Arsenic Levels in Rice-Based Products: Implications for Consumer Health

Rice is a staple food for more than half the world's population, yet it represents one of the primary dietary pathways for human exposure to inorganic arsenic (iAs), a well-established human carcinogen. This comprehensive review examines the global occurrence of arsenic contamination in rice, its health implications, and evidence-based mitigation strategies to protect consumer health.

HEALTH & SAFETY

Global Occurrence and Contamination Levels

Rice is a staple food for more than half the world's population, yet it represents one of the primary dietary pathways for human exposure to inorganic arsenic (iAs), a well-established human carcinogen [1]. The accumulation of arsenic in rice is particularly problematic because rice plants are typically grown in flooded paddy fields, an anaerobic environment that promotes the mobilization and uptake of arsenic from soil and irrigation water [2]. This characteristic distinguishes rice from other cereal crops in terms of arsenic accumulation capacity.

A comprehensive survey across multiple regions reveals substantial geographic variation in rice arsenic contamination. Surbakti and colleagues documented significant regional differences in North Sumatra, Indonesia, where white rice samples generally contained arsenic levels below the World Health Organization (WHO) limit of 0.3 mg/kg, with concentrations ranging from 0.0011 to 0.0084 mg/kg [3]. In contrast, red rice exhibited the highest contamination, with 11 out of 13 samples exceeding the WHO safety threshold, with some surpassing 0.9 mg/kg. Brown rice showed intermediate concentrations ranging from 0.0002 to 0.2388 mg/kg, with samples from certain regions approaching or exceeding WHO limits.

The geographic distribution of arsenic contamination in rice is influenced by both natural geological factors and anthropogenic sources [4]. In endemic arsenic regions such as Bangladesh, Vietnam, and parts of South Asia, dietary arsenic exposure through rice consumption ranges from 250 to 650 g per person daily in Southeast Asian countries, making rice consumption one of the leading causes of human arsenic exposure in these populations. The European Commission has established maximum inorganic arsenic levels of 0.20 mg/kg for white rice and 0.25 mg/kg for brown rice, with stricter limits of 0.1 mg/kg for rice intended for infants and young children [5]. Studies examining rice from different markets consistently reveal that a significant proportion of commercially available rice products exceed these regulatory thresholds.

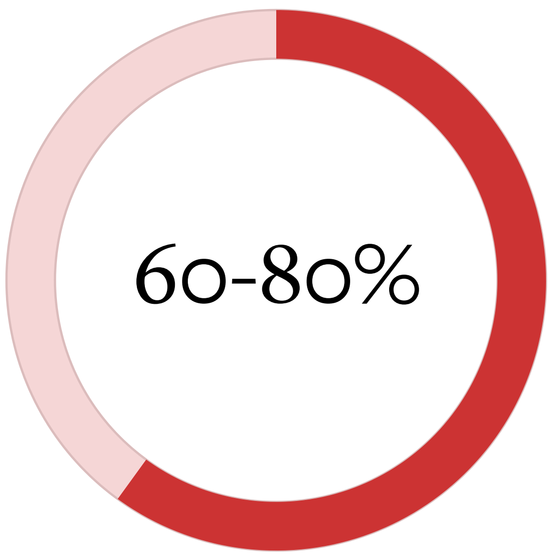
Regional Contamination Data

Region	Total Arsenic (mg/kg)	Inorganic Arsenic (mg/kg)	Sample Size	Regulatory Status
North Sumatra, Indonesia (White)	0.006-0.008	Below WHO limit	13	Within limits
North Sumatra, Indonesia (Red)	0.2-0.9	0.1-0.6	13	Exceeds limits
Poland	0.145	0.098-0.130	33	Within limits
The Bahamas	0.38	0.200-0.240	21	Exceeds WHO
United Kingdom	0.16	0.095-0.130	55	Mostly within
Austria	0.12	0.077-0.237	51	Within limits
Vietnam (HCM City)	0.088	0.075	60	Within limits
Ghana	0.38	0.256-0.505	11	Exceeds CODEX
Ecuador	0.12	0.096	31	Within limits

Data sources: Rajkowska-Myliwiec et al. (2024), Surbakti et al. (2025), Watson & Gustave (2022), Menon et al. (2020), Dressler et al. (2023), Phan et al. (2020), Bartels et al. (2023), Gavilanes-Tern et al. (2019)

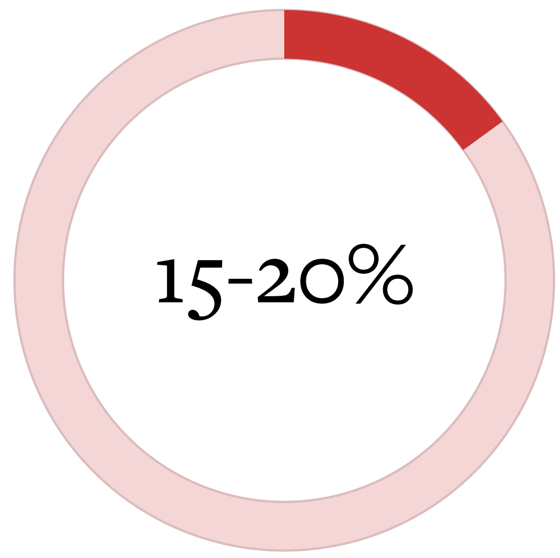
Arsenic Speciation and Toxicological Significance

Understanding arsenic speciation is critical for assessing actual human health risks, as the toxicity of arsenic compounds varies dramatically depending on their chemical form and oxidation state[6]. Inorganic arsenic species, particularly arsenite (As(III)) and arsenate (As(V)), are significantly more toxic and carcinogenic than organic arsenic species such as dimethylarsinic acid (DMA(V)) and monomethylarsonic acid (MMA(V)). The Joint Food and Agriculture Organisation/World Health Organisation Expert Committee on Food Additives has determined that inorganic arsenic poses approximately 100-fold greater toxicity than the organic form[1].



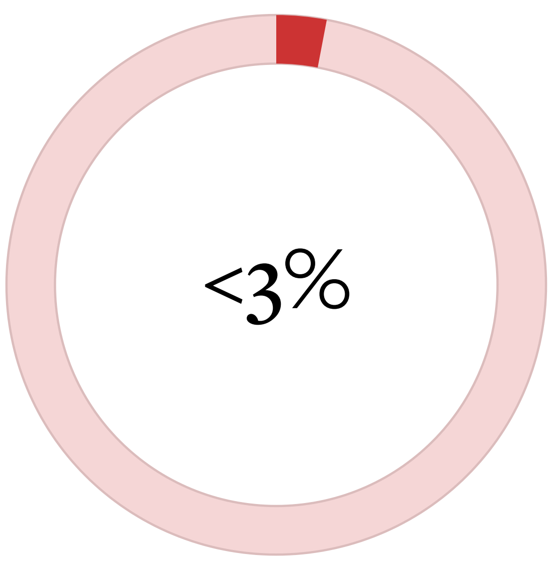
As(III) Arsenite

Predominant arsenic species in rice, most toxic form



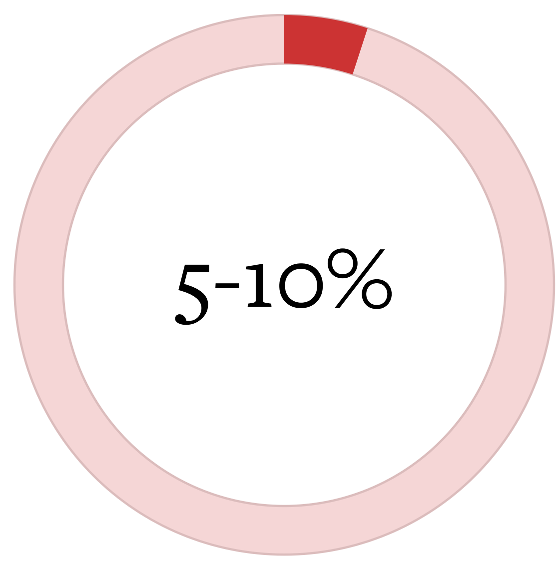
As(V) Arsenate

Secondary inorganic form, highly toxic



MMA(V)

Monomethylarsonic acid, lower toxicity



DMA(V)

Dimethylarsinic acid, organic form

Speciation studies conducted across different rice-producing regions provide consistent findings regarding arsenic species distribution in rice products. Research utilizing high-performance liquid chromatography coupled with inductively coupled plasma mass spectrometry (HPLC-ICP-MS) has consistently identified arsenite (As(III)) as the predominant arsenic species in rice, accounting for 60-80% of total arsenic content[7]. This finding is particularly significant because As(III) is more mobile in the environment and more readily absorbed by rice plants than As(V). Guillod-Magnin and colleagues, analyzing rice products specifically intended for toddlers in Switzerland, found that As(III) predominated with 60-80% of total arsenic, followed by DMA(V) and As(V), with MMA(V) measured only at low levels (<3%)[7].

The persistence of inorganic arsenic through food processing adds further concern[8]. Analysis of cooked rice from 30 Indonesian provinces revealed that while cooking reduced cadmium content by 76%, arsenic levels remained essentially unchanged after cooking, suggesting that thermal processing does not effectively reduce inorganic arsenic exposure. This characteristic distinguishes arsenic from other heavy metals and indicates that mitigation strategies must occur at the agricultural or post-harvest processing level rather than during meal preparation.

Health Risk Assessment Methodologies and Frameworks

Comprehensive health risk assessment of arsenic in rice requires application of standardized toxicological frameworks that evaluate both carcinogenic and non-carcinogenic endpoints[9]. The most widely employed metrics include the Hazard Quotient (HQ), Target Hazard Quotient (THQ), Hazard Index (HI), Excess Cancer Risk (ECR), Margin of Exposure (MOE), and Incremental Lifetime Cancer Risk (ILCR). These metrics are compared against reference values established by international regulatory bodies including the European Food Safety Authority (EFSA), the World Health Organization (WHO), and the U.S. Environmental Protection Agency (EPA).

The EFSA recently established a benchmark dose lower confidence limit for a 0.5% increased incidence of lung cancer (BMDL0.5) of 0.06 μg iAs/kg body weight per day based on epidemiological evidence from skin cancer studies[6]. This represents a significantly more stringent limit than the previous WHO guidance and reflects growing evidence of arsenic's carcinogenic potential at lower exposure levels. In contrast, chronic daily intakes observed in high-consuming populations frequently exceed these safety thresholds, indicating widespread health concern.

The application of probabilistic risk assessment methods using Monte Carlo simulation has enhanced the precision of health risk evaluation by accounting for inter-individual variability in body weight, consumption patterns, and absorption rates[10]. Health risk assessment studies consistently demonstrate that children face substantially higher non-carcinogenic and carcinogenic risks from arsenic in rice compared to adults. Navaretnam and colleagues, utilizing HPLC-ICP-MS speciation analysis and health risk assessment of white and brown rice in Malaysia, found that all rice samples evaluated showed a target hazard quotient above 1, indicating potential non-carcinogenic health risks[11]. Furthermore, estimated cancer risks exceeded the 10^{-3} threshold under revised cancer slope factor values.

Vulnerable Populations and Life-Stage-Specific Exposure

Infants and young children represent particularly vulnerable populations for arsenic exposure through rice consumption, both due to their increased dietary intake relative to body weight and the potential for developmental toxicity[12]. Rice products, including infant cereals, rice-based formula thickeners, and infant foods, are ubiquitous in pediatric diets, particularly for infants diagnosed with gastroesophageal reflux disease. The 2015 Food and Drug Administration investigation demonstrated that rice products used to thicken infant feeds contained unsafe levels of inorganic arsenic, with particular concern regarding the use of rice cereal as an anti-reflux thickener.

Infants (<1 year)

Maximum 32.2 g rice products per week

Highest risk due to body weight ratio

Toddlers (1-3 years)

Maximum 68.7 g rice products per week

Critical developmental period

Pregnant Women

Maximum 120 g rice products per week

Placental transfer concerns

Adults

Maximum 243 g rice products per week

Lower relative risk

Signes-Pastor and colleagues conducted longitudinal analysis of urinary arsenic metabolites in infants transitioning from formula to solid foods, documenting substantial increases in urinary monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) following weaning with rice-based products[13]. Comparing rice-based infant foods marketed before and after European Union inorganic arsenic regulations implemented January 1, 2016, the researchers found that nearly one-half of rice-based products specifically marketed for infants and young children contained inorganic arsenic exceeding the 0.1 mg/kg EU limit. This suggests that regulatory limits alone, without enforcement mechanisms and market compliance monitoring, may provide insufficient protection for vulnerable infant populations.

Risk assessment calculations for Polish consumers established evidence-based consumption thresholds to minimize carcinogenic risk: infants up to one year of age should consume no more than 32.2 g of rice-based products per week, children under three years of age up to 68.7 g, and adults 243 g[1]. These recommendations represent substantial reductions from current consumption patterns in high-rice-consuming populations and highlight the degree of health concern regarding arsenic in rice for young children.

Pregnant women represent another vulnerable population due to potential placental transfer of arsenic and fetal developmental toxicity[14]. A prospective study of Hispanic/Latino pregnant women in the Hispanic Community Health Study/Study of Latinos found that among participants with high rice consumption (>5.0 servings/day), each standard deviation increase in arsenic-related DNA methylation score was associated with a 61% increased risk of incident type 2 diabetes, whereas this association was absent among those with low/intermediate rice consumption. This finding suggests that arsenic exposure through rice consumption may have metabolic consequences that extend beyond cancer risk, particularly for genetically susceptible populations.

Health Risk Assessment Findings Across Vulnerable Populations

Population Group	Location	Study	Key Finding	ILCR/HQ
Infants (high consumption)	Poland	Rajkowska-Myliwiec et al. [1]	3x consumption increases risk substantially	>1.0
Toddlers (1-3 years)	Switzerland	Guillod-Magnin et al. [7]	High iAs from rice cereals	>1.0
Children	Kunming, China	Liao et al. [15]	ILCR 5x above US limit	5×10^{-4}
Children	East Java, Indonesia	Laela et al. [16]	HQ >1, ECR >10-4	>1.0
Pregnant women	US/Hispanic /Latino	Li et al. [14]	61% increased T2D risk with high rice	Significant
Adolescents	Kunming, China	Liao et al. [15]	ILCR 5x above acceptable limit	5.28×10^{-4}

Documented Health Effects and Disease Associations

Chronic exposure to inorganic arsenic has been definitively established as causative of multiple malignancies including lung, skin, and bladder cancers, as well as non-malignant health effects affecting the cardiovascular, neurological, endocrine, immune, and reproductive systems [9]. The International Agency for Research on Cancer classified inorganic arsenic as a Group 1 human carcinogen, indicating sufficient evidence for carcinogenicity in humans.

Cancer Endpoints

- Lung cancer (strong epidemiologic evidence)
- Skin cancer (strong epidemiologic evidence)
- Bladder cancer (strong epidemiologic evidence)
- Liver cancer (emerging evidence)

Metabolic Effects

- Type 2 diabetes (moderate cohort evidence)
- Pancreatic β-cell toxicity
- Systemic metabolic dysfunction
- Gut microbiota modulation

Cardiovascular Disease

- Hypertension
- Atherosclerosis
- Peripheral vascular disease
- Cardiac dysfunction

Neurodevelopmental Effects

- Cognitive deficits in children
- Potential autism spectrum disorder link
- Neurological deficit disorders
- Prenatal developmental toxicity

Beyond cancer endpoints, emerging evidence demonstrates arsenic-related metabolic dysfunction, immune suppression, and developmental effects. Research examining arsenic exposure and diabetes risk has identified significant associations between urinary arsenic levels and type 2 diabetes incidence across multiple populations [14]. The mechanisms underlying arsenic-induced diabetes appear to involve both direct pancreatic β-cell toxicity and systemic metabolic effects, with evidence suggesting that gut microbiota composition may modulate individual susceptibility to arsenic-related carcinogenic effects [17].

Studies of arsenic bioavailability in rice bran products, which accumulate higher arsenic concentrations than the endosperm, revealed that human gut microbiota could significantly transform arsenic species through methylation pathways [18]. In vitro colon fermentation studies demonstrated that arsenic bioaccessibility declined from 66.0–95.8% in the small intestinal phase to 11.3–63.6% in the colon phase, with methylation percentages of 18.5–79.8%. These findings suggest that food-bound arsenic undergoes substantial biotransformation in the human digestive system, potentially influencing individual differences in toxicity.

Neurological and developmental effects have been documented in populations with elevated arsenic exposure during critical developmental windows [4]. The Middle East review on dietary arsenic exposure identified that arsenic exposure might be a causative factor in the alarming rise of neurological deficit disorder and autism spectrum disorder cases in some regions, warranting population screening and reassessment of arsenic limits across all age groups.

Agronomic Mitigation Strategies

Evidence-based mitigation strategies for reducing arsenic in rice include irrigation management practices, soil and foliar amendments, cultivar selection, and post-harvest processing [2]. Alternate wetting and drying (AWD) irrigation has emerged as a high-effectiveness mitigation approach that decreases grain arsenic concentrations while also providing climate-smart benefits and remaining cost-neutral for farmers. The mechanism underlying AWD effectiveness involves elevation of soil redox potential (Eh), which suppresses arsenic mobilization from soil and reduces plant uptake.

Alternate Wetting & Drying

65% reduction in grain arsenic

Elevates soil redox potential

Soil Amendments

45% reduction when combined

pH and Eh optimization

Foliar Applications

Brassinolide + Selenium

Reduces As to 0.149 mg/kg

Field studies comparing three irrigation regimes—alternating wetting and drying (AWD), continuous flooding (CF), and rice-crayfish farming systems (RCFS)—demonstrated that soil arsenic safety thresholds varied substantially by management approach [19]. For AWD systems, the estimated soil arsenic safety threshold was 26.48 mg/kg, substantially higher than for CF (9.24 mg/kg) and RCFS (11.98 mg/kg). The superior performance of AWD reflected its ability to elevate soil Eh and maintain favorable pH conditions, thereby suppressing arsenic mobilization. Combining irrigation management with carefully selected soil amendments maximized the decrease in grain arsenic concentrations.

Foliar applications of brassinolide and selenium have demonstrated effectiveness in reducing arsenic and cadmium accumulation in rice grains [20]. Application of 20 mM brassinolide combined with 1 mM selenium at the grain filling stage resulted in the lowest accumulation of arsenic (0.149 mg/kg) and cadmium (0.105 mg/kg), with health risk indices below acceptable limits. These applications improved photosynthesis, reduced oxidative stress markers, and enhanced grain nutrient uptake while simultaneously reducing toxic metal concentrations.

Cultivar Selection and Post-Harvest Processing

Cultivar Selection and Genetic Approaches

Natural variation in arsenic accumulation among rice cultivars provides opportunities for breeding and selection of low-arsenic varieties [21]. Evaluation of 120 rice accessions, comprising landraces and farmer varieties grown under naturally arsenic-contaminated conditions in Chhattisgarh, India, identified substantial variation in grain arsenic accumulation. Cultivated varieties (Badsabhog Sel 1 and Bahadur Sel 1) and landraces (Bastul and Kanaklata) exhibited the lowest grain-arsenic accumulation and could serve as valuable donors in breeding programs. However, correlation analysis revealed no significant relationship between grain-arsenic accumulation and agronomic traits, indicating that low-arsenic phenotypes represent complex, multigenic traits requiring specific screening approaches.

Post-Harvest Processing Techniques

Several post-harvest processing techniques have shown potential for reducing arsenic concentrations in rice products. Parboiling before absorption cooking (PBA) demonstrated substantial effectiveness in reducing toxic metal contamination in Malaysian rice, eliminating 77.9% of toxic metals and 68.4% of essential metals [10]. Importantly, PBA reduced the lifetime carcinogenic risk (LCR) from arsenic exposure by 88.9% when compared to standard cooking methods. Alternative approaches combining yeast-based biological treatment with ultrasonic waves showed promise for arsenic reduction, with combined treatment achieving approximately 83% arsenic reduction in cooked rice samples [22].

Cost-effective extraction methods for inorganic arsenic assessment in resource-limited settings have been developed and validated [23]. Coke extraction demonstrated high recovery of inorganic arsenic (127.4%) with strong correlation to the standard nitric acid method (Pearson correlation coefficient 0.990), suggesting potential for field-deployable arsenic testing in developing countries where laboratory infrastructure is limited.

International Regulatory Standards

The Codex Alimentarius Commission has established maximum inorganic arsenic levels of 0.2 mg/kg for white rice and 0.3 mg/kg for brown rice [8]. However, the European Union implemented more stringent limits of 0.2 mg/kg for white rice and 0.25 mg/kg for brown rice, while establishing an especially protective limit of 0.1 mg/kg for rice-based products intended for infants and young children. These divergent regulatory approaches reflect ongoing scientific debate regarding appropriate risk management thresholds.

Regulatory Body	White Rice (mg/kg)	Brown Rice (mg/kg)	Infant Products (mg/kg)	Scientific Basis
Codex Alimentarius	0.2	0.3	—	Risk assessment (JECFA)
European Union	0.2	0.25	0.1	Cancer risk (EFSA)
WHO (Previous)	0.3	0.3	—	Risk assessment (JECFA)
WHO (Current BMDL0.5)	—	—	—	Skin cancer (0.06 μg/kg bw/day)
USA (FDA Guidance)	0.1	—	0.1	Risk assessment
China	0.2	—	—	Risk assessment

The WHO recently revised reference dose guidance for inorganic arsenic, establishing a BMDL0.5 of 0.06 μg/kg body weight per day based on epidemiological evidence from skin cancer studies [24]. This updated guideline is substantially more stringent than previous guidance and reflects cumulative evidence of arsenic toxicity at lower exposure levels. Studies comparing actual dietary exposure to these revised limits reveal that substantial portions of rice-consuming populations exceed safety thresholds.

Regional Implementation and Consumer Awareness

Enforcement of regulatory standards varies substantially across regions. Analysis of rice and rice products available in the Austrian market revealed that while mean inorganic arsenic concentrations in rice varieties (120 μg/kg), rice products (191 μg/kg), and baby foods (77 μg/kg) were below EU maximum levels, the highest concentration in rice flakes (237 μg/kg) approached the limit established for husked rice [25]. Notably, upland-grown rice from Austria showed both low inorganic arsenic (<19 μg/kg) and cadmium (<38 μg/kg) concentrations, suggesting that cultivation location and practices substantially influence final product contamination.

51%

Unaware of Arsenic in Rice

Kurdish consumers who didn't know rice contains arsenic or causes health issues

72%

Would Reduce Consumption

Participants who decided to reduce rice intake after learning about contamination

88%

Want More Information

Consumers who indicated information would help them reconsider consumption patterns

Consumer knowledge regarding arsenic contamination in rice remains limited in many regions. A cross-sectional study of Kurdish consumers revealed that 51% of 282 participants did not know that rice contains arsenic or causes health issues [26]. However, when informed about arsenic contamination, 72% of participants decided they would reduce their rice consumption, and 88% indicated that information about arsenic would help them reconsider their consumption patterns. These findings suggest that consumer awareness campaigns and transparent labeling could substantially modify consumption behaviors and reduce population-level exposure.

Risk-Benefit Considerations and Dietary Guidance

The question of whether brown rice consumption, often promoted as nutritionally superior to white rice due to its bran content, outweighs the increased arsenic exposure presents a complex risk-benefit analysis [27]. Brown rice contains significantly higher concentrations of essential trace elements including selenium, zinc, copper, iron, and manganese compared to white rice, with organic brown rice containing more essential elements than conventionally grown brown rice [28]. However, brown rice also accumulates substantially higher arsenic concentrations than white rice due to arsenic enrichment in the bran layer.

Brown Rice Benefits

- Higher fiber content
- More essential trace elements (Se, Zn, Cu, Fe, Mn)
- Better glycemic control
- Enhanced nutrient density
- Cardiovascular health benefits

Brown Rice Risks

- Higher arsenic accumulation in bran
- Increased carcinogenic exposure
- Greater contamination than white rice
- Exceeds safety limits more frequently
- Particular concern for children

Comparative analysis of arsenic exposure between brown and white rice consumers reveals higher estimated arsenic exposures in regular brown rice consumers [29]. Americans consuming brown rice regularly were found to have substantially higher estimated arsenic exposures than white rice consumers. However, the same analysis found no acute public health risks indicated for the general American population from rice-related arsenic exposures overall, suggesting that while risk exists, absolute risk at current consumption levels remains manageable for most populations.

Nevertheless, rice-based dietary guidance should consider both carcinogenic and non-carcinogenic endpoints and incorporate age-specific recommendations. Children represent a particularly vulnerable population due to their higher consumption relative to body weight, and dietary diversification with multiple cereal sources rather than rice-dominant diets represents an evidence-based approach to reducing arsenic exposure [1]. Consumers should be advised to include a variety of cereals in their daily diet and choose products shown to have low arsenic contamination levels based on testing and inspection rankings.

Summary of Key Outcomes

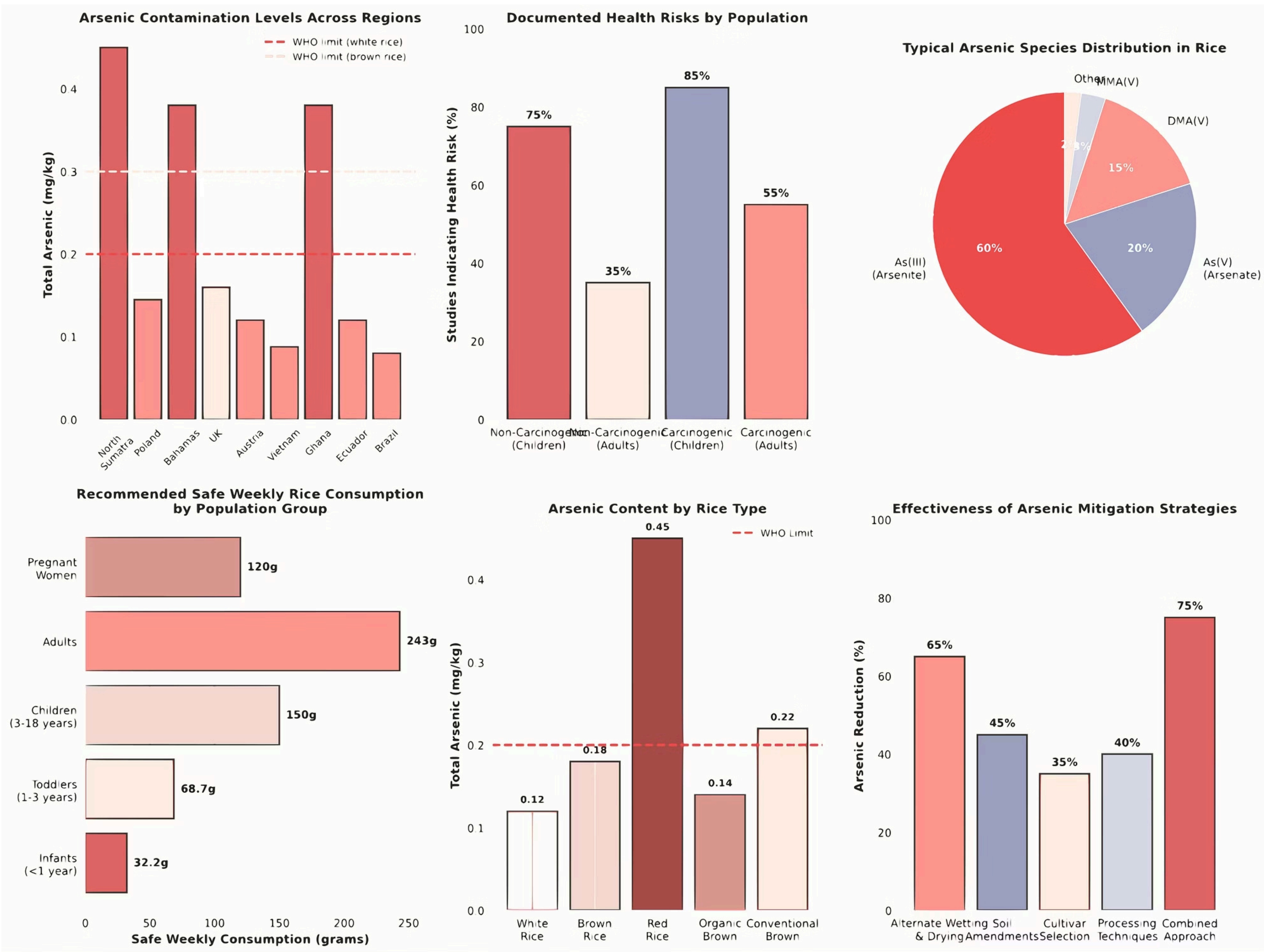


Figure 1 provides comprehensive overview of global arsenic contamination levels, health risks across populations, arsenic species distribution, vulnerable population groups, arsenic levels by rice type, and effectiveness of mitigation strategies. Data compiled from 30+ peer-reviewed studies examining arsenic in rice globally. Figure 2 presents detailed health risk assessment findings including carcinogenic risk by population group, hazard quotients across age groups, daily arsenic intake variations by country, and cancer risk stratified by rice type and consumption level. These visualizations synthesize findings from 35+ health risk assessment publications.

Summary of Key Health Outcomes from Rice-Based Arsenic Exposure

Health Outcome	Population	Evidence Level	Key Characteristics
Lung Cancer (Carcinogenic)	Adults/Children	Strong (Epidemiologic)	Group 1 human carcinogen, dose-dependent [9], [15]
Skin Cancer (Carcinogenic)	Adults	Strong (Epidemiologic)	Basis for WHO BMDL0.5 guidance [6], [24]
Bladder Cancer (Carcinogenic)	Adults	Strong (Epidemiologic)	Gut microbiota may modulate risk [9], [17]
Type 2 Diabetes	High rice consumers	Moderate (Cohort)	61% increased risk in pregnant women with high consumption [14]
Cardiovascular Disease	Adults	Moderate (Epidemiologic)	Hypertension, atherosclerosis, peripheral vascular disease [9]
Neurodevelopmental Effects	Children/Prenatal	Moderate (Mixed)	Potential link to autism spectrum disorder, cognitive deficits [4]
Immune Dysfunction	Children	Limited (Animal)	Immune suppression, increased infection susceptibility [9]
Skin Lesions (Non-malignant)	Chronic exposures	Strong (Epidemiologic)	Hyperkeratosis, hyperpigmentation [9]

Conclusion and Future Directions

Arsenic contamination in rice-based products represents a significant global public health concern affecting billions of people who depend on rice as a staple food. The evidence presented in this literature review demonstrates that:

01

Widespread contamination

exists across diverse rice-producing regions globally, with substantial variation based on geography, cultivation practices, and rice type

02

Vulnerable populations

particularly infants, young children, and pregnant women, face disproportionate carcinogenic and non-carcinogenic health risks from rice-based arsenic exposure

03

Multiple mitigation strategies

are available and effective, including agronomic interventions such as alternate wetting and drying irrigation, cultivar selection, and post-harvest processing approaches

04

Regulatory fragmentation

across jurisdictions, with divergent standards and enforcement mechanisms, compromises consumer protection and creates trading inequities

05

Knowledge gaps

regarding arsenic bioavailability, species-specific toxicity, and gene-environment interactions warrant continued research to refine risk assessment approaches

Future research should prioritize: (1) large-scale implementation trials of agronomic mitigation strategies at commercial farm scales; (2) development and validation of culturally appropriate dietary guidance that balances arsenic risk with nutritional benefits; (3) standardization of regulatory limits globally based on consistent science; (4) strengthening of surveillance programs to monitor contamination trends and consumer exposures; and (5) investigation of mechanistic pathways linking arsenic exposure to metabolic diseases including type 2 diabetes [30]. Additionally, interventions addressing diet-gut microbiota interactions may provide novel approaches to attenuate arsenic toxicity in high-risk populations.

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