of Food and Agriculture*, *98*(10), 3829-3835.

Meharg, A. A., & Rahman, M. M. (2003). Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. *Environmental science & technology*, *37*(2), 229-234.

Mondal, D., Banerjee, M., Kundu, M., Banerjee, N., Bhattacharya, U., Giri, A.K., Ganguli, B., Sen Roy, S. and Polya, D.A. (2010). Comparison of drinking water, raw rice and cooking of rice as arsenic exposure routes in three contrasting areas of West Bengal, India. *Environmental geochemistry and health*, *32*, 463-477.

Mridha, D., Ray, I., Sarkar, J., De, A., Joardar, M., Das, A., Chowdhury, N.R., Acharya, K. and Roychowdhury, T. (2022). Effect of sulfate application on inhibition of arsenic bioaccumulation in rice (Oryzasativa L.) with consequent health risk assessment of cooked rice arsenic on human: A pot to plate study. *Environmental Pollution*, *293*, 118561.

Ozturk, M., Metin, M., Altay, V., Bhat, R.A., Ejaz, M., Gul, A., Unal, B.T., Hasanuzzaman, M., Nibir, L., Nahar, K. and Bukhari, A. (2022). Arsenic and human health: genotoxicity, epigenomic effects, and cancer signaling. *Biological trace element research*, 1-14.

Rahaman, M.S., Rahman, M.M., Mise, N., Sikder, M.T., Ichihara, G., Uddin, M.K., Kurasaki, M. and Ichihara, S. (2021). Environmental arsenic exposure and its contribution to human diseases, toxicity mechanism and management. *Environmental Pollution*, *289*, 117940.

Rahman, M. A., Hasegawa, H., Rahman, M. M., Miah, M. M., &Tasmin, A. (2008). Arsenic accumulation in rice (Oryzasativa L.): human exposure through food chain. *Ecotoxicology and environmental safety*, *69*(2), 317-324.

Rahman, M. A., Hasegawa, H., Rahman, M. M., Rahman, M. A., & Miah, M. A. M. (2007). Accumulation of arsenic in tissues of rice plant. *Oryzasativa*, 942-948.

Rokonuzzaman, M., Li, W. C., Man, Y. B., Tsang, Y. F., & Ye, Z. (2022). Arsenic accumulation in rice: sources, human health impact and probable mitigation approaches. *Rice Science*, *29*(4), 309-327.

Roychowdhury, T., Tokunaga, H., Uchino, T., & Ando, M. (2005). Effect of arsenic-contaminated irrigation water on agricultural land soil and plants in West Bengal, India. *Chemosphere*, *58*(6), 799-810.

Sarkar, S.D., Swain, P.R., Manna, S.K., Samanta, S., Majhi, P., Bera, A.K., Das, B.K. and Mohanty, B.P. (2022). Arsenic contamination in food chain-a menace to food safety, human nutrition and health. *Journal of Environmental Biology*, *43*(3), 339-349.

Sengupta, M.K., Hossain, M.A., Mukherjee, A., Ahamed, S., Das, B., Nayak, B., Pal, A. and Chakraborti, D. (2006). Arsenic burden of cooked rice: traditional and modern methods. *Food and chemical toxicology*, *44*(11), 1823-1829.

Seyfferth, A. L., McCurdy, S., Schaefer, M. V., &Fendorf, S. (2014). Arsenic concentrations in paddy soil and rice and health implications for major rice-growing regions of Cambodia. *Environmental science & technology*, *48*(9), 4699-4706.

Signes, A., Mitra, K., Burló, F., &Carbonell-Barrachina, A. A. (2008). Effect of two different rice dehusking procedures on total arsenic concentration in rice. *European Food Research and Technology*, *226*, 561-567.

Signes-Pastor, A. J., Mitra, K., Sarkhel, S., Hobbes, M., Burló, F., De Groot, W. T., &Carbonell-Barrachina, A. A. (2008). Arsenic speciation in food and estimation of the dietary intake of inorganic arsenic in a rural village of West Bengal, India. *Journal of agricultural and food chemistry*, *56*(20), 9469-9474.

Smith, E., Juhasz, A. L., Weber, J., & Naidu, R. (2008). Arsenic uptake and speciation in rice plants grown under greenhouse conditions with arsenic contaminated irrigation water. *Science of the Total Environment*, *392*(2-3), 277-283.

Sun, G.X., Williams, P.N., Carey, A.M., Zhu, Y.G., Deacon, C., Raab, A., Feldmann, J., Islam, R.M. and Meharg, A.A. (2008). Inorganic arsenic in rice bran and its products are an order of magnitude higher than in bulk grain. *Environmental science & technology*, *42*(19), 7542-7546.

Thakur, M., Rachamalla, M., Niyogi, S., Datusalia, A. K., & Flora, S. J. S. (2021). Molecular mechanism of arsenic-induced neurotoxicity including neuronal dysfunctions. *International Journal of Molecular Sciences*, *22*(18), 10077.

Williams, P. N., Price, A. H., Raab, A., Hossain, S. A., Feldmann, J., &Meharg, A. A. (2005). Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. *Environmental science & technology*, *39*(15), 5531-5540.

Williams, P.N., Villada, A., Deacon, C., Raab, A., Figuerola, J., Green, A.J., Feldmann, J. and Meharg, A.A. (2007). Greatly enhanced arsenic shoot assimilation in rice leads to elevated grain levels compared to wheat and barley. *Environmental science & technology*, *41*(19), 6854-6859.

National Research Council. Arsenic in Drinking Water-2001 Update. Washington DC: National Academy Press, 2001

DukerAA, Carranza E J M, Hale M. Arsenic geochemistry and health. Environ Int, 2005, 31: 631–641

Ahmed MK, Shaheen N, Islam MS, Habibullah-Al-Mamun M, Islam S, Islam MM, Kundu GK, Bhattacharjee L (2016) A comprehensive assessment of arsenic in commonly consumed foodstuffs to evaluate the potential health risk in Bangladesh. Sci Total Environ 544:125–133

Althobiti RA, Sadiq NW, Beauchemin D (2018) Realistic risk assessment of arsenic in rice. Food Chem 257:230–236.

Andrew AS, Burgess JL, Meza MM, Demidenko E, Waugh MG, Hamilton JW et al (2006) Arsenic exposure is associated with decreased DNA repair in vitro and in individuals exposed to drinking water arsenic. Environ Health Perspect 114:1193–1198.

Das, A., Joardar, M., De, A., Mridha, D., Ghosh, S., Das, B., Mandal, J., Thakur, B.K. and Roychowdhury, T. (2024). Appraisal of treated drinking water quality from arsenic removal units in West Bengal, India: Approach on safety, efficiency, sustainability, future health risk and socioeconomics. *Journal of Hazardous Materials*, *465*, 133216.