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DETERMINATION OF ARSENIC CONTAMINATION IN RICE GRAINS FROM MULTIPLE SITES IN NORTH SUMATRA, INDONESIA

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ABSTRACT

Arsenic contamination in rice represents a serious public health concern, especially in regions with high rice consumption like Indonesia. This study aimed to analyze and evaluate arsenic levels in rice samples from multiple regencies across North Sumatra, Indonesia, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). A total of 39 rice samples (white, red, and brown rice) were collected using a cluster sampling approach from 13 regencies, directly from local farmers and traditional markets, and analyzed for total arsenic concentration. The health risk associated with arsenic exposure was assessed using Daily Intake (DI) and Excess Cancer Risk (ECR) calculations based on average rice consumption and body weight in Indonesia. The findings revealed a wide variation in arsenic concentrations across rice types and regions. White rice samples generally contained arsenic levels below the World Health Organization (WHO) limit of 0.3 mg/kg, with values ranging from 0.0011 to 0.0084 mg/kg. In contrast, red rice exhibited the highest contamination, with 11 out of 13 samples exceeding the safety threshold some surpassing 0.9 mg/kg. Brown rice showed intermediate arsenic concentrations, ranging from 0.0002 to 0.2388 mg/kg, with samples from Mandailing Natal and Nias Selatan approaching or exceeding the WHO safety threshold. Organic rice samples tended to show lower arsenic levels, though exceptions were observed, underscoring the influence of local environmental factors such as irrigation water and soil composition. The health risk evaluation indicated that while most white rice samples posed low cancer risk (ECR $< 1 \times 10^{-5}$), many red and brown rice samples presented significantly elevated ECR values ($p \leq 0.05$), exceeding safety limits by several orders of magnitude in some cases. These findings suggest that chronic exposure to arsenic through rice consumption in North Sumatra, particularly from red and brown rice, may contribute to long-term cancer risk. This study highlights the urgent need for regulatory intervention, public awareness, and continued monitoring of arsenic levels in Indonesian rice to protect consumer health, particularly in areas with known environmental contamination and high rice consumption rates.

Key words: Arsenic, Rice contamination, ICP-MS, North Sumatra, Food safety, Heavy metals

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INTRODUCTION

Arsenic contamination in rice has emerged as a significant global food safety concern. Arsenic (As) is a naturally occurring metalloid widely distributed in soil and water, and it readily enters agricultural systems [1]. In particular, the use of contaminated groundwater for irrigation of rice paddies is recognized as a major pathway for arsenic to enter the food chain [2]. Rice (*Oryza sativa* L.), a staple for over half the world's population, is known to accumulate arsenic more efficiently than other cereal crops, largely due to its cultivation in flooded soils which mobilize non-organic arsenic species [3]. Consequently, populations with rice-based diets face heightened exposure to arsenic, and this has raised worldwide alarm regarding arsenic in rice grains [4].

Arsenic is highly toxic in its non-organic form and is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) [5]. Chronic arsenic exposure, even at low concentrations, can lead to myriad adverse health effects without a safe threshold for intake [6]. Long-term ingestion of arsenic through water or food has been causally linked to skin lesions and cancers of the skin, lung, bladder, and other organs, as well as to cardiovascular disease, diabetes, and developmental problems in children [7]. The toxicological profile of arsenic encompassing genotoxic and carcinogenic effects makes any significant arsenic content in a staple food like rice especially concerning for public health [8].

Arsenic can infiltrate rice paddies through both geogenic and anthropogenic sources. Naturally, arsenic is present in certain minerals and may be released into soils and water by processes such as mineral weathering or volcanic activity [9]. In many parts of Asia, including Bangladesh and Vietnam, arsenic-rich groundwater used for irrigating paddy fields is the primary source of rice arsenic, leading to elevated arsenic uptake by the plants [10]. Anthropogenic contributions such as legacy arsenic-based pesticides, industrial effluents, and mining activities further exacerbate soil arsenic levels in agricultural lands [11]. Under flooded anaerobic conditions, arsenic in the soil (often as arsenite, As^{3+}) becomes more bioavailable and is readily absorbed by rice roots via phosphate and silica uptake pathways, accumulating in the grain [12,13]. Notably, brown rice (whole grain) tends to contain higher arsenic than polished white rice since arsenic concentrates in the outer bran layers [14].

Extensive surveys have documented that arsenic in rice is a widespread problem across multiple continents. Reported concentrations of total arsenic in rice grain vary widely, from relatively low levels (around 0.01–0.08 mg/kg) in some regions to highly elevated levels above 0.5–1 mg/kg in others [15]. For example, studies in South Asia have found mean and maximum arsenic levels in rice that frequently exceed international food safety standards. Rice from Bangladesh can contain arsenic on the order of 0.1–1.8 mg/kg, with some samples even approaching 2 mg/kg [16]. Similarly, parts of India, China, and other rice-growing countries with geogenic arsenic in groundwater have reported grain arsenic concentrations well above 0.2–0.3 mg/kg [17]. Such findings underscore that arsenic in rice is not confined to one country, but is a global issue prompting regulatory agencies to set guidelines, such as the Codex Alimentarius recommendation of 0.2–0.3 mg/kg non-organic as in rice [18].

South-east Asia faces its own challenges regarding arsenic in rice. Countries like Cambodia and Vietnam are known to have arsenic contamination in groundwater and agricultural soils, which has raised concerns about rice safety. In Indonesia, rice is the staple food for the majority of the population, with one of the world's highest per capita rice intakes (~200–350 g/person/day) [19]. Despite this heavy reliance on rice, there has historically been a paucity of data on arsenic levels in Indonesian rice, and no national standard for arsenic in rice had been established as of the late 2010s. Recent studies suggest that arsenic contamination of rice may indeed be an issue in Indonesia. Ginting *et al.* [20] reported arsenic concentrations in rice sold in Medan (North Sumatra) up to 3.71 mg/kg in certain locally available rice varieties [20]. Another survey in Bandung found rice arsenic levels averaging around 0.0775-0.2550 mg/kg [21]. These levels substantially exceed the Codex guideline, indicating potential health risks if such rice is consumed regularly. Collectively, these findings highlight that Indonesian rice can contain unsafe arsenic levels and reinforce the need for more comprehensive monitoring across different regions of the country.

North Sumatra is a populous and agriculturally important region of Indonesia that has received little attention in terms of arsenic in food crops. Given its diverse geology (including volcanic areas) and the possible use of ground or surface water for irrigation, an investigation into arsenic contamination in North Sumatran rice is highly pertinent. Additionally, North Sumatra's inhabitants, like most Indonesians, consume rice multiple times a day, compounding any arsenic exposure from this source. Studying rice from several regions of North Sumatra will therefore provide valuable insight into the extent of arsenic contamination in the local food supply and associated health implications. The present study aims to analyze and evaluate the arsenic content in rice grains collected from multiple districts of North Sumatra, Indonesia. By establishing baseline data on rice arsenic levels in this region, the study addresses a critical knowledge gap and contributes to the global effort to assess dietary arsenic exposure. The findings are expected to inform risk assessments and guide local authorities in developing strategies or regulations to ensure rice safety and protect public health.

MATERIALS AND METHODS

Study Design

This research employed a descriptive design to evaluate and characterize arsenic contamination in various rice types cultivated across multiple agroecological zones in North Sumatra, Indonesia. The analysis was conducted without examining causal relationships, focusing instead on arsenic levels in rice grains obtained from different regions and cultivation practices.

Sampling and Sample Collection

Rice samples were collected using a cluster sampling method. Ten districts in North Sumatra were selected as clusters: Deli Serdang, Serdang Bedagai, Simalungun, Langkat, Humbang Hasundutan, South Nias, Karo, Toba, Tapanuli, and Padang Lawas. From each region, locally cultivated rice samples grown using diverse fertilization methods were obtained directly from traditional farmers. The rice types included white rice (*Oryza sativa* L.), red rice (*Oryza punctata*), brown rice (*Oryza rufipogon*).

Instruments and Reagents

The analysis was carried out at the Industrial Agro Laboratory, Bogor, Indonesia, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Hitachi GBC 906AA) equipped with an argon-air burner and arsenic-specific cathode lamp. Additional tools included glassware, aerator, microwave digestion system (SCP Science), analytical balance (Mettler Toledo), filter papers (Whatman No. 41), and standard laboratory equipment. Reagents used were pro-analysis grade chemicals: nitric acid (HNO_3 65%), hydrochloric acid (HCl 37%) from E. Merck, and demineralized water. Certified arsenic standard powder (E. Merck) was used to prepare calibration curves.

Sample Preparation and Digestion

Approximately 10 g of rice grains were washed, drained, and ground into flour using a blender. One gram of rice flour was placed in a microwave digestion vessel with 5 mL HNO_3 and 3 mL HCl. The mixture was allowed to stand for 10 minutes, then heated at 260°C for 30 minutes in the microwave digestion system. A clear solution indicated complete digestion. The digest was transferred to a 100 mL volumetric flask, diluted with demineralized water, and filtered through Whatman No. 41 filter paper [22].

Arsenic Determination

Arsenic concentration in the digested samples was determined using ICP-MS at a detection wavelength of 193.7 nm. A standard arsenic solution (100 mg in 100 mL HCl 0.1 N) was prepared to generate a calibration curve, with working solutions in

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the range of 0.02–1 µg/mL. Calibration was performed by plotting absorbance values against known concentrations, using the linear regression equation:

$Y = aX + b$

where Y is the absorbance and X is the arsenic concentration [23].

Quantitative Analysis

The arsenic content in rice samples was calculated using the regression equation obtained from the calibration curve. Concentrations were expressed in µg/g (mg/kg) of rice using the formula [24]:

Arsenic content (µg/g) = $(C \times V \times DF) / W$

Where: C = arsenic concentration from regression (µg/mL),
V = total volume (100 mL),
DF = dilution factor,
W = sample weight (1 g).

Qualitative Confirmation

A qualitative test was performed by adding 1 mL sulfide solution in acidic conditions to the sample. A yellow precipitate of As_2S_3 confirmed the presence of arsenic. The precipitate was insoluble in concentrated HCl but dissolved in hot concentrated HNO_3 and alkali hydroxides [25].

Risk Evaluation

The assessment of potential health risks associated with arsenic exposure through rice consumption was conducted based on the calculation of Daily Intake (DI) and Excess Cancer Risk (ECR), following the guidelines established by the World Health Organization (WHO) [26]. The Daily Intake (DI) of arsenic was determined using the following equation:

$DI = (C \times R \times EF \times ED) / (BW \times H)$

Where:
C = arsenic concentration in rice (mg/kg),
R = average daily rice consumption (0.2 kg/day)
EF = exposure frequency (350 days/year),
ED = exposure duration (30 years),
BW = average body weight (55 kg for men, 47 kg for women),
H = average lifetime (70 years × 365 days = 25,550 days).

The Excess Cancer Risk (ECR) was subsequently calculated using the formula:

ECR = DI × Cancer Slope Factor (CSF)

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A cancer slope factor of 1.5 (mg/kg/day)$^{-1}$ was applied in accordance with established health risk models to estimate the lifetime carcinogenic risk associated with arsenic exposure.

Statistical Analysis

All measurements were carried out in triplicate for each rice sample. The mean arsenic concentrations were expressed as mean ± standard deviation (SD). Data normality was assessed using the Shapiro-Wilk test. Parametric or non-parametric tests (ANOVA or Kruskal-Wallis) were used accordingly. Confidence intervals were calculated at a 95% level. The limit of detection (LOD), defined as the lowest concentration of arsenic that can be reliably distinguished from background noise, and the limit of quantification (LOQ), defined as the lowest concentration that can be measured with acceptable precision and accuracy, were established from the calibration curve. Method precision was expressed as Relative Standard Deviation (RSD). Statistical analysis was performed using SPSS v25 and Microsoft Excel.

RESULTS AND DISCUSSION

Survey Results of Rice Cultivation Areas in North Sumatra

Sumatra Island is recognized as one of the major rice-producing regions in Indonesia. Its diverse agroecological zones make it particularly suitable for the development of the agricultural sector. Among the provinces on the island, North Sumatra plays a strategic role in supporting Indonesia’s national food security program, often referred to as the “food estate” initiative. This status is supported by the province's varied land resources, including irrigated rice fields and rain-fed lowland paddies. Figure 1 illustrates administrative map of North Sumatra province.

Figure 1: Administrative map of the Indonesian province of North Sumatra, Sumatra, Indonesia (from: www.dreamstime.com)

The high rice productivity observed in North Sumatra is attributed to the significant contributions of several key regencies. Each of these regencies plays a crucial role in maintaining and increasing regional rice production from year to year. According to the Provincial Statistics Agency (BPS Sumatera Utara, 2022), the ten regencies with the largest rice cultivation area and production volume in 2021 are presented in Table 1.

The survey findings highlight the significant contribution of North Sumatra to Indonesia's rice production system, with Deli Serdang and Serdang Bedagai standing out as the leading regencies in both harvested area and total production volume. These regions benefit from favorable agroecological conditions, access to irrigation, and the implementation of improved agricultural practices. In contrast, areas such as Padang Lawas and Tapanuli contribute less due to more limited infrastructure and possibly less favorable topography or rainfall patterns. This spatial variation in rice productivity underscores the importance of localized agricultural policies and land management strategies that are tailored to each regency's specific conditions. Moreover, the data serve as a baseline for assessing environmental health risks related to rice consumption. The geographic diversity across North Sumatra's rice-producing regions also introduces variability in potential exposure to contaminants such as arsenic a naturally occurring element known to accumulate in paddy soils, especially under flooded conditions. Understanding the relationship between rice production zones and arsenic levels is critical, given the chronic health implications associated with long-term exposure.

Given that regions like South Nias, Humbang Hasundutan, and Toba are major producers yet differ in landscape and soil types compared to lowland areas such as Deli Serdang and Serdang Bedagai, the risk profiles for arsenic exposure may also vary significantly. This reinforces the need for spatially stratified monitoring of arsenic levels in rice, incorporating both environmental assessments and public health surveillance. The subsequent sections of this study will analyze the arsenic content in rice samples collected from these key regencies and evaluate the associated health risks based on dietary exposure estimates.

To complement this contextual overview, specific values for harvested area and production volumes are presented in Table 1. Deli Serdang contributed the largest harvested area (53,778 ha) and production volume (327,608 quintals), followed by Serdang Bedagai (48,122 ha; 268,604 quintals) and Simalungun (32,952 ha; 181,397 quintals). Lower contributions were observed in Padang Lawas (12,583 ha; 58,975 quintals) and Tapanuli Selatan (14,226 ha; 61,661 quintals). Such differences are not only agricultural but also relevant to health risk assessments, as high-yield regions supply the majority of rice consumed by local populations. When linked to arsenic concentration data in subsequent tables, this highlights a clear gradient of exposure: populations in high-production regencies face greater potential dietary intake of arsenic if contamination levels are elevated. Therefore, the combination of productivity data with arsenic levels strengthens the interpretation of health risk by showing both where rice is produced most intensively and where contamination risk is greatest.

Determination of Arsenic Concentration in Rice

The calibration curve in Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was constructed by introducing a series of arsenic standard solutions with known concentrations into the system, followed by measurement of their corresponding signal intensities. According to analytical best practices, at least five different concentrations along with one blank solution should be prepared to ensure a reliable and linear calibration curve (1). This curve represents the relationship between the analyte concentration (X-axis) and the measured intensity or absorbance (Y-axis), allowing for quantitative analysis of arsenic in rice samples. Based on the calibration results, a linear relationship was obtained between arsenic concentration and absorbance.

The calibration curve produced a correlation coefficient (r) of 0.9999, exceeding the minimum threshold of 0.9995 required to confirm linearity (2). This high correlation value indicates a very strong linear association between concentration and signal intensity, confirming the reliability and validity of the regression model for arsenic quantification. The graphical representation of this calibration curve is shown in Figure 2.

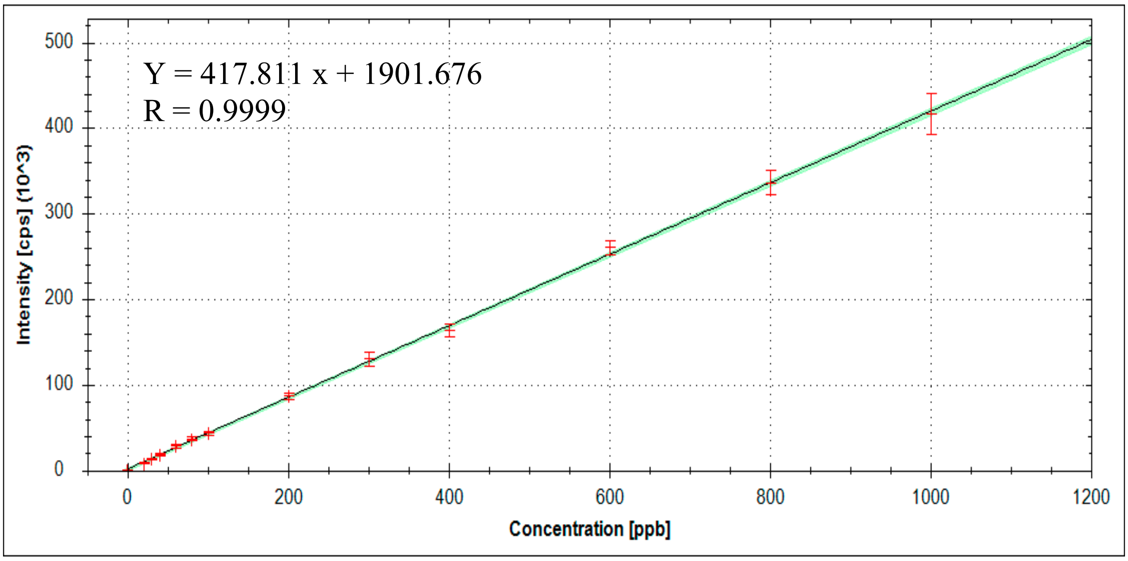

Figure 2: Arsen calibration curve

The arsenic concentration in rice samples

The arsenic concentration in rice samples from various regencies in North Sumatra was determined using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS). The measured arsenic levels in white, red, and brown rice are presented in the following tables. Each value represents the average of six replicates. Data present in Tables 2, 3 and 4.

The data reveal that white rice consistently exhibited arsenic concentrations well below the WHO maximum allowable limit of 0.3 mg/kg for non-organic arsenic [27]. This aligns with previous studies that report polished white rice tends to contain lower arsenic due to removal of the outer bran layer where arsenic accumulates [28].

Conversely, red rice samples demonstrated the highest contamination rates, with 11 out of 13 samples exceeding the 0.3 mg/kg limit. The red rice from Humbang Hasundutan recorded the highest level at 0.9702 mg/kg. This supports earlier findings that red rice, due to minimal milling, retains more bran and thus accumulates higher arsenic concentrations [29, 30]

Although brown rice showed moderately elevated levels in certain regencies for example Mandailing Natal and South Nias, all samples remained below the WHO threshold. Still, the elevated values in some regions may reflect environmental factors such as arsenic-contaminated irrigation water or soil [31]. Organic rice generally displayed lower arsenic levels, particularly in Serdang Bedagai and Simalungun. This observation may be attributed to the avoidance of arsenic-based pesticides and chemical fertilizers in organic farming. However, not all organic samples were below non-organic counterparts, indicating that soil and water contamination remain major contributors regardless of farming practice [32].

Environmental contamination plays a pivotal role in arsenic uptake. Inundated paddy fields promote arsenite formation, a more bioavailable form of arsenic for rice plants [33]. Groundwater used for irrigation, especially in regions with known arsenic contamination, is a primary factor behind elevated arsenic levels in rice [34]. The variation across regencies highlights the influence of local agronomic practices, soil characteristics, and water management on arsenic accumulation. This underscores the importance of monitoring and implementing mitigation strategies, including alternative irrigation techniques, soil amendments such as silicon or iron oxides, and breeding or selecting rice varieties with low arsenic uptake capacity [35]. Overall, while white and brown rice in North Sumatra are generally within safe arsenic limits, red rice presents a significant health risk. Consumer education, improved agricultural practices, and governmental regulation are essential to minimize long-term exposure.

Arsenic Safety evaluation in Rice Samples

The safety evaluation of arsenic in rice was determined based on Daily Intake (DI) and Excess Cancer Risk (ECR). These parameters were calculated using arsenic concentration in rice, daily consumption rate, and average body weight. According to WHO guidelines, the safe ECR threshold is 1×10^{-5}. Any value above this is considered to pose a cancer risk. The result of evaluation for Daily Intake (DI) and Excess Cancer Risk (ECR) present in Tables 5,6 and 7.

The results show that while most white rice samples are within the WHO-recommended safety threshold ($ECR < 1 \times 10^{-5}$), almost all red rice and a significant portion of brown rice samples exceed this limit, indicating potential carcinogenic risks, especially with long-term consumption. Arsenic accumulation in rice is influenced by multiple environmental and agronomic factors. Paddy soils, often flooded, create anaerobic conditions that enhance arsenic bioavailability particularly inorganic arsenic due to reductive dissolution of iron oxides. Brown and red rice retain the outer bran layer, which accumulates more arsenic, whereas white rice, being polished, contains lower concentrations. These findings are consistent with Malabadi *et al*. [36], who reported that brown rice contains 80% more arsenic than white rice . Furthermore, similar studies in West Bengal (India) have documented high ECR values in populations consuming rice with arsenic concentrations as low as 0.15 mg/kg, suggesting that the WHO guideline of 0.3 mg/kg may be insufficient for rice-consuming countries [37]. According to Mishra *et al*. [38], reducing rice arsenic concentration may reduce the risk of bladder and lung cancer by up to 23% . This study also aligns with De Vizcaya *et al.* [39], who demonstrated that prolonged exposure to even low levels of inorganic arsenic in rice can contribute to genotoxic effects and increase oxidative stress biomarkers. The result reaffirms that chronic exposure, especially in high-consumption regions like Indonesia (200–350 g/day), poses a disproportionately greater risk compared to Western populations (9–50 g/day). These findings underscore the need for Indonesia to develop rice-specific arsenic thresholds that reflect local dietary patterns. Policy interventions should also include regular arsenic monitoring, promotion of low-arsenic rice varieties, and public health campaigns to raise awareness. Future research should explore soil remediation, cultivar selection, and irrigation management to minimize arsenic uptake.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study reveals significant health concerns related to arsenic exposure from rice consumption in North Sumatra. Although most white rice samples remain within the WHO's acceptable risk threshold, many brown rice samples and nearly all red rice samples exceed the Excess Cancer Risk (ECR) limit of 1×10^{-5}. The elevated arsenic levels in whole grain rice are likely due to the accumulation of inorganic arsenic in the outer bran layer. Given Indonesia's high rice consumption, the health risks may be more pronounced than in lower-consumption countries. These findings call for stricter national regulations on arsenic levels in rice, particularly for brown and red varieties. Additionally, continuous monitoring, public awareness campaigns, and agricultural mitigation strategies are essential to reduce arsenic exposure and protect public health in rice-dependent regions. Future research should focus on identifying contamination sources and promoting low-arsenic rice cultivation.

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Conflict of interest

The authors declare that they have no conflicts of interest to disclose.

Table 1: Rice productivity of North Sumatra province

No	Regency	Harvested Area (Ha)	Production (Quintals)
1	Deli Serdang	53,778.61	327,607.62
2	Serdang Bedagai	48,121.62	268,604.09
3	Simalungun	32,951.83	181,397.14
4	Langkat	25,770.65	127,008.47
5	Humbang Hasundutan	22,894.78	130,116.81
6	South Nias	18,107.44	110,304.87
7	Karo	18,045.46	95,524.01
8	Toba	17,431.92	77,005.15
9	Tapanuli	14,225.79	61,661.33
10	Padang Lawas	12,583.03	58,974.69

Source: Badan Pusat Statistik Provinsi Sumatera Utara (2022)

Table 2: Arsenic Levels in White Rice Samples from North Sumatra

No	Regency	Rice Type	Source	Arsenic Level (mg/kg)
1	Deli Serdang	Non-organic	Rice refinery of Bakaran Batu	0.0011
2	Serdang Bedagai	Non-organic	Rice refinery of Tani Jaya	0.0031
		Organic	Rice refinery of Lubuk Bayas	0.0020
3	Simalungun	Non-organic	Rice refinery of Tiga Langguing	0.0054
		Organic	Traditional Market of Tiga Langguing	0.0013
4	Langkat	Non-organic	Rice refinery of Restu Tani	0.0034
5	Tapanuli Utara	Non-organic	Rice refinery of Harianja	0.0050
6	Toba	Non-organic	Rice refinery of Binsar	0.0040
7	Tapanuli Selatan	Non-organic	Rice refinery of Pasar Sitinjak	0.0028
8	Mandailing Natal	Non-organic	Rice refinery of Cimanngis	0.0031
9	Nias Selatan	Non-organic	Rice refinery of Nikmat	0.0042
10	Labuhan Batu	Non-organic	Rice refinery of Bandar Jaya	0.0038
11	Karo	Non-organic	Rice refinery of Kabanjahe	0.0084
12	Humbang Hasundutan	Non-organic	Rice refinery of Pangaribuan	0.0014
13	Padang Lawas	Non-organic	Rice refinery of Saba Ballaka	0.0018

Table 3: Arsenic Levels in Red Rice Samples from North Sumatra

No	Regency	Rice Type	Source	Arsenic Level (mg/kg)
1	Deli Serdang	Non-organic	Rice refinery of Bakaran Batu	0.2445
2	Serdang Bedagai	Non-organic	Rice refinery of Tani Jaya	0.4962
		Organic	Rice refinery of Mandiri	0.2367
3	Simalungun	Non-organic	Rice refinery of Tiga Langguing	0.3743
		Organic	Traditional Market of Tiga Langguing	0.2529
4	Langkat	Non-organic	Rice refinery of Restu Tani	0.6812
5	Tapanuli Utara	Non-organic	Rice refinery of Harianja	0.3257
6	Toba	Non-organic	Rice refinery of Binsar	0.6409
7	Tapanuli Selatan	Non-organic	Rice refinery of Pasar Sitinjak	0.7493
8	Mandailing Natal	Non-organic	Rice refinery of Cimanngis	0.9666
9	Nias Selatan	Non-organic	Rice refinery of Nikmat	0.7307
10	Labuhan Batu	Non-organic	Rice refinery of Bandar Jaya	0.4938
11	Karo	Non-organic	Rice refinery of Kabanjahe	0.1326
12	Humbang Hasundutan	Non-organic	Rice refinery of Pangaribuan	0.9702
13	Padang Lawas	Non-organic	Rice refinery of Saba Ballaka	0.5630

Table 4: Arsenic Levels in Brown Rice Samples from North Sumatra

No	Regency	Rice Type	Source	Arsenic Level (mg/kg)
1	Deli Serdang	Non-organic	Rice refinery of Bakaran Batu	0.0110
2	Serdang Bedagai	Non-organic	Rice refinery of Tani Jaya	0.0035
		Organic	Rice refinery of Mandiri	0.0012
3	Simalungun	Non-organic	Rice refinery of Tiga Langguing	0.0029
		Organic	Traditional Market of Tiga Langguing	0.0002
4	Langkat	Non-organic	Rice refinery of Restu Tani	0.0007
5	Tapanuli Utara	Non-organic	Rice refinery of Harianja	0.0099
6	Toba	Non-organic	Rice refinery of Binsar	0.0043
7	Tapanuli Selatan	Non-organic	Rice refinery of Pasar Sitinjak	0.0979
8	Mandailing Natal	Non-organic	Rice refinery of Cimanngis	0.2388
9	Nias Selatan	Non-organic	Rice refinery of Nikmat	0.2387
10	Labuhan Batu	Non-organic	Rice refinery of Bandar Jaya	0.0077
11	Karo	Non-organic	Rice refinery of Kabanjahe	0.0028
12	Humbang Hasundutan	Non-organic	Rice refinery of Pangaribuan	0.0024
13	Padang Lawas	Non-organic	Rice refinery of Saba Ballaka	0.0120

Table 5: Data of White Rice for Daily Intake (DI) and Excess Cancer Risk (ECR)

Region	Type	Sex	Body Weight (kg)	Daily Intake (mg/kg/day)	ECR (Cancer Risk)	Safety Status
Deli Serdang	Non-organic	M	55	1.70×10^{-6}	2.60×10^{-6}	Safe to consume
		F	47	2.07×10^{-6}	3.10×10^{-6}	
Karo	Non-organic	M	55	1.20×10^{-5}	1.85×10^{-5}	**Unsafe to consume**
		F	47	1.44×10^{-5}	2.16×10^{-5}	
Tapanuli Utara	Non-organic	M	55	7.53×10^{-6}	1.10×10^{-5}	**Unsafe to consume**
		F	47	8.81×10^{-6}	1.30×10^{-5}	
Nias	Non-organic	M	55	6.31×10^{-6}	9.40×10^{-6}	Safe to consume
		F	47	7.39×10^{-6}	1.10×10^{-5}	
Mandailing Natal	Non-organic	M	55	4.61×10^{-6}	6.91×10^{-6}	Safe to consume
		F	47	5.39×10^{-6}	8.08×10^{-6}	
Humbang Hasundutan	Non-organic	M	55	2.12×10^{-6}	3.18×10^{-6}	Safe to consume
		F	47	2.48×10^{-6}	3.73×10^{-6}	
Langkat	Non-organic	M	55	5.13×10^{-6}	7.70×10^{-6}	Safe to consume
		F	47	6.01×10^{-6}	9.01×10^{-6}	
Padang Lawas	Non-organic	M	55	2.79×10^{-6}	4.18×10^{-6}	Safe to consume
		F	47	3.26×10^{-6}	4.89×10^{-6}	
Serdang Bedagai	Non-organic	M	55	4.71×10^{-6}	7.12×10^{-6}	Safe to consume
		F	47	5.56×10^{-6}	8.34×10^{-6}	
	Organic	M	55	3.09×10^{-6}	4.63×10^{-6}	Safe to consume
		F	47	3.61×10^{-6}	5.42×10^{-6}	
Simalungun	Non-organic	M	55	8.19×10^{-6}	1.22×10^{-6}	Safe to consume
		F	47	9.58×10^{-6}	1.43×10^{-6}	
	Organic	M	55	2.05×10^{-6}	2.40×10^{-6}	Safe to consume
		F	47	2.40×10^{-6}	3.08×10^{-6}	
Labuhan Batu	Non-organic	M	55	5.81×10^{-6}	8.71×10^{-6}	Safe to consume
		F	47	6.79×10^{-6}	1.01×10^{-5}	
Toba	Non-organic	M	55	3.64×10^{-6}	9.10×10^{-6}	Safe to consume
		F	47	4.26×10^{-6}	1.06×10^{-6}	
Tapanuli Selatan	Non-organic	M	55	4.19×10^{-6}	6.29×10^{-6}	Safe to consume
		F	47	4.91×10^{-6}	7.36×10^{-6}	

Description: M= Male, F= Female

Table 6: Data of Red Rice for Daily Intake (DI) and Excess Cancer Risk (ECR)

Region	Arsenic Type	Sex	Body Weight (kg)	Daily Intake (mg/kg/day)	ECR (Cancer Risk)	Safety Status
Deli Serdang	Non-organic	M	55	3.60×10^{-3}	5.50×10^{-3}	**Unsafe to consume**
		F	47	4.00×10^{-4}	6.00×10^{-4}	
Karo	Non-organic	M	55	1.00×10^{-4}	2.00×10^{-4}	**Unsafe to consume**
		F	47	2.00×10^{-4}	3.00×10^{-4}	
Tapanuli Utara	Non-organic	M	55	4.00×10^{-4}	7.00×10^{-4}	**Unsafe to consume**
		F	47	5.00×10^{-4}	8.00×10^{-4}	
Nias	Non-organic	M	55	1.00×10^{-3}	1.60×10^{-3}	**Unsafe to consume**
		F	47	1.20×10^{-3}	1.90×10^{-3}	
Mandailing Natal	Non-organic	M	55	1.40×10^{-3}	2.10×10^{-3}	**Unsafe to consume**
		F	47	1.60×10^{-3}	2.50×10^{-3}	
Humbang Hasundutan	Non-organic	M	55	1.40×10^{-3}	2.10×10^{-3}	**Unsafe to consume**
		F	47	1.60×10^{-3}	2.50×10^{-3}	
Langkat	Non-organic	M	55	1.00×10^{-3}	1.50×10^{-3}	**Unsafe to consume**
		F	47	1.10×10^{-3}	1.70×10^{-3}	
Padang Lawas	Non-organic	M	55	8.00×10^{-4}	1.20×10^{-3}	**Unsafe to consume**
		F	47	9.00×10^{-4}	1.40×10^{-3}	
Serdang Bedagai	Non-organic	M	55	7.00×10^{-4}	1.10×10^{-3}	**Unsafe to consume**
		F	47	8.00×10^{-4}	1.30×10^{-3}	
	Organic	M	55	3.00×10^{-4}	5.00×10^{-4}	**Unsafe to consume**
		F	47	4.00×10^{-4}	6.00×10^{-4}	
Simalungun	Non-organic	M	55	5.00×10^{-4}	8.00×10^{-4}	**Unsafe to consume**
		F	47	6.00×10^{-4}	9.00×10^{-4}	
	Organic	M	55	3.00×10^{-4}	5.00×10^{-4}	**Unsafe to consume**
		F	47	4.00×10^{-4}	6.00×10^{-4}	
Labuhan Batu	Non-organic	M	55	7.00×10^{-4}	1.10×10^{-3}	**Unsafe to consume**
		F	47	8.00×10^{-4}	1.20×10^{-3}	
Toba	Non-organic	M	55	9.00×10^{-4}	1.40×10^{-3}	**Unsafe to consume**
		F	47	1.10×10^{-3}	1.60×10^{-3}	
Tapanuli Selatan	Non-organic	M	55	1.10×10^{-3}	1.60×10^{-3}	**Unsafe to consume**
		F	47	1.30×10^{-3}	1.90×10^{-3}	

Description: M= Male, F= Female

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Table 7: Data of Brown Rice for Daily Intake (DI) and Excess Cancer Risk (ECR)

Region	**Arsenic Type**	**Sex**	**Body Weight (kg)**	**Daily Intake (mg/kg/day)**	**ECR (Cancer Risk)**	**Safety Status**
Deli Serdang	Non-organic	P	55	1.65×10^{-5}	2.48×10^{-5}	**Unsafe to consume**
		W	47	1.94×10^{-5}	2.91×10^{-5}	
Karo	Non-organic	P	55	4.20×10^{-6}	6.30×10^{-6}	Safe to consume
		W	47	4.91×10^{-6}	7.27×10^{-6}	
Tapanuli Utara	Non-organic	P	55	1.49×10^{-5}	2.23×10^{-5}	**Unsafe to consume**
		W	47	1.74×10^{-5}	2.61×10^{-5}	
Nias	Non-organic	P	55	3.00×10^{-4}	5.00×10^{-4}	**Unsafe to consume**
		W	47	4.00×10^{-4}	6.00×10^{-4}	
Mandailing Natal	Non-organic	P	55	3.00×10^{-4}	5.00×10^{-4}	**Unsafe to consume**
		W	47	4.00×10^{-4}	6.00×10^{-4}	
Humbang Hasundutan	Non-organic	P	55	3.66×10^{-6}	5.49×10^{-6}	Safe to consume
		W	47	4.28×10^{-6}	6.43×10^{-6}	
Langkat	Non-organic	P	55	6.00×10^{-4}	9.00×10^{-4}	**Unsafe to consume**
		W	47	7.00×10^{-4}	1.00×10^{-3}	
Padang Lawas	Non-organic	P	55	1.85×10^{-5}	2.78×10^{-5}	**Unsafe to consume**
		W	47	2.17×10^{-5}	3.25×10^{-5}	
Serdang Bedagai	Non-organic	P	55	5.27×10^{-6}	7.91×10^{-6}	Safe to consume
		W	47	6.17×10^{-6}	9.26×10^{-6}	
	Organic	P	55	1.80×10^{-6}	2.75×10^{-6}	Safe to consume
		W	47	2.15×10^{-6}	3.22×10^{-6}	
Simalungun	Non-organic	P	55	4.32×10^{-6}	6.48×10^{-6}	Safe to consume
		W	47	5.05×10^{-6}	7.58×10^{-6}	
	Organic	P	55	4.11×10^{-7}	6.17×10^{-7}	Safe to consume
		W	47	4.81×10^{-7}	7.22×10^{-7}	
Labuhan Batu	Non-organic	P	55	1.15×10^{-5}	1.73×10^{-5}	**Unsafe to consume**
		W	47	1.35×10^{-5}	2.02×10^{-5}	
Toba	Non-organic	P	55	6.52×10^{-6}	9.78×10^{-6}	Safe to consume
		W	47	7.63×10^{-6}	1.14×10^{-5}	
Tapanuli Selatan	Non-organic	P	55	1.00×10^{-4}	2.00×10^{-4}	**Unsafe to consume**

Description: M= Male, F= Female

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