Egypt. J. Chem. **Vol. 68**, No. 4. pp. 237 - 244 (2025)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Effects of Soaking, Washing, and Cooking on Heavy Metal Concentrations in Five Polished Rice Varieties from Al-Ahsa local market, Saudi Arabia

Gamal A. El-Sharnouby*[a] & Saeed A. Asiri[b]

a Food Science & Technology Department, Faculty of Agriculture, Al-Azhar University, Nasr City 11884, Cairo, Egypt.

bFood Science & Nutrition Department, Faculty of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, P.O.Box 420, Saudi Arabia.

Abstract:

Rice (*Oryza sativa* L.) may contain harmful substances such as heavy metals, posing health risks to humans. Several factors contribute to rice serving as a source of toxic heavy metals. This study aims to conduct a comprehensive risk assessment of heavy metals contamination (Cd, Cr, Pb, As, Ni, Zn, Hg, Fe, and Cu) of polished rice in the local market of Al-Ahsa, Saudi Arabia. We employed an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) to assess the impact of a 2-hour soaking, washing, and cooking process on the concentrations of heavy metals in rice samples. In raw polished rice, the level of arsenic (As) remained within the safe limit without any significant difference being observed. However, lead (Pb) was present at high levels with a highly significant difference observed. Levels of zinc (Zn) and mercury (Hg) were lower than the specifications set by the World Health Organization (WHO) and the Saudi Standard Specification. Cadmium (Cd) and chromium (Cr) were detected in all samples. In cooked rice samples, the mean concentrations were within the limits recommended by the WHO, except for lead (Pb). Whereas insuring food safety and safeguarding citizens' health holds great significance, the study also demonstrated the effectiveness of pre-cooking treatments, including soaking, washing, and cooking, in significantly reducing the concentrations of toxic elements in rice and the results obtained were within safe and recommended limits.

Key Words: ICP OES; Rice (*Oryza sativa* L.); Heavy metals; hazard index; toxic elements

1. Introduction

Cereals like rice, oats, and maize are included in the typical daily diet, supplying humans with essential nutrients, including proteins and carbohydrates. Rice, scientifically known as (*Oryza sativa* L.), is one of the most extensively cultivated grains and plays a vital role in meeting global food demands. It serves as the primary staple food for more than half of the world's population, especially in developing countries in Asia [28]. Recent reports from the Food and Agriculture Organization reveal that rice production have reached 498.3 million metric tons, with 90% of it being used for consumption [11; 17]. With over 110,000 cultivated varieties worldwide, varying in quality and nutritional content, rice is grown in more than 100 countries. Following post-harvest processing, rice can be classified as either white or brown. The availability and consumption of rice are ultimately determined by regional and cultural preferences, as well as the need for stability during storage and transportation. According to economic reports, Saudi Arabia imported approximately 1.5 million tons of rice in 2022, with an average annual import value exceeding 4 billion Saudi riyals. Per capita rice consumption reached 45 kilograms per year. Therefore, if the population of the kingdom reaches 55 million people by 2030, Saudi Arabia may require around 2.47 million tons of rice in that year. In financial terms, the value of rice imports could reach 15.5 billion Saudi riyals annually [13; 24].

Rice prices are subject to fluctuations in global markets and crop quantities in producing countries, which directly impacts Gulf countries, including Saudi Arabia, as one of the largest rice importers. Saudi Arabia's annual rice consumption is approximately 1.55 million tons. India is the leading exporter of rice to the kingdom. The Saudi market offers various rice varieties, with Indian Basmati rice being the most important. Saudi Arabia is one of the largest consumers of rice outside of East Asian countries. In the Saudi market, the most popular rice types are Indian Basmati rice, including the Mazza and white varieties, which account for about 60% of the market. American rice follows with a 15% share, followed by various types of Pakistani rice, representing 12% of the market. Thai rice holds a share of around 5%, while Egyptian (Australian) rice accounts for approximately 3%. In 2022, Saudi Arabia imported $ 1.23 billion worth of rice, securing its position as the world's third-largest rice importer. Saudi Arabia imports rice primarily from: India ($990M), Pakistan $107M), United States ($68M), Vietnam ($20.2M), and Thailand ($10.1M) [23]. Although brown rice is often marketed as a healthier option due to its unique bioactive compounds absent in polished white rice, the latter remains more popular despite its lower fiber and fat

*__Corresponding author__: Gamali59@azhar.edu.eg ; (Gamal A. El-Sharnouby)
Receive Date: 14 July 2024, Revise Date: 08 August 2024, Accept Date: 14 August 2024
DOI: 10.21608/EJCHEM.2024.304208.10011

content. Nonetheless, rice remains a beneficial source of several essential nutrients, including magnesium, phosphorus, manganese, selenium, iron, folic acid, thiamin, and niacin. Its popularity stems from factors such as ease of cooking, taste preference, and longer shelf life. In Saudi Arabia, rice holds a significant position in the diet influenced by culture and traditions. A traditional Saudi Arabian dish called "Kabsah" consists of rice and meat [5]. Al-Mssallem et al. [3] stated that there are over 150 types of rice worldwide, with "Basmati" being the most preferred in Saudi Arabia, followed by American and Calrose rice. Due to unsuitable climate and water conditions, Saudi Arabia relies entirely on rice imports. According to [6], Saudi Arabia ranked fourth in global rice import quantity and second in global rice value from 2009-2013. The same authors indicated that consumer preferences led Saudi Arabia to import more expensive rice. The presence of contaminants in both locally produced and imported rice raises concerns about regulatory measures and quality control practices in the Saudi local market. Additionally, diet can be a source of toxic elements exposure [2]. Heavy metal poisoning may lead to serious complications, as lead, mercury, arsenic, and cadmium are among the most common metals that may cause poisoning in people. Here are the most prominent complications of poisoning with each of them: (1) Complications of lead poisoning Complications of lead poisoning include: severe, high blood pressure, destruction of tissues of the reproductive system, anemia, kidney disease, depression, and anxiety. (2) Complications of mercury poisoning include destruction of tissues and cells of the lungs and brain, vision disturbance, gastrointestinal disorders, skin changes, hearing loss, memory disorder, mouth and throat irritation, and gingivitis. (3) Complications of arsenic poisoning include disorders of the nervous and digestive systems, persistent low blood pressure, anemia, cardiomyopathy, and cancer. (4) Complications of cadmium poisoning include: decreased functional capacity of the lungs and kidneys, anemia, disorder or loss of sense of smell, and softening of the bone sheet [10].

Naturally occurring toxic metals such as cadmium (Cd), manganese (Mn), lead (Pb), arsenic (As), chromium (Cr), and antimony (Sb) have contaminated the environment, including water, air, soil, and food, leading to negative impacts on human health [38]. The excessive mobility of As, Cd, and Pb in soil due to indiscriminate pesticide and fertilizer use is a serious concern for producing safe and uncontaminated crops globally [16]. Although rice is a popular source of nutrients for humans, including vitamins, carbohydrates, minerals, and essential elements, it also poses a significant risk of toxic metal exposure due to its tendency to accumulate more metals compared with other cereals [27]. Rice plants are particularly effective at absorbing arsenic and cadmium into their grains compared with other cereal crops; the levels in rice grains depend on cultivation conditions. The bioavailability of these toxic metals increases under flooded conditions [27]. However, industrial activities have made these toxic heavy metals one of the most pressing environmental issues [33], primarily due to intensified agriculture as well as rapid urbanization and industrialization. Heavy metals, as they bioaccumulate through the food chain, pose significant risks to human health [4]. Assessing the contamination of toxic metals in food is crucial for ensuring its quality. Exceeding certain threshold levels can lead to various adverse health effects [7], considering their resistance to biodegradation, ability to accumulate over time, and long biological half-lives. Exposure of humans to high or low levels of toxic metals like As, Pb, and Cd through polluted air or diet may result in severe detrimental effects on lung, skin, kidney, prostate, and gallbladder cancer [22]. Foodstuffs typically contain varying concentrations of toxic elements [25]. If large amounts of food containing heavy metals are consumed, it can lead to negative health effects like neurological disorders, cancer, and damage to vital organs such as the kidneys, lungs, and liver [20]. Rice plays a vital role as a staple food in Saudi Arabia, and its different varieties vary in terms of their origin, essential components, and levels of toxic metals. All rice imports to the Kingdom undergo inspection at entry ports and by the Food and Drug Authority to ensure compliance with specifications. Imports that do not meet the authority's requirements or the specifications stated in shipping documents are not allowed and are either returned or re-exported. These measures ensure that the Saudi market is not exposed to products of questionable quality. However, there may still be variations in quality levels among different types of rice, leading to price differences in the local market.

Rice has become a staple on the dining tables of most Saudi households, making Saudi consumers the largest consumers of rice in the kingdom, particularly when it comes to high-quality Basmati rice. However, there is also a significant segment of the Indian, Filipino, and Bengali labor force that consumes lower-quality varieties, such as parboiled rice and others. Arab nationalities rank next in terms of rice consumption. According to the latest statistics and studies, the annual rice consumption in the Kingdom is approximately 1.55 million tons [8; 34].

The concentration of heavy metals in foods should always be lower than the recommended guidelines by the WHO [12]. Rice contains beneficial bioactive compounds such as ferulic acid, phytosterols, and oryzanol, but it can also contain heavy metals like Cd, Hg, and Pb [39]. The Gulf Cooperation Council (GCC) Standardization Organization (GSO 2055-2), a regional regulatory body, is involved in ensuring food safety [14]. There is limited information available on the levels of toxic elements in foods consumed in Saudi Arabia due to its heavy reliance on imported foods from various countries. This study aims to determine and verify the impact of soaking, washing, and cooking processes on heavy metals of five varieties of polished rice in Al-Ahsa, Kingdom of Saudi Arabia, using a modern analytical method (ICP-OES). The obtained results were compared with the recommended safe limits by the WHO and the Gulf specifications for rice [18] to ensure the safety of rice and preserve the health of citizens.

2. Materials & Methods:

2.1. Materials:

2.1.2. Sampling

In March 2023, a comprehensive set of 125 representative samples was gathered from the Al-Ahsa market in Saudi Arabia. These samples encompassed five distinct types of polished rice, specifically: long-grain/creamy 2022 (India), long-grain/white 2022 (USA), long-grain/red 2022 (Hassawi), long-grain/white 2022 (Pakistan), and long-grain/white 2022 (Vietnam). Each variety was represented by twenty-five samples, resulting in a total of 125 samples. Every sample weighed 2 kg and was obtained from selected suppliers. Subsequently, the collected samples were transported to the laboratory of the Food Science & Nutrition Department at the College of Agriculture & Food Science, King Faisal University. Samples were stored in polypropylene plastic bags at room temperature for further analysis.

2.2.Methods:

This study estimated the levels of certain heavy elements in samples of five varieties of local and imported rice (*Oryza sativa* L.) from the local market of Al-Ahsa, Saudi Arabia. The estimation was carried out using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) Model Agilent 5100 Synchronous Vertical Dual View (SVDV) Serial No. MY15180008, as mentioned by Khan et al. [23].

2.2.1. Preparation and cooking of samples:

The rice samples were randomly selected. Saudi Arabian tap water, a blend of desalinated and groundwater, can contain contaminants. To prevent heavy metal contamination, deionized water was used. To prepare the rice samples for cooking, we followed common pretreatment methods commonly used by local consumers. These methods involved soaking the rice in a 5:1 ratio of deionized water to rice for 2 hours, followed by rinsing it three times with deionized water. Each rice sample was then cooked individually in a stainless-steel pot for 40 minutes [7]. Finally, we assessed the levels of heavy metals before and after the cooking process was completed.

2.2.2. Heavy metals analysis:

Using the ICP-OES Model Agilent 5100 Synchronous Vertical Dual View (SVDV) Serial No. MY15180008, rice samples were analyzed for metal ion concentrations of cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), zinc (Zn), iron (Fe), mercury (Hg), nickel (Ni), and copper (Cu), in accordance with APHA guidelines [9] Quality control samples from the National Institute of Standards and Technology (NIST) were utilized to confirm instrument readings, and accuracy and precision were confirmed using standard reference materials and external references. The National Research Center, Dokki, Giza, Egypt, central laboratories network, spectroscopy lab, and other locations hosted analyses. The following are the limits of quantification (LOQ) and limits of detection (LOD) for certain metals: There is a 0.002 mg/L LOD and a 0.0076 mg/L LOQ for Cd; Pb.

2.2.3. Statistical analysis:

The collected data were statistically analyzed using the Statistical Package for Social Science (SPSS) software (version 20.0, produced by IBM Software, Inc., Chicago, USA). We used Paired samples t-test to evaluate the significance before and after cooking. We performed a one-sample t-test to compare the results of each group with specific values indicated by WHO. Duncan multiple range test was performed to compare the content of heavy metals among different types of rice. The data was presented as mean ± standard error of the mean (SEM).

3. Results and discussion:

3.1. Heavy Metal Content of Rice Samples:

Rice plays a vital role as a staple food in Saudi Arabia. The Kingdom of Saudi Arabia places significant importance on ensuring food safety and implementing strict measures to protect the health of its citizens. The Food and Drug Authority consistently issues stringent instructions to minimize food contamination and prevent the spread of chronic diseases. As the Kingdom imports approximately 1.55 million tons of rice annually from various sources, primarily India, there is a possibility of some rice samples exceeding the safe limits for heavy metal content [31]. Due to the potential dangers heavy metals pose to human health, such as cancer and environmental harm.

The analysis of heavy metal content in raw rice samples before any treatments is presented in Table (1). A total of 125 rice samples commonly consumed in the Al-Ahsa region of Saudi Arabia were analyzed for concentrations of heavy metals and other elements. These samples included various varieties of Al-Ahsa (Saudi Arabia), India, Pakistan, the USA, and Vietnam. The analysis was conducted on unwashed samples in 5 replicates. The heavy metal content, including Cd, Cr, Pb, As, Ni, Zn, Hg, Fe, and Cu, was analyzed and compared to the safe limits set by the WHO and the Saudi Arabian standard specifications for rice and the results are summarized in Table (1).

The selected rice samples exhibited varying concentrations of heavy metals. Higher concentrations of Cr, Pb, Ni, Fe, and Cu were observed, while lower concentrations of Cd, Zn, Hg, and as were recorded in raw rice samples. The data in Table (1) revealed significant variations in Fe and Zn concentrations, which could be attributed to differences in the sources of rice. There were significant differences in Cd content between Indian and Pakistani rice samples, with a statistically significant level of 0.05%. Indian and Pakistani rice samples fell within the safe limits for mercury, zinc, arsenic, and chromium content, while Vietnamese rice exceeded the safe limit for lead. Raw American rice demonstrated safe limits for heavy metal content, except for slightly exceeding the maximum limits for lead, iron, and copper as specified in the standard. However, all tested samples showed significantly elevated lead and iron contents, surpassing the maximum safe limits by four times. These findings align with previous studies. Notably, the copper content in the rice samples fell within acceptable limits according to WHO [14] and Gulf specifications for heavy metal content [3].

Table 1. Mean heavy metal contents of some polished rice collected from various areas in Al-Ahsa market (n= 5, on dry weight, mg/kg).

Rice type	**Heavy metals (mg/kg)**								
	Cd	Cr	Pb	As	Ni	Zn	Hg	Fe	Cu
Standard	0.10c	0.30c	0.20e	0.05a	0.50c	40.00a	0.20a	0.80e	3.00d
Hindi	0.28a	0.30c	0.97a	0.06a	0.68a	23.60d	0.01bc	5.33b	4.57a
Pakistan	0.16b	0.32bc	0.88b	0.05a	0.62b	24.14c	0.01bc	21.87a	3.21c
USA	0.08d	0.22d	0.75c	0.04a	0.46d	16.27f	0.02b	4.53c	3.20c
Vietnam	0.08d	0.34b	0.51d	0.04a	0.29e	17.44e	0.01bc	3.87d	2.41e
Hasawi	0.09cd	0.72a	0.91b	0.05a	0.28e	25.47b	0.01c	4.71c	3.24b
p-value	0.000	0.000	0.000	0.427	0.000	0.000	0.000	0.000	0.000
Mean	0.13	0.37	0.70	0.05	0.47	24.49	0.04	6.85	3.27
SEM	0.006	0.006	1.11	0.005	0.003	0.113	0.001	0.070	0.005

The same letter indicates no significant difference ($p > 0.05$) between the same values in a column.

The WHO standard of polished rice regarding Cd, As, Ni, Zn, and Hg content was favorable, with values of 0.09, 0.05, 0.28, and 25.47 mg/kg, respectively [15; 37]. Similarly, Vietnamese rice exhibited content values of 0.08, 0.04, 0.29, 17.44, and 0.01 mg/kg for Cd, As, Ni, Zn, and Hg, respectively. It is important to note that all tested samples showed significant differences and elevated levels of lead and iron, surpassing the maximum safe limits by four times. These findings are consistent with previous reports by [4; 34]. However, the copper content in the rice samples fell within acceptable safe limits. Cadmium and arsenic, particularly, have a greater inclination to accumulate in rice due to their characteristics. This is due to the conversion of arsenic into arsenate during rice cultivation, leading to its significant accumulation in rice grains, up to 10 times higher than in other staple crops. Lead, the second most commonly occurring element after arsenic, is highly toxic to humans, especially when it exceeds the maximum allowable limits in food. These heavy metals can also stress rice plants during growth, potentially causing tissue expansion and ultimately posing a risk to consumers [7].

Based on the findings presented in Table (1), the levels of arsenic in the polished rice samples before soaking and cooking were within the safe range, ranging from 0.05 to 0.06 mg/kg for all five samples. The results obtained agree with [1; 36]. However, all rice varieties exhibited notably higher iron content, ranging between 2.18 and 6.07 mg/kg, suggesting their potential to address iron deficiency concerns [19].

In this study, we evaluate the efficacy of various pretreatment methods, including soaking in deionized water, rinsing, and cooking, on the retention and elimination of essential and toxic heavy metals in rice. The concentrations of Cd, Cr, Pb, As, Ni, Zn, Hg, Fe, and Cu were analyzed in 125 samples of five commonly consumed rice varieties in the Saudi Arabian market using ICP-OES.

The analysis was performed before and after subjecting the rice samples to a 2-hour soaking, washing, and cooking process. The results, presented in Table (2), revealed a significant reduction in the levels of heavy metals post-treatment, with the 2-hour soaking proving highly effective in reducing the concentration of toxic elements. The findings were compared to the standard specifications established by the WHO to assess the safety and nutritional value of the treated rice samples.

This comprehensive investigation into the impact of pretreatment methods on heavy metal retention and elimination in rice is crucial for ensuring the preservation of essential elements while minimizing the risk of toxic metal exposure through this widely consumed staple food. The study highlights the importance of employing appropriate pretreatment techniques to enhance the safety and nutritional quality of rice, thereby contributing to the overall health and well-being of consumers.

Table (2) clearly shows that the levels of lead (Pb) exceeded the recommended limits set by [35]. However, the concentrations of Ni, Cd, Cr, As, Zn, Hg, and Fe remained within the acceptable range according to the [29] and [35]. The levels of Cu were higher than the recommended limits, except for the Vietnam and Hassawi rice samples. Nonetheless, the presence of Cd, Pb, and Hg in the environment pose a significant risk to human health. Moreover, soaking and washing partially removed toxic metal concentrations.

The variations in the levels of essential and toxic elements in rice can be attributed to several factors, including rice variety, the permeability of the outer layers of rice grains to water, the specific elements in question, and the ability of organic compounds and proteins in the grains to bind with metals. These observations align with earlier studies that investigated the impact of various rice processing techniques on the alteration of crucial elements [26;30]. Rinsing rice grains with water successfully reduced Pb concentrations to safe levels in 36 rice brands [4]. Some elements can penetrate the inner layers of rice grains and migrate to the surface after a brief soaking period of 2-hours. However, extended soaking durations, such as overnight soaking, proved more efficient in removing toxic minerals from the rice. Therefore, the length of the soaking time affects the reduction of elemental concentrations in the samples [26; 30]. Several studies have emphasized the importance of treating rice before cooking and consumption to ensure food safety and prevent foodborne diseases from a biological and health perspective. This involves steps such as rice washing, soaking, and proper cooking [4; 7; 26]. It is recommended to follow the guidelines provided by local health and food safety authorities to implement best practices in rice handling [30].

Exposure to these contaminants can result in chronic symptoms resembling those of other disorders. Cadmium, a poisonous, non-essential element, is commonly present in phosphate fertilizers and byproducts of zinc manufacturing. It has various industrial applications and can cause degenerative changes and carcinogenic activity in different organs. Lead gradually accumulates over time, primarily in bones, leading to toxic consequences in bodily systems [2; 26; 32]. Statistical analysis tests were conducted to assess the impact of pre-cooking treatments (such as soaking, washing, and cooking) on different rice samples. These tests focused on the average levels of heavy metals for each rice variety separately. The aim was to determine which rice types are most affected and responsive to these treatments and identify which specific heavy elements are influenced and removed by soaking, washing, rinsing, and cooking.

Table 2. Effect of sawing, washing, and cooking on means heavy metal contents of some polished rice collected from various areas of Al_Ahsa market (n= 5, on dry weight, mg/kg).

Rice type	Heavy metals (mg/kg)								
	Cd	Cr	Pb	As	Ni	Zn	Hg	Fe	Cu
Standard	0.10^{a}	0.30^{a}	0.20^{d}	0.05^{a}	0.50^{a}	40.00^{a}	0.20^{a}	0.80^{e}	3.00^{d}
Hindi	0.06^{b}	0.10^{c}	0.57^{a}	0.04^{a}	0.33^{b}	11.42^{e}	0.00^{c}	3.07^{b}	4.19^{a}
Pakistan	0.03^{c}	0.12b^{c}	0.48^{b}	0.04^{a}	0.49^{a}	19.70^{c}	0.00^{c}	6.07^{a}	3.01^{cd}
USA	0.08^{a}	0.12^{b}	0.35^{c}	0.03^{b}	0.25^{bc}	9.42^{f}	0.00^{c}	2.56^{c}	3.09^{bc}
Vietnam	0.08^{a}	0.13^{b}	0.21^{d}	0.03^{b}	0.18^{c}	13.39^{d}	0.00^{c}	2.18^{d}	2.17^{e}
Hasawi	0.09^{a}	0.12^{b}	0.51^{b}	0.03^{b}	0.15^{c}	20.93^{b}	0.01^{b}	2.28^{cd}	3.11^{b}
P-value	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Mean	0.07	0.15	0.39	0.04	0.32	19.14	0.04	2.83	3.10
S.E.M	0.006	0.005	0.011	0.004	0.003	0.200	0.001	0.009	0.003

The same letter indicates no significant difference ($p > 0.05$) between the same values in a column.

Tables (3–7) present the effects of the initial treatments on each rice variety individually. The results in Table (3) revealed a significant effect of lead on the Indian rice variety. Although the lead averages did not show clear differences among the Indian rice replicates, the statistical analysis indicated that it was still affected by the pre-cooking treatments. Similarly, for the Pakistani variety, arsenic, cadmium, and chromium did not appear in Table (4). The impact of heavy metals like lead, chromium, and mercury on the Hassawi rice variety is evident from Table (5). The American rice variety showed a high response to pre-cooking processes, especially with lead and cadmium (Table 6). Furthermore, the statistical analysis in Table (7) indicated that the Pakistani rice variety was most affected, with arsenic, cadmium, cobalt, and mercury showing a significant impact at a significance level of less than 0.05 [18; 29]. Additionally, the results of the study showed significant reductions in harmful mineral content through the pre-cooking treatments.

Tables (4-7) for all five rice varieties. According to the WHO and standard specifications, most heavy element concentrations have decreased to safe levels. These reductions were statistically significant at a level of less than 0.05%. Based on the findings, the safest rice varieties were ranked as follows: Pakistani, Hassawi, American, Vietnamese, and Indian. Overall, this study demonstrated the significant effect of pre-cooking processes (soaking, washing, and cooking) on removing heavy metals from rice samples, ensuring consumer safety. These results highlight the commitment of systems to quality standards and consumer protection. In general, the results obtained are consistent with the recommended legislation [21].

In a comprehensive study conducted in Beijing, the presence of heavy metals in commercially available rice was monitored.The study analyzed 537 rice samples in Beijing for nine heavy metals: Cd, Cr, Cu, Fe, Mn, Ni, Pb, strontium (Sr), and Zn. The ranking of heavy metal pollution grades in rice was as follows: Pb had the highest grade, followed by Zn, Ni, Cu, Cd, and Cr. Similarly, the risk grades were ranked as follows: Cu had the highest risk grade, followed by Zn, Cd, Pb, Cr, and Ni. The findings demonstrated that the level of heavy metal pollution in rice, as indicated by the Nemerow pollution index, was low. This suggests that the overall health status of rice in Beijing was deemed safe [21]. Also, In the end, we can say that the health status of rice inspected is safe.

Table 3. Comparison between Mean heavy metal contents (mg/kg) of Hassawi rice before and after pre-treatments.

Variable	Difference \Mean	Stander deviation	*t* statistic	*p*-value
As	0.01333	0.01155	2.000	0.184
Cd	0.22667	0.02517	15.600	0.004
Ni	0.35000	0.04583	13.229	0.006
Zn	12.18333	0.34385	61.370	0.000
Fe	2.25667	0.05132	76.168	0.000
Cu	0.37667	0.06807	9.585	0.011

Pc, Cr and Hg not detected (more affected) n= 5 measurements – (P > 0.05) no significant

Table **4**. Comparison between Mean heavy metal contents (mg/kg) of Hindi rice before and after pre-treatments.

Variable	Difference \Mean	Stander deviation	*t* statistic	*p*-value
As	0.00667	0.01155	1.000	0.423
Cd	0.12667	0.02082	10.539	0.009
Cr	0.20333	0.00577	61.000	0.000
Ni	0.12600	0.12817	1.703	0.231
Hg	0.01100	0.00100	19.053	0.003
Zn	4.44333	0.49410	15.576	0.004
Fe	15.80333	0.29501	92.783	0.000
Cu	0.19667	0.00577	59.000	0.000

Pb not detected (more affected) n = 5 measurements – (P > 0.05) no significant

Table 5. Comparison between Mean heavy metal contents (mg/kg) of Vietnam rice before and after pre-treatments.

Variable$^+$	Difference \Mean	Stander deviation	*t* statistic	*p*-value
As	0.01333	0.01155	2.000	0.184
Cr	0.09667	0.00577	29.000	0.001
Ni	0.21000	0.01732	21.000	0.002
Hg	0.01300	0.00300	7.506	0.017
Zn	6.85000	0.23431	50.637	0.000
Fe	1.97667	0.38786	8.827	0.013
Cu	0.11000	0.01732	11.000	0.008

Pb, Cd, not detected (more affected) n = 5 measurements – (P > 0.05) no significant

Table 6. Comparison between Mean heavy metal contents (mg/kg) of USA rice before and after pre-treatments.

Variable	Difference \Mean	Stander deviation	*t* statistic	*p*-value
As	0.01667	0.01155	2.500	0.130
Cr	0.21000	0.01732	21.000	0.002
Ni	0.10367	0.02829	6.347	0.024
Hg	0.01200	0.00100	20.785	0.002
Zn	4.05333	0.07572	92.719	0.000
Fe	1.69333	0.11015	26.626	0.001
Cu	0.23667	0.05508	7.443	0.018

Pb and Cd not detected (more affected) n = 5 measurements – (P > 0.05) no significant

Table 7. Comparison between Mean heavy metal contents (mg/kg) of Pakistan rice before and after pre-treatments.

Variable	Difference \Mean	Stander deviation	*t* statistic	*p*-value
Pb	0.39667	0.00577	119.000	0.000
Ni	0.12333	0.04041	5.286	0.034
Zn	4.54000	0.40336	19.495	0.003
Fe	2.42667	0.03055	137.579	0.000
Cu	0.12667	0.06429	3.413	0.076

As, Cd, Cr, and Hg not detected (more effected) n = 5 measurements – ($P > 0.05$) no significant

4.Conclusion:

In conclusion, this comprehensive study provides valuable insights into heavy metal levels in commonly consumed rice varieties in Saudi Arabia's Al-Ahsa region. The findings highlight the need for regular monitoring and strict quality control to ensure rice product safety and protect consumer health. The analysis indicated that although some heavy metals, like arsenic, were within safe limits, lead was present at elevated levels in raw polished rice samples. However, the study also demonstrated that pre-cooking treatments, including soaking, washing, and cooking, significantly reduced toxic element concentrations in rice. Furthermore, regular monitoring and analysis of food samples are essential to ensure ongoing compliance with food safety regulations and protect public health. Ultimately, these findings contribute to the overarching goal of ensuring a safe and nutritious food supply.

Author Contributions: G.A. El-Sharnouby and S.A. Asiri: conceptualization, investigation, data collection, formal analysis, statistical analysis, and data curation.

Funding: None.

Conflicts of Interest: The authors declare no conflict of interest.

Availability of data and materials:

All data generated or analysed in this study are included in this article.

Acknowledgments: The authors would like to thank Dr. Mustafa Hasham , Assistant Professor, Faculty of Agriculture, Al-Azhar University for his efforts to perform the statistical analysis, and to thanks Dr. Mohammed Hamdy Farouk, Professor at the Faculty of Agriculture, Al-Azhar University, for his help in writing references through the EndNote program.

5. References

[1] Abu-Almaaly, R.A., 2020. Effect of cooking method on the content of heavy metals in rice that available in local market. Plant Arch 20, 2976-2981.

[2] Al-Harbi, H.F., Al-Mohaimeed, A.M., El-Tohamy, M.F., 2023. Assessment of essential elements and heavy metals in Saudi Arabian rice samples underwent various processing methods. Open Chemistry 21.

[3] Al-Mssallem, M.Q., Al-Khayri, J.M., Alessa, F.M., Al-Shalan, H.Z., 2024. Contribution of Hassawi Rice to Food and Nutritional Security in Saudi Arabia, in: Ahmed, A.E., Al-Khayri, J.M., Elbushra, A.A. (Eds.), Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 2 : Macroeconomic Policy and Its Implication on Food and Nutrition Security. Springer International Publishing, Cham, pp. 321-336.

[4] Al-Saleh, I., Abduljabbar, M., 2017. Heavy metals (lead, cadmium, methylmercury, arsenic) in commonly imported rice grains (*Oryza sativa*) sold in Saudi Arabia and their potential health risk. Int J Hyg Environ Health 220, 1168-1178.

[5] Alalwan, T.A., Mandeel, Q.A., Al-Sarhani, L., 2017. Traditional plant-based foods and beverages in Bahrain. Journal of Ethnic Foods 4, 274-283.

[6] Alamri, Y., Reed, M., Saghaian, S.J.B.J.o.A.S., 2020. Competition in the Saudi Arabian rice market. 26, 275-281.

[7] AlMulla, A.A., Dahlawi, S., Randhawa, M.A., Zaman, Q.U., Chen, Y., Faraj, T.K., 2022. Toxic Metals and Metalloids in Hassawi Brown Rice: Fate during Cooking and Associated Health Risks. Int J Environ Res Public Health 19.

[8] Alwatan, 2024. https://www.alwatan.com.sa/article/1140520.

[9] APHA, 2005. Eaton, A.D., APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation). 2005. .

[10] Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R., Sadeghi, M., 2021. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. 12.

[11] Bielecka, J., Markiewicz-Żukowska, R., Nowakowski, P., Grabia, M., Puścion-Jakubik, A., Mielcarek, K., Gromkowska-Kępka, K.J., Soroczyńska, J., Socha, K., 2020. Content of Toxic Elements in 12 Groups of Rice Products Available on Polish Market: Human Health Risk Assessment. 9, 1906.

[12] Codex Alimentarius, 2023. Regional Standard for Cooked Rice Wrapped in Plant Leaves Asia CXS 355R-2023, FAO & WHO.

[13] FAO, 2024. World agriculture towards 2030 2050

[14] Faour-Klingbeil, D., Al-Busaidi, M.A., Todd, E.C.D., 2022. Chapter 8 - Legislation for food control in the Arab countries of the Middle East, in: Savvaidis, I.N., Osaili, T.M. (Eds.), Food Safety in the Middle East. Academic Press, pp. 275-322.

[15] Galinyte, D., Balciunaite-Murziene, G., Karosiene, J., Morudov, D., Naginiene, R., Baranauskiene, D., Sulinskiene, J., Kudlinskiene, I., Savickas, A., Savickiene, N., 2023. Determination of Heavy Metal Content: Arsenic, Cadmium, Mercury, and Lead in Cyano-Phycocyanin Isolated from the Cyanobacterial Biomass. Plants (Basel) 12.

[16] Gao, Y., Li, X., Dong, J., Cao, Y., Li, T., Mielke, H.W., 2020. Snack foods and lead ingestion risks for school aged children: A comparative evaluation of potentially toxic metals and children's exposure response of blood lead, copper and zinc levels. Chemosphere 261, 127547.

[17] Ghuniem, M.M.K., Mona A. El-safty, Sherif M. Souaya, Eglal R. Khalil, Mostafa M. H., 2020. Assessment of human health risk due to potentially toxic elements intake via consumption of Egyptian rice-based and wheat-based baby cereals. International Journal of Environmental Analytical Chemistry 102, 6936-6954.

[18] GSO, 2021. Rice Kernal 05/DS 1003. GCC Standardization Organization (Gso).

[19] Hassan, M.J., Zhang, G., Wu, F., Wei, K., Chen, Z., 2005. Zinc alleviates growth inhibition and oxidative stress caused by cadmium in rice. 168, 255-261.

[20] Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N., 2014. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol 7, 60-72.

[21] Junxiao, W., Yuanbo, G., Kuang, C., 2018. The heavy metal content monitoring and dietary risk assessment of commercial rice in Beijing. Modern Food Science and Technology 34, 267-273.

[22] Khalaf, E.M., Taherian, M., Almalki, S.G., Asban, P., Kareem, A.K., Alhachami, F.R., Almulla, A.F., Romero-Parra, R.M., Jawhar, Z.H., Kiani, F., Manesh, I.N., Mohammadi, M.J., 2023. Relationship between exposure to heavy metals on the increased health risk and carcinogenicity of urinary tract (kidney and bladder).

[23] Khan, S.R., Sharma, B., Chawla, P.A., Bhatia, R., 2022. Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): a Powerful Analytical Technique for Elemental Analysis. Food Analytical Methods 15, 666-688.

[24] Khan, Z.I., Ahmad, K., Rehman, S., Siddique, S., Bashir, H., Zafar, A., Sohail, M., Ali, S.A., Cazzato, E., De Mastro, G.J.E.S., Research, P., 2017. Health risk assessment of heavy metals in wheat using different water qualities: implication for human health. 24, 947-955.

[25] Liang, G., Gong, W., Li, B., Zuo, J., Pan, L., Liu, X., 2019. Analysis of Heavy Metals in Foodstuffs and an Assessment of the Health Risks to the General Public via Consumption in Beijing, China. Int J Environ Res Public Health 16.

[26] Liu, K., Zheng, J., Chen, F., 2018. Effects of washing, soaking and domestic cooking on cadmium, arsenic and lead bioaccessibilities in rice. J Sci Food Agric 98, 3829-3835.

[27] Pateriya, A., Verma, R.K., Sankhla, M.S., Kumar, R.J.L.i.a.N., 2020. Heavy metal toxicity in rice and its effects on human health. 10, 1833-1845.

[28] Seck, P.A., Diagne, A., Mohanty, S., Wopereis, M.C.S., 2012. Crops that feed the world 7: Rice. Food Security 4, 7-24.

[29] SFDA, 2022. Code Of Practice For The Prevention And Reduction Of Arsenic Contamination In Rice, Report.

[30] Sharafi, K., Yunesian, M., Nodehi, R.N., Hossein Mahvi, A., Pirsaheb, M., Nazmara, S., 2019. The reduction of toxic metals of various rice types by different preparation and cooking processes - Human health risk assessment in Tehran households, Iran. Food Chem 280, 294-302.

[31] Statista, 2024. Our research and content philosophy. https://www.statista.com/aboutus/our-research-commitment.

[32] Thabit, T., Elgeddawy, D.I.H., 2018. Determination of Phosphine Residues in Wheat and Yellow Corn with a New Developed Method Using Headspace and SIM Mode GC-MS. J AOAC Int 101, 288-292.

[33] Ugulu, I., Khan, Z.I., Aslam, Z., Ahmad, K., Bashir, H., Munir, M., 2021. Potentially toxic metal accumulation in grains of wheat variety Galaxy-2013 irrigated with sugar industry wastewater and human health risk assessment. Euro-Mediterranean Journal for Environmental Integration 6, 38.

[34] Wang, C.C., Zhang, Q.C., Yan, C.A., Tang, G.Y., Zhang, M.Y., Ma, L.Q., Gu, R.H., Xiang, P., 2023. Heavy metal(loid)s in agriculture soils, rice, and wheat across China: Status assessment and spatiotemporal analysis. Sci Total Environ 882, 163361.

[35] WHO, 2023. Lead poisoning. Report 11 August 2023.

[36] Yim, S.R., Park, G.Y., Lee, K.W., Chung, M.-S., Shim, S.-M., 2017. Determination of total arsenic content and arsenic speciation in different types of rice. Food Science and Biotechnology 26, 293-298.

[37] Youssef, H.M., 2018. Health Risk Assessment of Some Potentially Toxic Elements (Ptes) in Rice Grown in Deekernes Sector, Dakahleya Governorate, Egypt. International Journal of Advanced Research 6, 1377-1382.

[38] Zheng, S., Wang, Q., Yuan, Y., Sun, W., 2020. Human health risk assessment of heavy metals in soil and food crops in the Pearl River Delta urban agglomeration of China. Food Chemistry 316, 126213.

[39] Zubair, M., Anwar, F., Arshad, I., Malik, S., Zafar, N.M., 2023. Rice Nutraceuticals and Bioactive Compounds: Extraction, Characterization and Antioxidant Activity: A Review. Combinatorial Chemistry & High Throughput Screening 26, 2625-2643.